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Battery Swapping Systems (Stations)—BSS

INTEROPERABILITY, STANDARDIZATION, INNOVATION AND POLICY PRIORITIES

CEEW

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Executive Summary

The drive towards decarbonizing the transport sector is crucial in the global quest to mitigate climate change and achieve sustainable energy goals. A pivotal element in this transformation is the widespread adoption of electric vehicles (EVs). Principles of standardization and interoperability within battery systems and the associated infrastructure is a major force multiplier for accelerating EV uptake. **Interoperability** involves the ability of different systems and components—such as EVs, battery swapping stations, and charging networks—to work seamlessly together. **Standardization** refers to the establishment of consistent technical specifications and protocols that can be universally adopted across the industry for compatibility, safety, and performance reliability. These principles are foundational to accelerating EV penetration, optimizing economic efficiencies, aligning regulatory frameworks, and enhancing the resilience of energy grids.

Benefits of Standardization and Interoperability

Enhanced User Convenience and Market Expansion—Standardized battery systems allow EV owners to swap batteries at any compatible station, irrespective of the brand or operator. Interoperability fosters a competitive market by opening the infrastructure to multiple players. This inclusivity drives innovation, as manufacturers and service providers can focus on developing better products and services without compatibility concerns.

Economic Efficiency and Cost Reduction— Standardizing components leads to significant cost reductions through economies of scale. These lowers operational costs for service providers and results in cost savings for consumers. The Battery-as-a-Service (BaaS) model exemplifies how standardization can lower the upfront cost of EVs, making them more affordable for price-sensitive customers.

Enhanced Safety and Reliability—Consistent safety protocols reduce the risk of malfunctions and ensure reliable operations across different conditions. This reliability builds user trust, supporting the broader acceptance and adoption of EV technology.

Streamlined Operations and Future-Proof Infrastructure—Standardized components and processes simplify the operation and maintenance of battery systems. Service providers benefit from reduced complexity, as standardized parts and procedures ensure compatibility and efficiency. whilst maintaining high service levels and minimizing downtime. This future-proof approach ensures that infrastructure can evolve with changing market demands without frequent and costly upgrades.

Sustainability and Environmental Impact—Standardized batteries and components are easier to recycle and reused, repurposed or remanufactured for second use applications. Additionally, streamlined operations and the reduction of custom solutions support more sustainable manufacturing and operational practices.

Facilitate Innovation and Competition: A common framework allows manufacturers and service providers to compete and innovate without compatibility concerns. This drives technological advancements and leads to more efficient BSS.

Ensure Regulatory Coherence and Global Competitiveness—Government can more effectively implement and monitor policies when there is industry-wide uniformity, which eases the complexity and administrative burden. Aligning with international standards facilitates easier integration into global supply chains and enhances the ability of Indian manufacturers to export their products and technologies, driving economic growth and innovation

Challenges to Interoperability and Standardization in India

- **Fragmented Market and Diverse Stakeholders**—India's EV market is characterized by a diversity of manufacturers and service providers, each with proprietary technologies complicating the establishment of unified standards
- **Technical and Operational Barriers**—Varied technical specifications across different EV systems pose challenges for achieving interoperability. Differences in battery technologies, charging protocols, and communication interfaces complicate standardization
- **Economic and Financial Constraints** —High initial costs for developing and implementing standardized and interoperable systems can be prohibitive, especially for smaller and newer players.
- **Infrastructure Gaps and Regional Disparities**—Disparities in the availability and quality of battery swapping services between urban and rural areas affect overall accessibility and equity.

Summary Insights from Global Landscape, Key Reports and Literature

China's approach exemplifies a "Symbiotic Business Model," where coordinated efforts between political, industrial, and institutional players drive the rapid development and commercialization of battery swapping technologies across all vehicle segments from 2Ws to heavy-trucks. The Chinese government's National Standard for Battery Swap Safety Requirements for Electric Vehicles (GB/T 40032-2021) ensures safety and interoperability across different manufacturers and vehicle types. Leading automakers like NIO and Geely have integrated these standards into their extensive networks, enhancing operational efficiency and scalability.

The **EU** Battery Regulation introduces detailed reporting obligations, including the concept of a digital "battery passport," which tracks the lifecycle of batteries. This regulation, combined with the European Sustainable Products Regulation (EPSR), supports the standardization of battery sizes, connectivity, and performance. Pilot projects highlight the importance of standardized data reporting across the battery value chain, facilitating maintenance and recycling

Japan's strategy focuses on modularity and interoperability, particularly through initiatives like the Gachaco project, where major automakers collaboratively to develop standardized battery designs and interfaces. Japan is advancing battery swapping through collaborative standards and pilot projects. Major automakers, including Honda and Yamaha, are participating in the Gachaco initiative, which standardizes battery designs under modular and interoperable specifications

ASEAN countries are working towards a unified EV ecosystem, emphasizing regional harmonization of infrastructure and technology. The ASEAN+3, including China, Japan, and South Korea, have endorsed efforts to integrate technical standards and regulations to enable interoperability across the region.

Developing a Standardized and Interoperable Battery Swapping Ecosystem

1. Dual Strategy: Vehicle Platform and Form Factor Approaches India's diverse vehicle market necessitates a flexible strategy encompassing both vehicle platform design and form factor innovation. A focus on creating platforms that support both fixed and swappable battery architecture can accommodate a wide range of vehicles, from two-wheelers to heavy commercial vehicles. Standardizing battery sizes and shapes will enhance interoperability among different vehicles and manufacturers, simplifying integration and reducing costs.

2. Phased Approach to Standardization To ease the transition for manufacturers and operators, initial focus could focus on component-level standards. The next phase could expand to include entire vehicles and operational processes for seamless integration between EVs and the battery swapping infrastructure. The final phase involves building the necessary infrastructure, including charging facilities, IT systems, and renewable energy integration, to support a fully operational and interoperable network.

3. Standardization and Interoperability for Energy Transition. National standards for battery packs, connectors, and swapping protocols are essential for system-wide interoperability. The evolution of battery swapping from a niche solution for just 2Ws and 3Ws in the automotive sector to a versatile industry-agnostic Energy-as-a-Service (EaaS) model represents a significant leap in energy management. Standardized energy storage systems can enhance grid resilience, balance local supply and demand, and participate in energy markets, optimizing energy use and contributing to grid stability.

4. Inclusive and Equitable Support. Supporting MSMEs in manufacturing and integrating informal BSS operators will spur inclusive economic growth, create jobs, stimulate local economies, ensure widespread service availability, bridge economic, geographic, regional and urbanization divide.

5. Stakeholder Collaboration and Engagement Industry consortia or working groups should be formed to develop and promote interoperability standards, including representatives from both large-scale operators and smaller, informal networks.

6. Targeted Pilots Implementing targeted pilot projects is crucial for developing a scalable and efficient BSS. These pilots validate technical and operational aspects, provide insights into consumer behavior, and address region-specific challenges. The data collected from diverse environments inform policy and regulatory frameworks, driving the broader adoption of standardized and interoperable BSS solutions.

Battery Swapping Systems (Stations)—BSS
Interoperability, Standardization, Innovation and Policy Priorities

1 Introduction

India's transportation landscape is unique, characterized by a vast array of vehicle types, from two-wheelers and auto-rickshaws to heavy-duty trucks and buses. Urban congestion, high fuel costs, and environmental concerns are driving the need for efficient and sustainable transport solutions. India's commitment to sustainable mobility is underscored by its ambitious targets for EV adoption. India's EV transition is primarily driven by the two-wheeler (e2W) and three-wheeler (e3W) segments, which cater to a significant portion of the population and play a crucial role in urban and peri-urban transport, first and last mile connectivity and B2B/B2C logistics. As of 2024, roughly 1.7 million[1] EVs were registered in India, with e2Ws and e3Ws leading this transition, accounting for roughly 55% and 37% of total EV registrations, respectively. Approximately 17,000 charging[2] and 2500[3] battery swapping stations are currently installed. Despite these advances, cost, range anxiety and charging infrastructure barriers continue to impede the widespread adoption of EVs.

Traditional charging is well-suited for personal use, where vehicles can be charged overnight at homes or during work hours. However, the prolonged charging time, land requirements and the current scarcity of fast-charging stations pose challenges for commercial operations and high-utilization vehicles such as logistics, delivery services and ride-sharing. Battery swapping systems offers a promising solution to these challenges. It offers a viable alternative for commercial fleets, public transport systems, and high-usage personal vehicles, providing the flexibility and efficiency[4]. BSS allows for the quick exchange of a depleted battery with a fully charged in minutes, effectively eliminating downtime. By adopting a Battery-as-a-Service (BaaS) model, where users lease batteries instead of owning them, the initial purchase price of an EV is lowered. Expansion and scalability of the BSS infrastructure, though potentially costlier and more complex initially compared to traditional charging, can be more efficient for high-utilization use-cases sectors. While battery swapping offers advantages over traditional charging methods, its success and widespread adoption hinge on the establishment of standardized and interoperable systems. These elements are essential for creating a unified, efficient, and consumer-friendly battery swapping network.

The MHI[5] has laid a robust foundation for enhancing EV market penetration through FAME, ACC and PLI programs. With the objective of achieving significant electrification of vehicles by 2030, the government is exploring innovative solutions to overcome the current limitations of EV charging infrastructure. To that end, this report is submitted to provide a focused exploration of BSS interoperability and standardization as an integral component of this effort. The report starts by providing normative definitions of interoperability and standardization, and then delves into their diverse interpretations. Next, the advantages and contextual difficulties of achieving interoperability and standardization are described. Subsequently, the report offers a summary of global initiatives and success

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[1] NITI Aayog (2024). The shift to Evs in the road transport sector. https://iced.niti.gov.in/analytics/ice-and-ev-vehicle-registered

[2] Vasudha Foundation (2024). Evaluating the Expansion of India's EV Charging Infrastructure Sector https://www.vasudha-foundation.org/evaluating-the-expansion-of-indias-electric-vehicle-charging-infrastructure-sector/

[3] Hindustan Times (2024). Swapping: A solution for India's e-mobility. https://www.hindustantimes.com/ht-insight/governance/swapping-a-solution-for-india-s-emobility-101710321412317.html

[4] Tripathi, S., Barala, C. P., Mathuria, P., & Bhakar, R. (2023, March). Battery Swapping Policy Review: An Indian and International Scenario. In *2023 IEEE PES Conference on Innovative Smart Grid Technologies-Middle East (ISGT Middle East)* (pp. 1-5). IEEE.

[5] Ministry of Heavy Industries Evaluation of Electric Vehicle (EV) Policy, 26th report, Lok Sabha Secretariat.

stories, giving valuable insights into effective implementation and approaches used in other regions. These case studies from countries like China, the European Union, Japan, and the ASEAN region offer valuable insights and practical lessons that can inform India's approach. Report concludes by outlining core tenets of a framework tailored to India's unique needs and opportunities in advancing its battery swapping infrastructure, accelerating EV transition and meeting its energy transition goals.

2 Interoperability & Standardization: Definition & Scope

Interoperability facilitates the flexible use of battery packs and swapping stations, ensuring that EV users can exchange batteries regardless of the vehicle's make or the station's manufacturer. This capability is essential for supporting the growing network of EVs and enhancing user convenience and system accessibility. Interoperability extends across various levels—from the physical and mechanical compatibility of battery components to the seamless communication between different system modules.

Standardization establishes the common rules and specifications that allow these diverse components to interact safely and efficiently. It defines critical aspects such as battery sizes, connector types, and charging protocols, which are necessary to maintain uniformity and safety across different systems. Standardization not only simplifies the production and integration of components but also reduces costs and operational complexities, facilitating broader market adoption and scalability.

2.1 Different Aspects of Interoperability

Interoperability can be interpreted at various aggregation levels, each focusing on different aspects of integration and compatibility into component, system and network.[6]

- **Component Level:** This level focuses on the interoperability of individual parts such as battery cells, connectors, and management systems. It involves ensuring that these components can interface correctly and function together within a system[7].
- **System Level:** At this level, the interaction between the battery pack, the vehicle, and the swapping station is considered. It involves ensuring that the battery can be safely integrated and operated within different vehicles and charged or swapped at various stations. Modular and scalable battery systems are cases in point[8].
- **Network Level:** This broader perspective involves the entire network of swapping stations and service providers. It ensures that users have access to a cohesive network of services, allowing them to use any station within a given network or across different networks without compatibility issues.

Interoperability can also refer or be interpreted along one or more of the following facets[9]

Physical and Mechanical Interoperability:

[6] Chen, X., Xing, K., Ni, F., Wu, Y., Xia, Y., 2022. An Electric Vehicle Battery-Swapping System: Concept, Architectures, and Implementations. IEEE Intelligent Transportation Systems Magazine 14(5), 175-194.
[7] Swappable Battery Motorcycle Consortium (SBMC) (2023). https://www.sb-mc.net/news/sbmcs-remarkable-progress-from-prototyping-to-standardization
[8] Shankavaram, R., Neelam, J. R., Schiffbaenker, P., Rekhi, G., Flagmeier, N., & Siyal, K. (2019). *Modular and Swappable 48V Battery Systems for Emerging Markets* (No. 2019-26-0032). SAE Technical Paper.
[9] Fahma, F., Sutopo, W., Pujiyanto, E., & Nizam, M. (2024). Dynamic open innovation to determine technology-based interoperability requirement for electric motorcycle swappable battery. *Journal of Open Innovation: Technology, Market, and Complexity*, *10*(2), 100259.

- Battery Dimensions and Connectors**:** Standardized dimensions and connectors are essential for batteries to fit properly into different vehicles and swapping stations. This includes the size, shape, and physical mounting mechanisms that ensure a secure fit and easy exchange.
- Mechanical Robustness**:** The connection mechanisms ability to withstand the physical demands of battery swapping and vehicle operation, including vibrations, shocks, and other mechanical stresses.

Electrical Interoperability:

- Voltage and Power Specifications**:** Battery and vehicle alignment in terms of voltage levels, power capacity, and current ratings. This compatibility is crucial for safe and efficient power transfer during vehicle operation and battery swapping.
- Electrical Safety**:** Interoperability standards include ensuring that electrical connections prevent risks such as short circuits, overheating, or electrical shocks, thereby maintaining safety during battery exchange and use.

Communication and Data Interoperability[10]:

- Standardized Communication Protocols**:** Effective data exchange between the battery, vehicle, and swapping station relies on common communication protocols. These protocols manage the transmission of data on battery status, charging requirements, and operational conditions.
- Integration with Vehicle Systems**:** The battery's management system interface with the vehicle's onboard systems, providing real-time monitoring and control to optimize performance and safety.

Operational Interoperability:

- Swapping Process**:** Standardizing the swapping process ensures that batteries can be quickly and efficiently exchanged at any station. This includes automated systems that facilitate the insertion and removal of batteries.
- Charging Algorithms**:** Swapping stations use specific algorithms to charge batteries. Standardizing these algorithms allows stations to safely recharge different types of batteries while maximizing their lifespan and performance.

User and Service Interoperability:

- User Interface and Experience**:** Consistency in the user interface across different platforms simplifies the process for users, making battery swapping straightforward and intuitive regardless of the service provider.
- Service Network Compatibility**:** Ensuring that services are compatible across various networks allows users to access a wide range of swapping stations, enhancing convenience and promoting the use of battery swapping services

[10] Panwar, N. G., Singh, S., Garg, A., Gupta, A. K., & Gao, L. (2021). Recent advancements in battery management system for Li-ion batteries of electric vehicles: future role of digital twin, cyber-physical systems, battery swapping technology, and nondestructive testing. *Energy Technology*, *9*(8), 2000984.

2.1.1 Interoperability: Benefits [11]

— **Enhanced User Convenience[12]:** Users benefit from the flexibility to swap batteries at a wide range of stations, regardless of the brand or operator, making battery swapping a more practical and attractive option for EV owners.

— **Cost Efficiency:** Standardizing components allows for mass production, which reduces manufacturing costs. It also simplifies maintenance and reduces the need for specialized parts and services, lowering overall operational costs.

— **Market Expansion and Innovation:** A common interoperable framework opens the market to multiple players, fostering competition and driving innovation. This leads to the development of better products and services as manufacturers and service providers compete

— **Future-Proof Infrastructure:** Systems designed with interoperability in mind are better equipped to adapt to future technological changes and market demands. This flexibility ensures long-term sustainability and reduces the need for frequent upgrades and overhauls.

— **Safety and Reliability:** Standardized protocols and safety measures enhance the overall safety and reliability. This builds user trust and encourages the adoption of the technology by ensuring consistent and secure operations

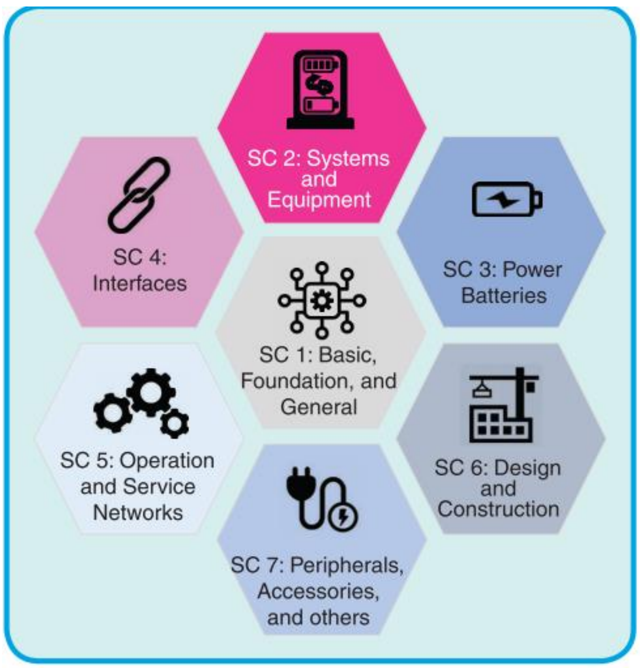

Figure 1 Stylized representation BSS standards and its standard classes (SC)[13]

[11] Invest India (2022). Battery Swapping: India's Opportunity for India's Opportunity for Global Dominance
[12] Huang, F. H. (2020). Understanding user acceptance of battery swapping service of sustainable transport: An empirical study of a battery swap station for electric scooters, Taiwan. *International Journal of Sustainable Transportation*, *14*(4), 294-307.
[13] Chen, X., Xing, K., Ni, F., Wu, Y., Xia, Y., 2022. An Electric Vehicle Battery-Swapping System: Concept, Architectures, and Implementations. IEEE Intelligent Transportation Systems Magazine 14(5), 175-194.

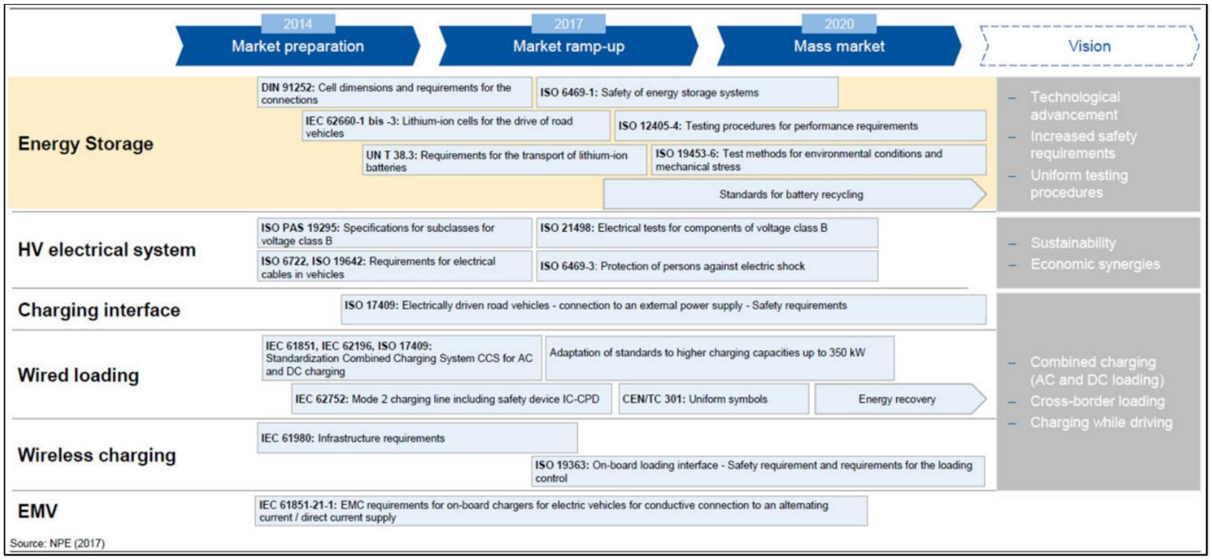

Figure 2 Overview of non-battery standards and workflows[14]

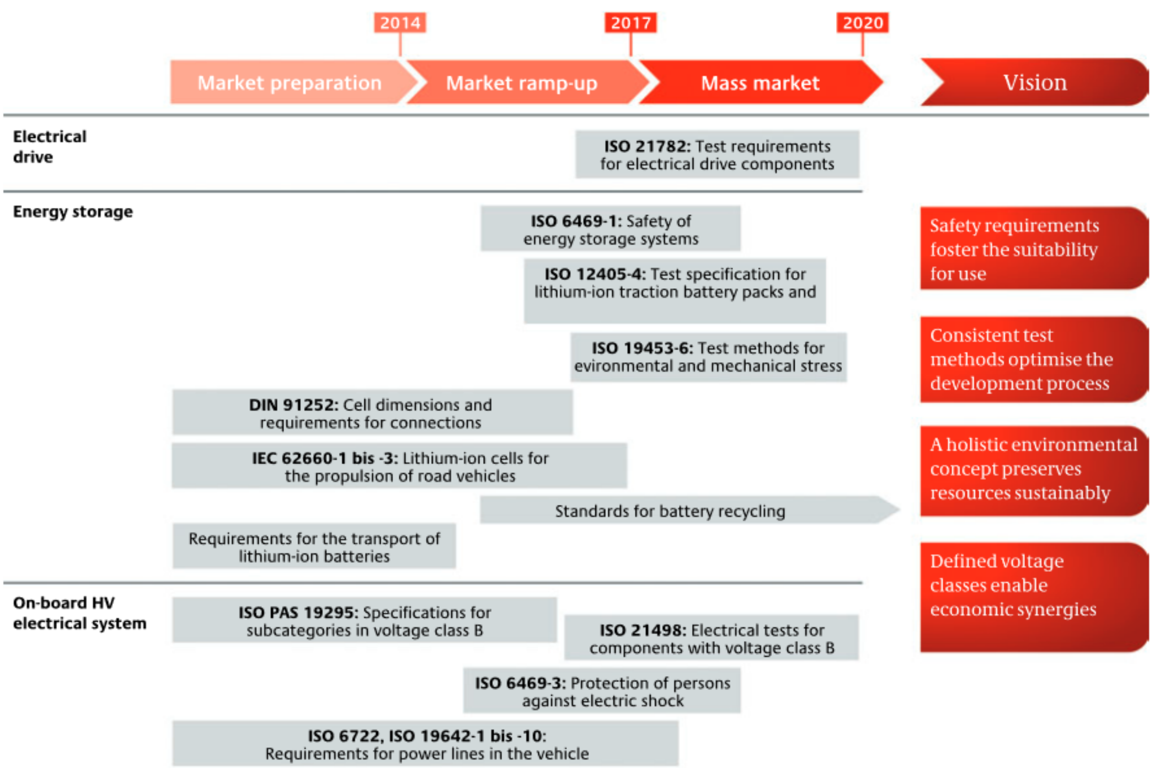

Figure 3 The German Standardization Roadmap[15]

[14] Sankaran, G., Venkatesan, S., 2023. Role of standardized battery pack geometry in electric vehicles design, 11TH ANNUAL INTERNATIONAL CONFERENCE (AIC) 2021: On Sciences and Engineering.
[15] NPE (2020). The German Standardization Roadmap. Nationale Platform Electromobilitat (NPE) https://www.din.de/resource/blob/235254/a0d14b63b9685859b1c0c297827e50f8/roadmap-en-2020-data.pdf

2.2 Standardization

Standardization involves setting common guidelines and specifications for various components and operations. These standards ensure that different systems and devices can interact effectively and safely, facilitating the broader adoption and efficiency of battery swapping technologies. Figure 1 depicts a generalized framework for BSS standards. Germany's approach towards standardization is particularly noteworthy as it encompasses storage, non-storage, and on-board aspects (*Figure 2*,Figure 3).

2.2.1 Key Elements of Standardization

Battery Dimensions and Specifications[16]:

- Uniform Sizes and Shapes**:** Defining standardized sizes, form factors and shapes for batteries allows them to be used across different vehicles and swapping stations. This uniformity simplifies the design and deployment of both batteries and swapping stations, ensuring compatibility and ease of use.
- Consistent Specifications**:** Standard specifications for battery capacity, voltage, and other technical parameters are crucial. They ensure that batteries meet the operational requirements of various vehicles and can be safely and efficiently integrated into the swapping process.

Connector Types and Interfaces[17]:

- Standardized Connectors**:** Establishing common designs for connectors and interfaces ensures that batteries can be connected and disconnected from vehicles and stations without issues. This includes both the mechanical and electrical connections that facilitate power transfer and secure attachment.
- Robust Interface Design**:** Connectors and interfaces must be designed to handle the operational stresses encountered during battery swapping and use, including variations in temperature, humidity, and mechanical wear.

Charging Protocols[18]:

- Unified Charging Standards**:** Standardized protocols for charging manage how batteries are recharged during the swapping process. This includes controlling the voltage, current, and timing of charging to ensure safety and efficiency.
- Adaptable Charging Algorithms**:** Charging protocols must accommodate different battery types and chemistries, optimizing charging rates and maintaining battery health over time.

Safety Measures:

- Comprehensive Safety Guidelines**:** Standardizing safety measures involves creating guidelines for handling, charging, and maintaining batteries to prevent accidents. This includes protocols

[16] Aqidawati, E. F., Sutopo, W., & Pujiyanto, E. (2020, August). Lesson learned in developing and implementing global business strategy to commercialize battery swap technology: A comparative study. In *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management, IEOM Society, Detroit, MI, USA* (pp. 10-14).
[17] Bakker, S., Leguijt, P., & Van Lente, H. (2015). Niche accumulation and standardization–the case of electric vehicle recharging plugs. *Journal of Cleaner Production*, *94*, 155-164.
[18] Jain, S., Ahmad, Z., Alam, M. S., & Rafat, Y. (2020, December). Battery swapping technology. In *2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE)* (pp. 1-4). IEEE.

for detecting and managing potential hazards such as overheating, short circuits, and mechanical failures.

- Emergency Response Procedures**:** Developing standardized procedures for responding to emergencies, such as battery fires or chemical leaks, helps ensure swift and effective action to minimize risks and damage.

Communication and Data Exchange[19]:

- Common Communication Protocols**:** Standardizing the protocols for data exchange between batteries, vehicles, and swapping stations enables effective communication and coordination. This includes sharing information on battery status, operational conditions, and charging needs.
- Integration with Control Systems**:** Data from batteries must be integrated with vehicle and station control systems to provide real-time monitoring and management, enhancing the overall functionality and safety of the system

2.2.2 Standardization: Benefits

— **Cost Reduction:** Standardization reduces costs by enabling the mass production of components, which leads to economies of scale. This approach minimizes the need for bespoke or customized solutions, which are typically more expensive and complex to produce. Manufacturers can streamline production, reduce material and labor costs, and pass these savings on to consumers. Additionally, standardization simplifies the integration of different system components, reducing both initial setup and ongoing operational expenses. This cost efficiency is crucial for their widespread adoption and scalability.

— **Enhanced Safety and Reliability:** Standardized safety protocols, testing and operational procedures ensure that all systems adhere to the same safety and performance benchmarks. This consistency reduces the likelihood of accidents, such as battery malfunctions or electrical faults. Reliability is also improved as standardized systems are typically subject to extensive testing and validation processes before deployment, ensuring they operate correctly under various conditions. This enhances user trust and supports their broader acceptance.

— **Rationalized Operations:** Standardizing components and processes across BSS simplifies their operation and maintenance. This uniformity ensures that all parts and procedures are compatible and can work together seamlessly, reducing the complexity of managing different system elements. Maintenance is also simplified, as service providers can use standardized parts and follow common repair procedures, which reduces downtime and improves system efficiency. These are vital for maintaining high service levels.

— **Facilitate Innovation and Competition:** Standardization creates a level playing field where different manufacturers and service providers can compete within a common framework. The Dutch EV charging infrastructure[20] is an illustrative example in this regard. This fosters innovation as companies can focus on improving their products and services without worrying about compatibility issues, further driving technological advancements.

19 Kumar K, J., Kumar, S., & VS, N. (2022). Standards for electric vehicle charging stations in India: A review. Energy Storage, 4(1), e2

20 Michel, C. I. (2012). *Standardisation of Infrastructure that supports Innovation: The case of the Dutch EV Charging Infrastructure* (Master's thesis).

- **Improved User Experience[21]:** Standardization ensures that users have a consistent, predictable and reliable experience across different BSS. This uniformity makes the user experience easier, intuitive and dependable. It reduces complexity, learning curve and fosters a sense of trust.q

- **Sustainability and Environmental Impact[22]:** Standardized systems contribute to sustainability by reducing waste and promoting the efficient use of resources. Standardized batteries and components are more likely to be recycled and reused, which minimizes environmental impact. Additionally, it supports sustainable manufacturing and operational practices in the battery swapping industry.

3 Indian Context: BSS Interoperability & Standardization

The ecosystem comprises various stakeholders, including vehicle OEMs, battery manufacturers, swap station operators, technology providers, and regulatory bodies. The Indian market for battery swapping is characterized by a mix of formal and informal BSS. Understanding these two categories and their dynamics is crucial for grasping the full potential and challenges.

3.1 Formal and Informal BSS Fragmentation

Formal BSS are operated by established companies and adhere to stringent safety, operational, and regulatory standards. Major players in the formal BSS market include SUN Mobility, GoGoRo, Ola Electric, and newer entrants like Ample and Battery Smart. These companies invest heavily in technology, infrastructure, and partnerships. The formal sector is expected to dominate due to its ability to leverage scale, provide consistent service quality, and adhere to safety and operational standards. Formal BSS leverage cutting-edge technology for automated and seamless battery swapping. This includes the use of robotics, IoT for real-time monitoring, and AI-driven systems for operational optimization. These systems are designed for high throughput and can handle large volumes of battery swaps efficiently. Formal BSS are predominantly located in urban centers where the demand for quick and convenient energy replenishment is highest. These locations are strategically chosen to maximize accessibility and convenience for users. They are often integrated with existing urban infrastructure such as parking lots, commercial centers, and public transport hubs.

Informal BSS are typically smaller, unregulated setups that operate in local markets and cater to specific needs, these stations are crucial for providing essential services in regions that lack the investment and infrastructure for formal BSS[23]. They offer flexibility and lower costs, making them accessible to a broad range of users and their local transportation needs. The informal BSS market, while less documented, is highly disaggregate, often driven by local entrepreneurs and small businesses. According to NITI Aayog, the informal sector is expected to grow alongside the formal sector, particularly in regions where there is a high demand for affordable and flexible battery swapping solutions. A significant portion of the informal BSS market cater to e-rickshaw and low-speed EVs.

3.2 Contextual Challenges

India's efforts to standardize and achieve interoperability in battery swapping stations face a myriad of complex issues that span technical, regulatory, economic, infrastructural, and policy domains, which are elaborated below.

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[21] Huang, F. H. (2018). Measuring user experience of using battery swapping station. In *Advances in Usability and User Experience: Proceedings of the AHFE 2017 International Conference on Usability and User Experience*

[22] Serohi, A. (2021). Importance of Battery Recycling and Swapping: The Next Inevitable Step in Electric Vehicle Supply Chain. *Int. J Sup. Chain. Mgt Vol*, *10*(1), 1.

[23] Joshi, R., Deshpande, P., Borah, S., & Sharma, M. (2023). Informal and Shared Mobility: Status and Opportunities in India.

Features & specifications	LFP	NMC	LCO	LTO	NCA
Energy density	90-150 Wh/kg	150-220 Wh/kg	150-250 Wh/kg	50-100 Wh/kg	200-280 Wh/kg
Power density	300-500 W/kg	600-1000 W/kg	300-500 W/kg	1000-3000 W/kg	800-1500 W/kg
Cycle life	2000-4000	1000-2000	500-1000	5000-10000	1000-2000
Charge and discharge rates	1C-3C	1C-3C	1C-3C	5C-50C	1C-3C
Thermal stability	High	Medium	Low	Very High	High
Recyclability	Yes	Yes	Yes	Yes	Yes
Capacity retention (per cycle)	Low	Medium	Varies	Lowest	Medium
Cost	$100-150/kWh	$150-200/kWh	$200-250/kWh	$300-400/kWh	$200-250/kWh

Battery Chemistry

Excellent   Good   Average   Below Average

*Cathodes considered with a graphite anode- LFP, NMC, LCO, NCA, the anode LTO is paired with NMC or LMO battery chemistry.

Figure 4 Comparison of widely used EV battery chemistries in India [24,25]

India's EV market includes a broad spectrum of vehicles, from e-rickshaws and scooters to electric buses and commercial vehicles. Each of these categories has distinct technical requirements for batteries and swapping mechanisms, making it **challenging to develop one-size-fits-all standards**. Different battery chemistries and configurations are used across the market. Standardizing these disparate technologies into a coherent system is complex, as it involves **reconciling varying capacities, voltages, and physical dimensions**. Comparative techno-economics and performative aspects of widely used EV battery chemistries in India is depicted in Figure 4. Currently LFP (40%–50%) dominates the EV battery chemistry by market share followed by NMC (30%–40%) and NCA (10%–15%) [26,27].

Integrating various BMS and ensuring they can communicate effectively with different vehicle and station systems is technically demanding. Achieving interoperability necessitates the development of advanced technologies that can handle the integration and communication between different batteries, vehicles, and swapping stations. Ensuring **safety across these diverse systems is also a critical challenge.** Manufacturers and service providers often have **proprietary technologies** and business models that may **conflict with the move towards standardization and interoperability**. Aligning these interests to support a unified framework is a major impediment.

Low-speed e2W e-bikes, e-mopeds, e-scooters, and mini utility vehicles, often **operate outside the formal regulatory framework defined by the CMVR**[28]. These vehicles are typically popular in urban and semi-urban areas for short-distance travel and last-mile connectivity. Many low-speed EVs do not meet the safety, design, and operational standards set by the CMVR, leading to concerns about their safety. In-

[24] Mihet-Popa, L. Advances in Batteries, Battery Modeling, Battery Management System, Battery Thermal Management, SOC, SOH, and Charge/Discharge Characteristics in EV Applications.
[25] Lohum (2023). Types of Batteries Used in Electric Vehicles in India. https://lohum.com/media/blog/types-of-batteries-used-in-electric-vehicles-in-india/
[26] GrandViewResearch (2024). India Lithium-ion Battery Market Trends
[27] Mordor (2024). Li-Ion India Battery Market https://www.mordorintelligence.com/industry-reports/india-lithium-ion-battery-market
[28] Tractive power less than 250 W and top speed less than 25 kmph don't require registration or license. They are often driven without insurance and type-approval certificate from ARAI

use stock of such completely knocked down (CKD) e-scooters imported from China range anywhere from 300k to 1M[29] between 2020–2022.

Policy implementation varies significantly across different states, leading to disparities in infrastructure development and regulatory support. This inconsistency makes it difficult to establish nationwide standards and interoperable systems. Setting up and maintaining a network of standardized and interoperable battery swapping stations **requires significant investment**. These costs include not only the physical infrastructure but also the technological upgrades needed to ensure compatibility across various system. These costs can be **prohibitive, especially for Micro, small and medium-sized enterprises (MSMEs)** operating in the EV sector. High costs and uncertain economic returns can slow the rollout of battery swapping infrastructure, particularly in rural and less economically developed areas. Economic challenges can lead to disparities in the availability and quality of battery swapping services between urban and rural areas, affecting overall accessibility and equity.

Many regions in India, particularly rural and semi-urban areas, lack the robust grid infrastructure required to support the widespread deployment of BSS. Upgrading the grid to manage increased electrical loads and ensuring **a reliable power supply are significant hurdles.** Upgrading the grid to support high-demand applications involves substantial investment in transmission and distribution infrastructure, including substations, transformers, and grid stability mechanisms. India's vast geographic expanse and diverse demographic landscape pose significant **logistical challenges for the uniform deployment** of battery swapping stations. Urban areas, with their high population density and concentrated commercial activities, offer a conducive environment for setting up extensive swapping networks. However, rural and semi-urban areas present a stark contrast, with dispersed populations and lower vehicle densities, making it economically challenging to establish and maintain battery swapping infrastructure. **Strategic placement** of swapping stations to maximize coverage and convenience for users is complex as it involves analyzing travel patterns, demand hotspots, and logistical considerations. By some estimates nearly half of e4W sales and two-thirds of e2W sales are from rural areas and small towns[30].

3.3 Stakeholder Implications

Each stakeholder group plays a pivotal role in the development, implementation, and adoption of BSS. This section explores the perspectives and roles of key stakeholders, including vehicle Original Equipment Manufacturers (OEMs), battery manufacturers, retrofitters and operators, distribution companies (DISCOMs), and consumers. Figure 5 shows the industry players

[29] EVReporter (2022). https://evreporter.com/violation-of-cmvr-ccpa-norms-low-speed-electric-2ws/
[30] Blink Charging (2023). Electric Vehicles in Rural India https://blinkcharging.com/en-in/blog/electric-vehicles-in-rural-india

Powertrain, Vehicle, Car component OEMs	Energy Production & Distribution	Battery Management & Energy Storage	Charging Infrastructure and Mobility Services	Fleet Services
• Mahindra Electric • Tata Motors • Hyundai • Ashok Leyland • Piaggio • Kinetic Green • Bajaj Auto • Revolt Motors • Ola Electric • Tork Motors • Ather • Ultraviolette Automotive	• State DISCOMs • NTPC Limited • Tata BP Solar India • Tata Power • Bharat Heavy Electricals Ltd • Power Grid Corporation Of India • Adani Power • Reliance Power	• Ion Energy • Log 9 Materials • Honda Power Pack Energy India • Greentech • Inverted • Sun Mobility	• Gogoro • Honda Power Pack Energy India • Sun Mobility • Amara Raja • Exicom • Magenta Power • Fortrum • Plugin India • Charzer • Charge Zone+	• Ola • Euler Motors • Etrio • Gayam Motors • SmartE • ETO Motors • Smart-E • BluSmart

Figure 5 Snapshot (non-exhaustive) list of industry players in India's BSS market[31]

3.3.1 Vehicle OEMs

Standardization of battery packs and connectors can impose design constraints on vehicle manufacturers. OEMs may need to adapt their vehicle designs to accommodate standardized battery sizes and connection interfaces, potentially limiting design flexibility and innovation in vehicle architecture. Some OEMs may express concerns about the pace and nature of standardization, fearing it could stifle innovation or lead to proprietary technology being compromised. **Balancing the need for competitive differentiation with the benefits of interoperability remains a key challenge**. The automotive market thrives on differentiation. OEMs often compete by offering superior performance, efficiency, or innovative features. The push towards standardized battery systems could blur these lines of differentiation, leading to concerns among OEMs about losing their competitive advantage. Standardized battery packs might not align perfectly with an OEM's ideal vehicle layout, potentially affecting the vehicle's weight distribution, centre of gravity, and overall performance. This can be particularly challenging for high-performance or specialized vehicles where precision in these factors is crucial. This can slow down the pace of innovation as OEMs work to meet evolving standards while also striving to introduce new features and capabilities.

By **embracing modular design approaches, focusing on differentiation beyond battery systems, and leveraging emerging technologies, OEMs can navigate the complexities of standardization while continuing to innovate and thrive**. As battery systems become standardized, OEMs can shift their focus to differentiating their vehicles in other areas, such as advanced driver assistance systems (ADAS), connectivity, user interface design, and overall user experience. This shift allows OEMs to continue innovating and offering unique value propositions.

3.3.2 Battery Manufacturers

Standardization impacts various aspects of the manufacturing process, **from design and production to supply chain management and technological innovation**. Standardization requires battery manufacturers to align their production processes with standardized designs and specifications. This can involve significant adjustments to manufacturing lines, tooling, and supply chain management. Adopting standardized designs can enable manufacturers to achieve economies of scale, reducing per-unit costs

[31] NRI, 2022. India's Opening Gambit in Battery as a Service. Nomura Research Institute.

and enhancing production efficiency. It also simplifies the integration of advanced technologies like fast-charging capabilities and improved thermal management systems. Different battery chemistries, such as Lead acid, Li-ion, LFP and emerging technologies like Na-Ion and Solid-State batteries, present unique challenges and opportunities for standardization. Adoption of LFP batteries in India's public transport sector[32] showcases how specific chemistries can align with the needs of standardized, high-frequency usage environments.

3.3.3 Retrofitters and Operators

Retrofitters and operators must adapt their business models to accommodate the standards set for battery swapping. This can include investment in compatible swapping stations, training for technical staff, and development of new service offerings. Aligning with new standards can incur **significant costs, particularly for small and medium-sized operators**. This includes the expense of upgrading equipment, retraining staff, and ensuring regulatory compliance. Operators may need to invest in new technologies and systems to meet standardization requirements, such as advanced diagnostic tools, real-time monitoring systems, and automated swapping mechanisms. Rapid changes in market dynamics and evolving standards can pose challenges for operators trying to keep up with the latest requirements. They need to be agile and adaptive to remain competitive in a standardized market environment. While **standardization provides operational benefits, it also requires retrofitters and operators to balance flexibility with compliance**.

3.3.4 DISCOMs

DISCOMs play a crucial role in providing the necessary electrical infrastructure to support battery swapping stations. This includes ensuring a stable and reliable power supply, managing peak loads, and integrating renewable energy sources. DISCOMs can use battery swapping stations as distributed energy resources for load balancing, managing peak load and renewable energy coordination and support energy storage. This involves sophisticated load forecasting and demand response strategies. DISCOMs play a role in advocating for regulatory frameworks that support innovation in the energy sector. This includes promoting policies that encourage the development of smart grids, energy storage solutions, and the integration of advanced technologies in BSS. To support the increased energy demands from BSS, DISCOMs may need to upgrade existing distribution networks including but not limited to capacity of transformers, substations, and feeders.

3.3.5 Consumers and End-Users

BaaS decouples battery ownership from the vehicle, allowing consumers to lease batteries and swap them at standardized stations significantly **reducing CAPEX**. With economies of scale and competitive pricing from multiple providers, consumers benefit from reduced costs for battery maintenance and energy services **lowering OPEX.** Standardized systems remove the complexity of dealing with multiple incompatible technologies, making battery swapping more user-friendly and accessible. Standardized and interoperable systems mean that consumers are not locked into a single provider's network, giving them the freedom to choose the most convenient and cost-effective options. Standardized batteries and connectors mean easier access to replacement parts and services, reducing the time and cost of repairs.

[32] Mittal, G., Garg, A., & Pareek, K. (2024). A review of the technologies, challenges and policies implications of electric vehicles and their future development in India. *Energy Storage*, *6*(1), e562.

This is particularly beneficial for fleet operators and commercial users who rely on high vehicle uptime. By seamlessly integrating BSS with other services and technologies that users rely on, such as navigation apps, payment platforms, and customer support services, overall user experience improves.

3.4 Efforts thus far

In 2022, the Indian government introduced the Battery Swapping Policy[33,34] as part of a broader strategy to address the infrastructure challenges associated with fixed battery charging, reduce vehicular emissions, and promote sustainable transportation. The policy aims to establish a wide network of battery swapping stations. The policy promotes collaboration between public and private entities to facilitate the development of robust battery swapping infrastructure. This includes partnerships for setting up swapping stations, integrating advanced technologies, and leveraging existing urban infrastructure like parking lots and public transport hubs for station placements. One of the key features of the policy is the establishment of interoperability standards, which allow batteries from different manufacturers to be used interchangeably in various vehicles and swapping stations. Protocols for thermal management, handling procedures; stringent quality control measures to ensure that all batteries used in the swapping network meet high-performance standards and are regularly tested for safety and reliability; streamlined regulatory approval processes; financial incentives; support for R&D; and promoting pilot projects and demonstration programs are other notable features of this policy.

3.5 Summary Insights from Previous Stakeholder Consultations

3.5.1 Jan. 2023 Stakeholder Consultations

The Department of Consumer Affairs, Bureau of Indian Standards (BIS), Ministry of Road Transport and Highways, NITI Aayog, DST, SIAM, IBSA, and industry stakeholders met on **3 January 2023** to conclude the topic of interoperability (Minutes of the Meeting attached in Annexure). Point 14 under the Minutes state the following-

"After detailed deliberations, it was decided that Light Electric Vehicle (LEV) ***battery swapping interoperability standards may not be brought out at this stage*** *since the technology is still evolving and majority of manufacturers/swap operators are not in favour of the interoperable standards and the proposed dimensions for EV battery swapping. Further, the following was decided-*

1. *BIS to prepare horizontal standards and battery specific QCOs for all batteries*
2. *BIS may formulate stringent standards on performance and safety of batteries and remove size from the Draft standard of battery swapping.*
3. *A meeting of the Technical Committee, who have formulated the standards on batteries may be conducted at the earliest."*

Pursuant to the meeting held on 27 February 2024 by the Ministry of Consumer Affairs (MoCA), Government of India, with various industrial stakeholders, the following was agreed upon (Minutes of the Meeting attached in Annexure)-

[33] NITI Aayog (2022). https://www.niti.gov.in/sites/default/files/2022-04/20220420_Battery_Swapping_Policy_Draft_0.pdf
[34] PIB (2022). NITI Aayog Releases Draft Battery Swapping Policy for Stakeholder Comments. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1818569

"QCO on battery swapping station standards delineating the policy on swapping stations be developed by the Government of India in consultation with all the stakeholders, including Industry Associations. Ministry of Heavy Industries may be requested to take this forward"

'Indian standards on electric vehicle battery swapping' have been discussed for the past couple of years with Industry. Vehicle manufacturers have been following CMVR rules of MoRTH for the type approval process for swappable battery EVs. This involves comprehensive testing, evaluation, and certification of EVs to verify compliance with regulatory requirements. Several large companies hold the view that - Standardization of interoperability on battery size, form factor; connectors and communication protocol will restrict innovation as the industry is at a nascent stage. The industry is to work one on one with their own R&D to come up with safe and viable interoperable combinations for promoting battery swapping. Table 1 summarizes the scope and select examples covered by IS 17896.

Table 1 BIS drafts of IS 17896-1:2022/ IEC TS 62840-1:2016 and IS 17896-2:2022/ IEC 62840-2:2016

Standard(s)	Scope	Example Specifications
IS 17896 (Part 4/Sec 1): LEV - Guidelines and Pack Dimensions	Defines the physical dimensions, weight, and voltage ratings of swappable battery packs for LEVs	— Permissible dimensions and mass for battery packs — Nominal voltage for swappable battery systems (48—60 V)
IS 17896 (Part 4/Sec 2): Light Electric Vehicle - Connection System	Outlines the requirements for connectors and couplers used in swappable battery systems including types of connectors that should be used and their protection levels to ensure safety and compatibility	— Minimum Ingress Protection (IP) rating of IP67 for water and dust resistance — Standardization of connector shapes and pin configurations to ensure their fit
IS 17896[35] (Part 4/Sec 3): LEV - Communication Protocol	Details the communication protocols that should be used between vehicle-infrastructure. It includes the control area network (CAN) communication used for managing battery charging and discharging processes	— Standardized messages and data formats for battery state of charge (SOC), temperature, and charging parameters — Digital communication should be established via basic and high-level protocols, ensuring synchronization
IS 17896 (Part 2): Safety Requirements for Battery Swap Systems	Specifies the safety requirements for handling, storing, and transporting swappable batteries. It includes guidelines for protection against electric shock, thermal management, and fault protection	— Standards for thermal management systems to prevent overheating — adequate protection against electric shocks, including measures for both normal and fault conditions
IS 17896 (Part 3): Central Management System for Interoperable Battery Packs	guidelines for the central management system (CMS) that oversees the charging, discharging, and swapping of batteries. It includes requirements for energy management, monitoring, and data analytics	— Guidelines for integrating CMS with telecommunication networks — Standards for controlled current charging (CCC) to regulate the charging process and ensure batteries are charged efficiently and safely
Integration with IEC 62840-1[36] and IEC 62840-2[37]	general guidelines and safety requirements including specifications for battery management and swapping operations	— guidelines for battery management and safety can help align India's standards with global practices, facilitating international collaboration and market expansion

[35] Bureau of Indian Standards. (2022). Draft Indian Standard: Electric Vehicle Battery Swap System. *BIS*
[36] International Electrotechnical Commission. (2016). IEC 62840-1: Electric Vehicle Battery Swap System - Part 1: General and Guidance. *IEC*
[37] International Electrotechnical Commission. (2016). IEC 62840-2: Electric Vehicle Battery Swap System - Part 2: Safety Requirements. *IEC*

3.5.2 Jun. 2022 IBSA Submission on Battery Swapping Policy

The India Battery Swapping Association (IBSA) represents a coalition of stakeholders[38] in the electric vehicle (EV) ecosystem, including OEMs, battery manufacturers, swapping and charging companies, think tanks, and enthusiasts. Their submission to the Secretary of Consumer Affairs in June 2022 (Submission included in the Annexure) highlight critical considerations and recommendations for shaping the future of battery swapping in India. The focus is on ensuring that policy frameworks support innovation, safety, and a level playing field between fixed battery and swappable battery solution.

The IBSA argues that rushing to impose a single, rigid standard for battery swapping could stifle innovation and limit the flexibility needed in a rapidly evolving industry. They emphasize that the nascent stage of the market requires room for experimentation and development. Standardizing battery dimensions and connectors prematurely could constrain OEMs and battery manufacturers. For instance, the diverse power requirements of scooters ranging from 800W to 8000W necessitate different battery designs that may not fit a single standard. Current proposed standards are based on specific cell formats like 18650/21700, which may not meet the longevity needs (e.g., over 2000 cycles) for economically viable Battery as a Service (BaaS) models. This could limit the development of new technologies and battery chemistries.

On the issue of vehicle and station-level interoperability, IBSA highlights that defining interoperability at the vehicle level means any battery could be used in any vehicle, potentially leading to safety risks if non-approved or incompatible batteries are used. The risk of "fake" batteries could also increase, similar to challenges seen in the phone battery market. Swapping stations would need to handle diverse battery chemistries, charging protocols, and thermal management requirements. This complexity could introduce safety risks if not managed correctly, particularly in India's variable climate conditions.

Regarding liability and asset management, IBSA argues that precise and clear definition of liability is crucial when batteries are swapped between different operators' stations. Questions arise about who is responsible in case of fires or damages when batteries and stations from different entities interact.

Pertaining to business models and the dynamics of market evolution, it makes the case for precluding new entrants and international consortia from availing governmental investments and give unfair advantage, but rather continue to support existing players.

Recommendations from IBSA

- *Provide parity in incentives and GST rates between swappable and fixed battery solutions to create a level playing field*
- *Allow time for the development and maturation of interoperability standards with full industry participation, avoiding immediate enforcement that could compromise safety and innovation.*
- *Immediate emphasis should be on establishing safety norms that build consumer confidence.*
- *Regulatory bodies need to develop continuous oversight capabilities to manage the evolving market effectively.*
- *Phased implementation of standards: **Phase I - Backend Interoperability:** Define data interchange parameters for smart grid and urban planning applications; **Phase II - Monitoring***

[38] SUN Mobility, GoGoRo, Heo, Piaggio, Exicom, Hero were the major OEM partners of the IBSA

and Evaluation: *Monitor on-road safety and performance of different battery types and swapping stations; P**hase III - Fine-Tuning Standards:** Use field data to refine and improve standards, allowing for the inclusion of new technologies; **Phase IV - Final Decision:** Determine the feasibility of one or multiple standards based on comprehensive industry feedback and performance data*

3.5.3 Nov. 2022 Stakeholder Consultations

The meeting was convened to deliberate on the creation and implementation of Indian Standards for EV battery swapping and interoperability (Minutes of the Meeting attached in Annexure). During the meeting, industry stakeholders expressed a range of views on the proposed standards for EV battery swapping and interoperability. Many participants acknowledged the importance of standardization to ensure safety and facilitate the widespread adoption of electric vehicles. There was a consensus that while safety measures are paramount, imposing rigid specifications, particularly for battery dimensions and connectors, could stifle innovation and limit market flexibility. Some stakeholders advocated for a flexible approach that prioritizes safety and allows for voluntary compliance, to avoid creating monopolies and support diverse market needs, including export opportunities. The industry also highlighted the importance of aligning with international standards to foster a competitive and innovative environment for electric vehicle infrastructure development.

Figure 6 Eight key aspects of the Chinese Process towards battery swap systems and technologies[39]

4 Global Landscape of BSS Interoperability and Standardization

Battery swapping has gained traction in several countries, demonstrating its potential to address the limitations of traditional charging. Countries like China, Japan, and some European nations have already

[39] TRV (2021). Electrification of the Transportation System in China Exploring Battery-Swapping For Electric Vehicles In China. Trafikverket, TRV

started implementing and standardizing BSS and batteries as a whole across different sectors. This section synthesizes some of the major efforts including ongoing pilots.

4.1 China

China- Revival of the battery swapping ecosystem

The Chinese government and industry leaders have proactively developed and enforced standards that ensure the compatibility of batteries and swapping stations across different manufacturers and vehicle types. China has implemented numerous pilot programs to test and refine battery swapping technology. Pilot programs have provided essential data and operational insights, allowing stakeholders to refine technologies and business models before large-scale deployment. These pilots have provided valuable insights into the operational, economic, and technical challenges of battery swapping and have helped in scaling the technology effectively. Building on the success of pilot programs, China has rapidly scaled up battery swapping infrastructure. By 2021, the country had established over 562 battery-swapping stations, primarily concentrated in the eastern region. It is pertinent to note that despite the phase-out of national subsidies, registrations of new energy commercial vehicles (buses and trucks) in China maintained their momentum in 2023, growing by 29.8% year-on-year to a record high of 308,531 units. As a result, the penetration rate reached 10.8%, an increase of 1.6%[40] YoY.

The Chinese approach can be described as a "Symbiotic Business Model," where political, institutional, and industrial players collaboratively explore and implement battery-swapping solutions governed by the eight key aspects shown in Figure 6. This collective effort has facilitated the rapid development and commercialization of battery-swapping systems, integrating them into the broader energy and transportation ecosystem. Key strategies for large-scale implementation include: *Public-Private Partnerships; Supportive Policies and Incentives; Strategic Placement of Stations*

China's State Administration for Market Regulation (SAMR), approved the National Standard for Battery Swap Safety Requirements for EVs (GB/T 40032-2021[41]. This standard went into effect November 2021 thanks to the active contribution and role of major OEMs— Nio, Beijing Electric Vehicle Co Ltd and Geely. It covers multiple dimensions: i) **safety requirements**—*battery and vehicle interface, mechanical and electrical, thermal management and environmental resistance*; ii) **test methods**—*durability, impact and vibration, electrical and thermal*; and iii) **inspection rules**—*regular and routine maintenance, compliance and certification.* Interoperability is a key focus for China's battery swapping model. By adhering to unified standards, the country aims to create a seamless experience for EV users. This interoperability is particularly beneficial for commercial fleets and ride-sharing services that require quick and efficient battery swaps to maintain operational efficiency.

Leading Chinese automakers like NIO, Geely, and BAIC have embraced these standards, designing vehicles that are compatible with standardized BSS[42,43]. NIO, for instance, has integrated these standards into its extensive network of battery swap stations, which are capable of servicing multiple vehicle models. Other automakers like Geely and Lifan are also conducting pilot projects in various cities, focusing on

[40] InteractAnalysis (2024). China's new energy commercial vehicle sales up 30% to surpass 300k units in 2023 https://interactanalysis.com/insight/chinas-new-energy-commercial-vehicle-sales-up-30-to-surpass-300k-units-in-2023/

[41] GB/T 40032-2021 (2021) Safety requirements of battery swap for electric vehicles https://www.codeofchina.com/standard/GBT40032-2021.html

[42] Technode (2023). NIO partners with Geely to standardize battery swaps, mulls spin-off (2023). https://technode.com/2023/11/30/nio-partners-with-geely-to-standardize-battery-swaps-mulls-spin-off/

[43] Electrek (2024). NIO and Lotus announce plans to co-develop unified battery standards, charging, and swaps. https://electrek.co/2024/04/25/nio-lotus-to-co-develop-unified-battery-standards-charging-swaps/

commercial applications such as taxi services and logistics vehicles. These pilots are testing the scalability and operational efficiency of battery swapping for high-usage vehicles. In cities like Xiamen and Chongqing, battery swapping is being piloted for public buses, aiming to reduce downtime and increase operational efficiency for public transportation systems. More recently, Yadea, in collaboration with Meituan, has launched a pilot program in Shenzhen for the world's first sodium-ion battery swap system tailored for e2W[44].

CATL and Didi's joint venture, known as EVOGO[45], focuses on deploying modular battery swapping stations across China. These stations are designed to be compact, occupying only three parking spaces, and can store up to 48 battery blocks. The modular design allows for flexibility in managing battery supply and ensures that fully charged batteries are always available. Each battery swap takes approximately one minute, drastically cutting down the time needed compared to conventional charging methods. The EVOGO system is engineered to be adaptable to 80% of the BEVs on the market and those expected to enter the market in the next three years.

Battery swapping technology is playing an equally critical role in the rapid electrification of heavy-duty vehicles[46]. Sales of battery electric heavy-duty trucks (BEVs) in China have seen a dramatic increase. In January 2022, battery-swapped heavy trucks made up 45% of the total sales of pure electric heavy trucks, rising from just 19% the previous year. The market is expected to grow substantially, with projections estimating over 350,000 BEV heavy-duty trucks by 2030. This growth is largely driven by the efficiency and operational benefits that battery swapping offers for heavy-duty applications, especially in logistics and industrial sectors. The standardization of battery packs and the predictability of fixed routes for heavy-duty trucks make them particularly suitable for battery swapping, reducing the overall cost and complexity of infrastructure development.

4.2 European Union

EU Battery Regulation[47] and standardization as part of its revamped broader Industrial Strategy

This regulation requires detailed information about the lifecycle of batteries to be digitized, enhancing transparency, traceability, circularity and sustainability in the form of digital product passports (DPPs) or "battery passport"[48]. Together with the European Sustainable Products Regulation (EPSR), the DPP is being driven by Workstream 13 of The High-Level Forum on European Standardisation (HLF[49]). These regulations introduce series of reporting obligations, each with specified deadlines, which will be phased in incrementally from 2024 to 2028 from labelling to EoL. The concept of a battery passport and meta-structure for data reporting has already been demonstrated through pilots[50]. *Right-to-repair; ease of replaceability and removability; open standards for battery manufacturing; interoperable, extendable, platform and legacy system agnostic; as well safety testing* are notable features pertinent to battery swapping. Furthermore, multiple standardization efforts are underway focusing on *technical specifications (new, remanufactured or repurposed), state-of-health including data sharing* across the

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[44] SMM (2024). Yadea Launches World's First Sodium-ion Battery Swap Mode in Shenzhen Pilot Program https://news.metal.com/newscontent/102674715/yadea-launches-worlds-first-sodium-ion-battery-swap-mode-in-shenzhen-pilot-program
[45] CATL (2024). DiDi and CATL form joint venture for battery swapping. https://www.catl.com/en/news/6212.html
[46] Battery Swapping To Drive Rapid Heavy-duty Electrification In China (2022) https://interactanalysis.com/insight/battery-swapping-to-drive-rapid-heavy-duty-electrification-in-china/
[47] EU (2023). REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02023R1542-20230728
[48] Understanding the new EU Battery Regulation (2023) https://www.tuvsud.com/en-us/resource-centre/blogs/mobility-and-automotive/understanding-the-new-eu-battery-regulation
[49]Standardisation strategy (2022) https://single-market-economy.ec.europa.eu/single-market/european-standards/standardisation-policy/standardisation-strategy_en
[50]Battery Passport Pilot (2019) https://www.globalbattery.org/action-platforms-menu/pilot-test/

value chain and *reference architecture implementation* by the MOBI initiative and Global Battery Alliance[51].

These pilots highlight the importance of standardizing the reporting and tracking of battery data across the entire value chain. Efforts are underway to standardize the technical specifications for new, remanufactured, or repurposed batteries. These specifications include parameters for battery size, connectivity, and performance, ensuring that batteries can be used interchangeably across different systems and applications. The EU is developing frameworks for the real-time tracking and reporting of battery conditions, which are essential for optimizing battery use and facilitating maintenance and recycling.

4.3 Japan

Japan's Ministry of Land, Infrastructure, Transport and Tourism has established the Carbon Neutral Center to develop UN standards and to demonstrate these standards through targeted pilot projects[52]. In support of this initiative, major Japanese automakers—Honda, Yamaha, Kawasaki, and Suzuki—alongside the oil and gas conglomerate Eneos[53], have agreed to standardize battery designs under the initiative named Gachaco[54]. These modular and interoperable Battery-as-a-Service (BaaS) pilots are currently being implemented. The common specifications—including size, weight, durability, and safety—comply with the JSAE JASO TP 21003[55] standards. These guidelines are crucial for ensuring safety, compatibility, and performance across different manufacturers and models. They provide a framework for developing batteries that can be easily swapped and used interchangeably, promoting interoperability and user convenience

Mitsubishi Fuso[56], a key player in commercial vehicles, has partnered with Ample, a company specializing in battery swapping technology, to develop a battery swapping solution for electric trucks. This collaboration aims to address the specific needs of heavy-duty and commercial vehicles, which often require rapid turnaround times and extended range capabilities. The partnership focuses on creating battery systems that can be easily swapped, thereby minimizing downtime and maximizing operational efficiency for fleet operators.

4.4 ASEAN

ASEAN Region

From a Sectoral and Macro-economic perspective, APEC's Sub-Committee on Standards and Conformance (SCSC)[57] recommends *incentivizing harmonization of standards*; *developing and scaling Mutual Recognition Agreements (MRAs)*; *harness existing MRAs* for conformity assessment[58] whilst *shoring up the domestic infrastructure*; *building capacity and raising awareness* of the safety and fire risks of batteries. One of the central aspects of ASEAN's EV strategy is the standardization of infrastructure and

[51] Standards-Based Battery Passport for Interoperability, Extendability, and Cross-Border Compliance (2022) https://www.globalbattery.org/media/pilot/documents/mobi-batterytrak-one-pager-new-draft-01.pdf
[52] Monthly Japanese Industry and Policy News (2024) https://www.eu-japan.eu/sites/default/files/imce/MJIPN%202024.1.pdf
[53] Eneos (2024). Announcing the launch of the first fully automated modular battery swapping station for EVs https://www.hd.eneos.co.jp/english/newsrelease/20240328_01_02_2003128.pdf
[54] Rideapart (2023) Gachaco To Open Battery Swapping to Individuals. Here's Why It Matters (2023) https://www.rideapart.com/news/702581/gachaco-battery-swapping-open-individuals/
[55] JSAE - JASO TP 21003 Guideline for Swappable Batteries Of Electric Two Wheel Vehicles https://standards.globalspec.com/std/14517753/jaso-tp-21003
[56] Mitsubishi (2023). Mitsubishi Fuso and Ample to partner on battery-swapping technology for electric trucks (2023) https://www.mitsubishi-fuso.com/en/news-main/press-release/2023/07/26/mitsubishi-fuso-and-ample-to-partner-on-battery-swapping-technology-for-electric-trucks/
[57] https://www.apec.org/groups/committee-on-trade-and-investment/sub-committee-on-standards-and-conformance
[58] https://european-accreditation.org/mutual-recognition/iaf-ilac-recognition/

technology across member states. This harmonization is essential for creating a seamless and efficient EV ecosystem that transcends national borders.

In September 2023, the ASEAN Plus Three leaders[59], which include China, Japan, and South Korea, endorsed a statement underscoring the importance of developing a unified EV ecosystem. This statement highlighted the need for collective efforts to *integrate technical standards and regulations*, which will enable the *interoperability of EV components and infrastructure across the region*. This harmonized approach not only supports consumer convenience but also attracts investments and fosters innovation within the region. The Economic Research Institute for ASEAN and East Asia (ERIA) report[60] delves into the critical aspects of battery reuse and recycling within the context of ASEAN's EV ecosystem. This report highlights the strategic importance of developing robust standards and ensuring interoperability to foster the growth of a sustainable and efficient EV market across Southeast Asia

Indonesia's EV roadmap outlines the standardization of battery technologies as a key priority[61]. This roadmap aims to establish common specifications for battery packs and connectors to facilitate seamless swapping across various vehicle models and service providers. Public-private partnerships are encouraged to develop and operate battery swapping stations, ensuring that these facilities meet standardized safety and performance criteria.

Gojek, a leading ride-hailing company, has partnered with Pertamina[62], Indonesia's state-owned oil and gas corporation, to develop a battery swapping network for electric scooters. This initiative aims to reduce operational downtime for Gojek's delivery fleet and support the broader adoption of electric two-wheelers in urban areas. GESITS electric motorcycle, developed by a consortium led by Garansindo Group. GESITS motorcycles[63] are designed to be compatible with battery swapping, providing a practical solution for urban commuters. The project emphasizes local manufacturing and aims to promote sustainable mobility through standardized battery swapping infrastructure.

Thailand's National Science and Technology Development Agency (NSTDA) played a key role in developing a standard battery pack that fits universally across motorcycles and mopeds. The standardized dimensions, specifications, labelling, testing and general safety guidelines of 48 V/60 V/72 V rechargeable electrical energy storage system (REESS) is formalized in TIS 3316-2564[64] (Ref. Figure 7). These standards cover the technical specifications for battery packs, connectors, and safety protocols, promoting interoperability and ensuring that various systems can work together seamlessly. TISI's efforts are aligned with international standards to facilitate cross-border cooperation and integration

Energy Absolute, a leading renewable energy company in Thailand, has launched several battery swapping stations for electric scooters[65] and tuk-tuks (three-wheeled vehicles). The government has initiated pilot projects to test battery swapping for electric buses in Bangkok[66], aiming to enhance the efficiency and reliability of the city's public transport system. These projects focus on reducing the downtime associated with charging and ensuring that buses can maintain continuous operation throughout the day. In contrast to IS.

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[59] Asean plus three leaders' statement on developing of electric vehicle ecosystem (2023). https://asean.org/wp-content/uploads/2023/09/ASEAN-Plus-Three-Leaders-Statement-on-Developing-of-Electric-Vehicle-Ecosystem.pdf

[60] Reuse of Electric Vehicle Batteries in ASEAN. ERIA Research Project Report FY2023 No. 31. The Economic Research Institute for ASEAN and East Asia (ERIA)

[61] Indonesia E-mobility Country Profile (2022) https://asiantransportoutlook.com/documents/67/Indonesia_20231002b.pdf

[62] Electrum, Pertamina, Gogoro and Gesits' enhanced collaboration accelerates Indonesia's two-wheel electric vehicle ecosystem (2022). https://www.pertamina.com/en/news-room/news-release/a-synergy-of-electrum-pertamina-gogoro-and-gesits-to-accelerate-indonesia's-electric-vehicle-ecosystem

[63] "Gesits" Pioneer of Indonesia Electric Motorcycle (2023)https://aim2flourish.com/innovations/gesits-pioneer-of-indonesia-electric-motorcycle

[64] https://service.tisi.go.th/tisi-standard-shop/item/tis/5751

[65] Electric Mobility Two-Wheelers Toward Sustainable Society (2023). https://www.entec.or.th/entec-news_electric-mobility-two-wheelers-toward-sustainable-society/

[66] Bangkok E-Bus Programme (2024) https://www.klik.ch/en/international/activities/bangkok-e-bus

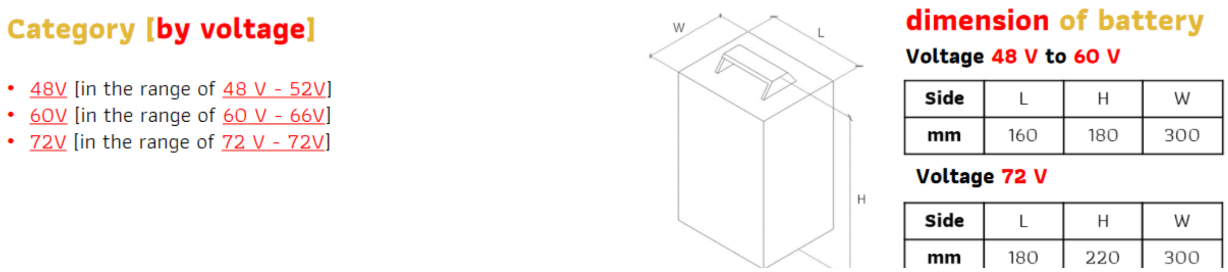

Figure 7 Thailaind's TITI 3316-2564 Standardized battery dimensions [67]

Singapore is integrating battery swapping into its broader strategy to enhance electric mobility and reduce carbon emissions. This initiative involves both light electric vehicles (LEVs) such as electric scooters and motorcycles, as well as heavier commercial vehicles. In March 2022, the Land Transport Authority (LTA) of Singapore introduced the updated National Electric Vehicle Charging Standard, known as TR25:2022[68,69]. TR25:2022 provides specifications for the physical and electrical characteristics of battery packs and connectors used in swapping systems. This includes dimensions, voltage levels, and connector types, ensuring that batteries from different manufacturers can be interchanged without compatibility issues. The standard mandates the use of standardized connectors that conform to internationally recognized specifications, promoting seamless integration across various battery and vehicle platforms. TR25:2022 also specifies the performance criteria that batteries must meet to be considered suitable for swapping, including durability, thermal management, and electrical stability.

Gogoro's network in Singapore aims to replicate its success in Taiwan by providing a convenient and efficient alternative to traditional charging. The project evaluates the operational efficiency, user acceptance, and economic viability of battery swapping for LEVs in Singapore's densely populated urban areas. BlueSG, a subsidiary of the Bolloré Group and operator of Singapore's electric car-sharing service, is expanding its scope to include electric scooters. The pilot involves integrating battery swapping technology into BlueSG's fleet of electric scooters, providing users with quick and easy access to fully charged batteries. The LTA's pilot projects also include the deployment of BSS for taxis, delivery trucks and buses. These high-utilization vehicles benefit significantly from the reduced downtime associated with battery swapping. The pilot projects aim to demonstrate the feasibility of swapping stations to support continuous operation, particularly during peak hours when traditional charging could lead to extended downtime. This initiative focuses on evaluating the logistics, operational efficiency, and user feedback from commercial fleet operators

4.5 Other Countries

Chile's approach to battery swapping emphasizes the importance of standardized systems and collaboration between public and private sectors. Chile's regulatory frameworks are designed to support the development of standardized BSS that ensure compatibility and safety. The government works closely with industry stakeholders to establish technical standards for battery packs, connectors, and operational protocols, promoting a cohesive and interoperable battery swapping ecosystem

[67] Thailand Automotive Institute (n.d.) Electric Mopeds and Motorcycles -Removable Rechargeable Electrical Energy Storage System
[68] Introduction of Updated National Electric Vehicle Charging Standard https://www.lta.gov.sg/content/ltagov/en/newsroom/2022/3/news-releases/introduction-of-updated-national-electric-vehicle-charging-stand.html
[69] Singapore to trial EV battery charging, swapping system https://www.argusmedia.com/en/news-and-insights/latest-market-news/2576862-singapore-to-trial-ev-battery-charging-swapping-system

Copec[70] is partnering with Gogoro to introduce its battery swapping system and Smartscooters for consumers and B2B delivery riders in Chile and Colombia. U Power[71] Limited has announced plans to introduce its UOTTA heavy truck battery swapping technology to the Chilean market. This technology is designed to facilitate rapid battery exchanges for heavy-duty trucks, addressing the challenges of long charging times and high utilization rates in freight and logistics operations.

Kenya's Energy & Petroleum Regulatory Authority[72] issued guidelines for battery swapping and public charging infrastructure that went into effect Sep. 2023. Guidelines covers installation space, UIN for both the battery (traceability, upstream manufacturing) and the swapping station, IoT for BMS, remote monitoring, diagnostics, performative evaluation, immobilization and utilization data retention throughout the lifecycle.

Emerging Standardization and Interoperability Initiatives

In addition to the IEC 62480, parts 1 and 2; part-3[73], emphasizes on the safety and interoperability of battery swap systems for removable storage, connected to a supply network rated 480 V AC/400 V DC and battery DC link voltage of up to 120 V. This has also been loosely referred for making the use-case for battery swapping in off-road applications like forklifts and automatic material handling equipment.

The ISO/TC 22/SC 38[74] on motorcycle and mopeds[75] is currently reviewing a draft proposal submitted by the Swappable Battery Motorcycle Consortium (SBMC)[76] that has identified six main topics for standardizing—*general & safety; mechanical parts; connectors; BMS— sensors, controllers and EMC; and test specifications.*

[70] Battery swapping system to deploy in Latin American cities (2024). https://www.smartcitiesworld.net/batteries-and-renewables/battery-swapping-system-to-deploy-in-latin-american-cities-9907
[71] PR Newswire. (2024). *U Power Limited's UOTTA Heavy Truck Battery Swapping Technology to Enter Chilean Market*. https://www.prnewswire.com/news-releases/u-power-limiteds-uotta-heavy-truck-battery-swapping-technology-is-expected-to-enter-the-peruvian-market-302152640.html
[72] Electric mopeds and motorcycles - removable rechargeable electrical energy storage system (2023) https://www.epra.go.ke/wp-content/uploads/2023/09/EPRA-E-Mobility-Guidelines.pdf
[73] Only the publicly accessible specifications are available as a pre-standard or intermediate specifications.
[74] https://www.iso.org/committee/5384008.html
[75] According to ISO 3833
[76] https://www.sb-mc.net/news/sbmcs-remarkable-progress-from-prototyping-to-standardization

5 Recommendations

5.1 Priorities for India

India's ambitious goals for EV adoption are an integral part of its broader strategy for sustainable development and energy transition. However, achieving these goals requires overcoming significant challenges posed by the diversity in its vehicle market and the unique regional demands across the country. This section outlines these strategic priorities

Dual strategy: vehicle platform and form factor approaches—India's vehicle market is diverse, with significant variations in vehicle types, usage patterns, and user needs. To cater to this diversity, a dual strategy focusing on vehicle platform flexibility and innovative form factor designs is essential. Incentivizing manufacturers to design vehicle platforms capable of supporting both fixed and swappable battery architectures. Such platforms would cater to a broad spectrum of vehicles, including two-wheelers, three-wheelers, and heavy commercial vehicles. For instance, China's successful adoption of battery swapping is largely due to its standardized battery packs used across multiple vehicle models, simplifying integration and reducing costs. Standardizing battery sizes and shapes will facilitate interoperability among different vehicles and manufacturers. By aligning form factor innovation with specific performance needs, India can simplify manufacturing, reduce costs, and support interoperability.

Phased Approach—Gradually introduce standards, starting with key components like batteries and connectors, and then expanding to include entire vehicles and infrastructure. This allows manufacturers and operators time to adjust and comply. After successfully implementing component-level standards, the next phase should expand to include entire vehicles and operational processes. This stage aims to create a seamless integration between EVs and the battery swapping infrastructure. Establish uniform operational protocols for battery swapping stations, including the procedures for battery handling, charging, and exchange. These protocols should ensure consistent service quality, minimize downtime, and maximize safety. The final phase focuses on building and integrating the supporting infrastructure required for a fully operational and interoperable battery swapping network. This includes the development of charging infrastructure, IT systems, and integration with renewable energy sources.

Standardization and interoperability through the prism of energy transition—India's push for EV adoption is a significant component of its broader energy transition strategy aimed at achieving sustainable development and reducing dependence on fossil fuels. In this context, standardization and interoperability in BSS should be seen not just as an alternative to traditional charging methods, but as integral elements that enhance the entire energy ecosystem. As the technology matures, battery swapping systems can be adapted to serve a wide range of industries, offering **Energy as a Service (EaaS)** solutions. EaaS refers to a model where energy storage and delivery are provided as a service, enabling various industries to access reliable and flexible energy without the need for significant capital investment in infrastructure. Developing and enforcing national standards for battery packs, connectors, and swapping protocols is crucial for system-wide interoperability. Standardized and interoperable energy storage systems enhance grid resilience by seamlessly integrating with renewable energy sources. They can serve as decentralized energy storage hubs, balancing supply and demand locally. Additionally, these systems can participate in energy arbitrage markets, buying electricity during low-demand periods and selling it during high-demand periods, thus optimizing the use of available energy and contributing to overall grid stability and efficiency. GoGoRo[77] BSS performance as an emergency backup when earthquake struck Taiwan few months back is worth noting.

[77] MIT (2024). How battery-swap networks are preventing emergency blackouts https://www.technologyreview.com/2024/06/11/1093465/battery-swap-gogoro-taiwan-earthquake/

Inclusive and equitable support—The development of a robust BSS in India depends heavily on the participation of Micro, Small, and Medium Enterprises (MSMEs) in the manufacturing sector and the effective integration of informal battery swapping service providers. Both these groups are crucial to expanding the reach and operational efficiency of BSS, particularly in rural and semi-urban areas where traditional charging infrastructure is underdeveloped. The combined support for MSMEs in manufacturing and the integration of informal BSS operators will drive inclusive economic development across India. This will create new job opportunities, stimulate local economies, and ensure the widespread availability of battery swapping services. The success of similar initiatives in other countries[78] highlights the potential benefits of fostering a diverse and inclusive BSS ecosystem.

Stakeholder Collaboration and Engagement—Establishing platforms and mechanisms for industry collaboration on standard setting and technological innovation is vital. Forming industry consortia or working groups dedicated to developing and promoting interoperability standards will facilitate this process. The EU's Green Deal has demonstrated the effectiveness of collaborative platforms in achieving ambitious environmental and technological goals. These consortia should represent both large-scale formal operators and smaller, informal networks to ensure that standards are inclusive and widely acceptable. Encouraging PPPs to finance and operate battery swapping infrastructure will leverage the strengths of both sectors. Joint ventures and co-investment models will accelerate the deployment of battery swapping stations and services. The successful implementation of PPPs in China's urban battery swapping projects showcases the potential of such collaborations in driving large-scale infrastructure development. Promote the development of shared battery swapping facilities that can serve multiple vehicle brands and types. This approach reduces resource duplication and optimizes the use of available land and facilities, making battery swapping more efficient and cost-effective.

Targeted Pilots— Implementing targeted pilot projects is a crucial step in developing a scalable and efficient BSS in India. These pilot projects help to validate technical and operational aspects, provide insights into consumer behavior, and identify region-specific challenges. Pilots and demonstration projects allow for the real-world testing of technical standards, ensuring compatibility across various vehicle types and manufacturers. They help identify and address region-specific challenges, refine operational protocols, and validate safety measures. By collecting and analyzing data from diverse environments, these projects provide actionable insights that inform policy and regulatory frameworks, driving the broader adoption of standardized and interoperable BSS solutions.

5.2 Regulatory Framework and Policy Support

A comprehensive regulatory framework is essential to support the development and adoption of standardized and interoperable BSS. This framework should include financial and non-financial incentives, robust support for R&D, and performance-based rewards to encourage innovation.

5.2.1 Financial Incentives

5.2.1.1 Subsidies and Grants

Financial support should be provided to both formal and informal BSS operators to lower the initial capital expenditure required for setting up battery swapping stations or upgrading existing facilities. India could emulate China's initiatives by offering matching grants to incentivize private and community-based

[78] Singapore, South Korea, China and the EU have dedicated initiatives for mainstreaming and integrated SMEs

operators to invest in battery swapping technology, particularly in tier-2 and tier-3 cities where financial barriers are higher.

5.2.1.2 Tax Incentives

Implement tax relief measures for businesses that comply with standardized battery swapping systems. This could include reduced corporate tax rates, accelerated depreciation on capital investments, or tax credits for R&D in battery swapping technologies.

5.2.2 Non-Financial Incentives

5.2.2.1 Expedited approval

Simplifying the regulatory approval process for battery swapping projects can significantly reduce the time and complexity involved in establishing new stations. Fast-track permitting and simplified documentation requirements should be implemented. Developing scaled-down compliance requirements for smaller operators that still uphold safety and efficiency standards without imposing the same level of regulatory complexity as for larger companies. Provide grace periods for informal operators to meet new regulatory standards, allowing them time to adapt their operations without immediate penalties. Single Window Clearance (SWC) can play a critical role by providing a unified platform where all necessary permissions, licenses, and clearances are processed through a single interface.

5.2.2.2 Land acquisition and infrastructure support

Providing access to land and resources for developing battery swapping stations is crucial. This support could include offering land at subsidized rates, assisting with site selection, and fostering public-private partnerships. The Dutch government's approach to providing public land for EV charging infrastructure can serve as a model. India could adopt similar policies to make strategic locations available for battery swapping stations, particularly in densely populated urban areas and along major transport routes.

5.2.2.3 R&D Support and Innovation Hubs

Establish a dedicated **Technology Upgradation/Assistance Fund** to support advancements in battery manufacturing and swapping systems. This fund could provide grants and low-interest loans to companies developing standardized and interoperable battery technologies. India could create a funds along the lines of Japan's METI[79] to encourage R&D in cost-effective and scalable battery solutions, ensuring these technologies are adaptable to the needs of both formal and informal sectors. Allocating dedicated funds for R&D initiatives focused on battery performance, safety, and standardization is critical. Encouraging collaboration between academic institutions, research organizations, and industry players will foster a dynamic R&D environment. The EU's funding mechanisms for collaborative R&D in battery technologies have led to significant advancements and widespread industry adoption. Establish innovation hubs that promote collaboration among academia, industry, and government to drive breakthroughs in battery swapping and energy integration. These hubs could provide facilities for prototyping and commercializing new technologies.

5.2.3 Performance Based Initiatives

Providing rewards to operators who maintain high levels of operational efficiency and customer satisfaction can motivate continuous improvement. Metrics such as uptime, utilization rates, carbon footprint of electricity used for charging, transaction speed, and customer feedback should be used to

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[79] Argus Media (2023). Japan unveils subsidy to incentivise battery production https://www.argusmedia.com/en/news-and-insights/latest-market-news/2415123-japan-unveils-subsidy-to-incentivise-battery-production . METI- Ministry of Economy, Trade and Industry

assess performance. Implementing a certification and rewards system for companies that meet or exceed performance benchmarks will drive continuous improvements in quality and reliability. The success of **performance-based incentives** in California's Low Carbon Fuel Standard (LCFS) program highlights the effectiveness of rewarding companies for achieving superior environmental performance. This can even be tailored to supplement providers of standardized and interoperable BSS. Encouraging the use of renewable energy in battery swapping operations through **green energy credits** can promote sustainability.

5.2.4 Role of Government and Regulatory Bodies

Establishing a dedicated agency or task force to oversee the implementation and compliance of BSS standards and regulations is essential. This agency should regularly review and update regulations to keep pace with technological advancements and market dynamics. The government should act as a facilitator and coordinator among stakeholders to promote collaboration and standardization. Organizing forums and working groups to engage industry players, consumer groups, and international standard organizations will drive consensus on critical issues and streamline standardization efforts. Implementing battery swap standards presents an opportunity to bring unregulated LSEVs under the CMVR, thereby improving safety, reliability, and compliance within the broader EV ecosystem is a pertinent case in point. Government should develop clear, inclusive policies that support both formal and informal BSS. These policies should define technical specifications, safety requirements, and operational standards that cater to different operational scales. The ASEAN region's strategy of harmonizing vehicle standards across member countries illustrates the benefits of robust regulatory oversight. This approach ensures compliance and facilitates market integration, which India could emulate to strengthen its regulatory framework.

5.2.5 Consumer Protection and Safety

Ensuring consumer safety and building confidence in BSS are paramount to their widespread adoption. Implementing stringent safety standards for the design, installation, and operation of battery swapping stations will protect users from potential hazards. Regular **safety audits and certifications** will ensure compliance with these standards. The rigorous safety protocols followed by Japan's automotive industry have set a benchmark for consumer protection and system reliability. Developing clear **legal frameworks to address liability and indemnity** issues is critical. A indemnity bond type process adopted by the Delhi DISCOM[80] is a relatable example that is worth noting and emulating. Establishing standardized contracts and liability clauses will clarify the responsibilities of manufacturers, service providers, and operators, reducing disputes and providing recourse for affected consumers. Mandating comprehensive insurance coverage for battery swapping service providers will further protect consumers against losses or damages. The comprehensive legal frameworks in the EU for EV infrastructure liability provide a robust model for India to follow.

5.3 Focus on MSMEs and Informal BSS

Implement targeted financial support programs that offer grants and low-interest loans to MSMEs and informal BSS providers. This financial backing will help these enterprises upgrade their technologies and meet standardization requirements. Develop simplified licensing and regulatory processes to facilitate the transition of informal BSS operators into the formal market. Reducing bureaucratic hurdles will enable these providers to operate within standardized frameworks and compete effectively. Foster partnerships between large BSS operators and MSMEs/informal providers to create collaborative ecosystems. These partnerships can facilitate knowledge transfer, shared resources, and co-development

[80] Indemnity Bond https://ncbrpl.bsesdelhi.com/assets/pdfs/Indemnity_bond_310321.pdf

opportunities, ensuring that smaller enterprises can thrive alongside larger players. To empower these enterprises, the government should provide targeted financial assistance, such as grants, low-interest loans, and subsidies. These financial supports will enable MSMEs to adopt standardized technologies and enhance their operational capabilities, positioning them competitively within the market. Initiatives such as Technology Upgradation or Assistance Funds should also be accessible to MSMEs and smaller players.

5.4 Long-term Strategic Planning

Long-term strategic planning is essential to ensure that BSS align with India's broader mobility and energy goals. The EU's Sustainable Urban Mobility Plans (SUMPs) provide a framework for integrating EV infrastructure with broader transport and urban planning goals. Aligning BSS with national energy strategies, including the use of renewable energy and smart grid technologies, will support sustainability goals and improve grid resilience. Germany's integration of EV infrastructure with its Energiewende (energy transition) strategy demonstrates the benefits of aligning transport and energy policies. Compatibility with smart grid technologies ensures that battery swapping stations can communicate with the grid to optimize energy flows. This capability is crucial for integrating renewable energy sources, which are often intermittent and require sophisticated management to ensure consistent supply. Participating in international standard-setting bodies and aligning domestic regulations with global practices will facilitate cross-border interoperability and enhance India's competitiveness in the global market. Establishing mechanisms for continuous review and adaptation of standards will ensure they keep pace with technological advancements and market needs. The harmonization efforts under the United Nations Economic Commission for Europe (UNECE) for EV standards illustrate the advantages of aligning domestic policies with international norms**.**

Standardization and Interoperability are the key and only mechanisms to unlock these potential synergies.

6 Conclusions

Battery swapping emerges as a powerful solution to overcome the key barriers hindering EV adoption in India, offering advantages that traditional charging methods cannot match. It provides a rapid and convenient method to mitigate range anxiety—a significant concern for EV users—by allowing batteries to be replaced in minutes rather than waiting hours for a charge. Moreover, BaaS model significantly lowers the upfront cost of EV ownership by decoupling battery costs from the vehicle purchase, making EVs more accessible to a broader range of consumers. This approach not only reduces the initial financial burden but also alleviates concerns about battery longevity and replacement costs. In addition to these consumer benefits, battery swapping presents a scalable and efficient pathway for infrastructure development. Unlike traditional charging stations, which require substantial grid capacity and longer charging durations, swapping stations can efficiently manage high traffic volumes and distribute power needs more evenly across the day. This makes them particularly suitable for densely populated urban areas and high-traffic corridors where space and time are at a premium.

To harness the full potential of battery swapping, it is essential to establish robust frameworks for standardization and interoperability. These frameworks ensure that batteries from different manufacturers and vehicles from various segments can seamlessly interact with swapping stations, regardless of the service provider. Standardization simplifies the technical and operational complexities, making it easier to deploy and maintain a cohesive network of battery swapping stations. Interoperability, on the other hand, allows for flexibility and choice, enabling users to swap their batteries at any station, much like refueling a petrol vehicle at any fuel station.

Strategic adoption of battery swapping technology, supported by robust interoperability and standardization frameworks, will significantly advance India's electric mobility and energy transition goals. By addressing the needs of its diverse vehicle market, fostering inclusive economic growth, and ensuring alignment with broader energy strategies, India can develop a resilient, scalable, inter-operable, standardized and efficient battery swapping infrastructure. This will enhance the convenience and affordability of EV ownership and contribute to road transport decarbonization, promote sustainable development and enhance energy security.

Annexure

Submitted separately

		Date and Time
1.	IBSA Submission to DoCA	27th June, 2022
2.	Minutes of interactive meeting for discussion on battery swap and interoperability standards	22nd November 2022 03:00 PM
3.	Minutes of the meeting to discuss Standards of Battery Swapping with DoCA, BIS and stakeholders	3rd January, 2023 3:00 PM