Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
National Metrology Institute

INTERNATIONAL COOPERATION

Circularity of Battery Energy Storage Systems for Renewable Energy

Standardisation and regulation to create the foundation for sustainable development of an emerging sector in India

NISE
National Institute of Solar Energy

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Circularity of Battery Energy Storage Systems for Renewable Energy

Standardisation and regulation to create the foundation for sustainable development of an emerging sector in India

Authors
Niels Ferdinand, Stephanie Binks, Dr Venkatasailanathan Ramadesigan, Maria Llauradó

January 2026

On behalf of

Federal Ministry for Economic Cooperation and Development

On behalf of the Federal Government of Germany, the Physikalisch-Technische Bundesanstalt promotes the improvement of the framework conditions for economic, social and environmentally friendly action and thus supports the development of quality infrastructure.

Disclaimer

This document was elaborated as part of "*Strengthening Quality Infrastructure for the Solar Industry*", a project implemented by the Physikalisch-Technische Bundesanstalt (PTB) and financed by the Federal Ministry for Economic Cooperation and Development (BMZ). It was developed by a team of authors from the Indian Institute of Technology Bombay (IIT Bombay) and Ferdinand Consultants. The information and conclusions presented in this study are based on a review of existing literature and input from national and international experts. The findings and views expressed herein are those of the authors and do not necessarily reflect the official views or positions of PTB, IIT Bombay, or Ferdinand Consultants.

Physikalisch-Technische Bundesanstalt (PTB)

PTB is the national metrology institute of Germany. Within PTB, the International Cooperation group functions as an implementing organisation of development cooperation and is commissioned by the BMZ and the European Union. It promotes the improvement of the framework conditions for economic, social and ecological action and as such supports developing and emerging countries in establishing and utilising a needs-based and internationally recognised quality infrastructure.

Indian Institute of Technology Bombay (IIT Bombay)

IIT Bombay is one of India's premier institutions, recognised as an Institute of Eminence for its outstanding academic and research contributions. It has a broad research footprint spanning engineering, basic sciences, humanities, design, and management, fostering strong interdisciplinary collaboration. Faculty members and students work on cutting-edge areas such as artificial intelligence, advanced materials, biotechnology, climate science, and public policy. IIT Bombay has a strong focus on sustainability, with significant research in renewable energy technologies, smart grids, and energy storage systems. These efforts support clean energy innovation, industry engagement, and national priorities for a sustainable and resilient future.

Ferdinand Consultants

Ferdinand Consultants is an international sustainability consultancy, fostering sustainable impact with a team that combines international experience and local knowledge. For over 20 years, the Ferdinand Consultants team has been advising national governments, international organisations, development agencies and the private sector on how to foster quality infrastructure in developing economies. The company's unique expertise and international field experience are applied in numerous projects which support quality, safety and sustainability in the renewable energy sector.

The Authors

Niels Ferdinand is founder and director of Ferdinand Consultants. With more than 25 years of experience in international consulting, he has supported organisations across five continents in developing and implementing strategies that generate positive sustainability impact. As an international consultant for organisations such as PTB, IRENA, the World Bank and IFC, Niels advises and supports projects focussed on strengthening quality infrastructure in developing and emerging economies. His work includes extensive engagement in renewable energy and energy storage, supporting quality infrastructure initiatives in countries such as India, Indonesia, Morocco, Vietnam, Ukraine and Tunisia. For battery energy storage systems (BESS), Niels has led efforts on behalf of PTB to prioritise and develop quality infrastructure services that ensure the quality, safety, and increased circularity of such systems.

Stephanie Binks works as a consultant at Ferdinand Consultants. Her areas of expertise are quality infrastructure, sustainability reporting and renewable energy. Since 2023, she has supported a PTB project on quality infrastructure for the solar industry in India and has contributed to stakeholder engagement processes to improve the circularity of PV systems and ensure the quality and safety of battery energy storage systems (BESS) in India.

Dr Venkatasailanathan Ramadesigan is a Professor in the Department of Energy Science and Engineering at IIT Bombay, with research spanning electrochemical energy systems, battery sustainability, and energy transition modelling. His work integrates physics-based and data-driven approaches to analyse lithium-ion battery performance, degradation, and safety, with direct relevance to battery recycling and second-life applications. He has contributed to degradation analysis, optimisation, lifecycle and techno-economic assessment, and materials recovery analysis to guide decisions on reuse, and recycling. In parallel, his research on energy transition modelling examines the role of energy storage, electrification, and policy in enabling low-carbon energy systems, supporting efficient and sustainable pathways across the energy value chain.

Maria Llauradó works as a junior consultant at Ferdinand Consultants. She is involved in projects focussed on international cooperation, climate change, renewable energy, quality infrastructure, and sustainability reporting. She has supported PTB projects in the areas of solar PV, green hydrogen and quality in the supply chain.

Contents

Executive Summary

Objectives

This paper provides policymakers and public administrators in India with information to support and strengthen the standardisation and regulatory framework needed to allow recycling of battery energy storage systems (BESS).

To align the paper with India's clean energy ambitions and circular economy goals, its intention is to guide policy development, strengthen quality infrastructure, and encourage innovation and collaboration across the BESS value chain.

Context

In December 2024, the National Institute of Solar Energy (NISE), the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), and the Physikalisch-Technische Bundesanstalt (PTB) jointly organised a workshop titled "Improving Quality Infrastructure for Battery Energy Storage Systems". The event was part of an ongoing initiative to strengthen quality infrastructure (QI) services for battery energy storage systems (BESS) in India.

During a subsequent meeting of the follow-up committee, increasing the circularity of BESS was identified as a key priority. In particular, the development of a dedicated standard or guidance document to support circular practices in the Indian BESS sector was agreed as a priority.

The following paper includes:

- Background, core concepts, and proposed scope for standardisation and regulation on BESS circularity in India
- Relevant international technical regulations, standards, and guidance documents designed to inform the standardisation and regulatory framework

Recommendations

To ensure the sustainable use of BESS in India, a comprehensive, lifecycle-based standardisation and regulatory framework is needed. Drawing from global best practices—particularly the EU Battery Regulation, IEC standards, and US DOE safety initiatives—India can adopt the following recommendations to strengthen its policy and technical landscape.

Adopt relevant international standards or adapt them to the Indian Standards System

Adopt relevant international standards for BESS circularity or adapt them to the Indian standards system, covering design, manufacturing, second-life qualification, and end of life (EoL) management. This would:

- Build investor and consumer confidence through uniform safety and performance criteria.
- Enable domestic recycling and circularity pathways for critical minerals.
- Serve as the foundation for public procurement and grid-integration standards.

The most relevant international standards in this regard are the following (see Annex for a full description):

- IEC 62933 Series — Core standard series for electrical energy storage (EES) systems.
- IEC 62619:2022 — Safety requirements for secondary lithium cells and batteries used in industrial applications, including stationary storage / BESS.
- IEC 62620:2014 — Performance, marking, and testing for industrial lithium-ion batteries, including those used for stationary storage.
- IEC 63338:2024 — Recommendations on reuse / repurposing of batteries and BESS.

Introduce a national BESS regulation aligned with international regulations and standards

Design & Manufacturing:

- **Introduce a national regulation on BESS, covering safety, environmental, circular-economy and digital traceability aspects.** Here, it is recommended to use the EU Battery Regulation 2023/1542 as a reference. In design and manufacturing, manufacturers should be required to declare battery carbon footprints and specify the minimum recycled content of critical metals (Li, Co, Ni and Pb) in new BESS units. Modular design and clear labelling should be mandatory to facilitate proper end of life (EoL) handling of BESS.
- **Include safety requirements for BESS in the (mandatory) CEA technical regulations.** The requirements should be aligned with international regulations and refer to technical specifications given in international standards, especially IEC 62933 (after adaptation to an IS standard).

Second-Life (Repurposing):

- **Pilot repurposing of EV batteries** for stationary storage.
- **Require traceable documentation on state of health (SoH) and safety screening of cells / modules**, referring to IEC 63338:2024 (or the adopted IS standard).
- **Develop a national certification scheme for repurposed batteries** aligned with the IEC 62933 series, IEC 62619:2022 and IEC 62620:2014 (or the adopted IS standards).

End-of-Life (Recycling & Disposal):

- **Define extended producer responsibility (EPR),** including the registration, financing of collection and recycling, provision of information and safe disposal or treatment of BESS. Additionally, mandatory material-specific minimum recovery rates should be defined. The EPR is also covered in EU Battery Regulation 2023/1542. For example, the following **recovery rates** are defined: ≥ 90% for cobalt, nickel, copper, and lead (the latter, not used in Li-ion batteries), as well as ≥ 50% for lithium.
- **Implement a third-party verification scheme on EPR** compliance of BESS.

Data and Traceability:

- **Introduce a digital battery passport** tracking chemistry, capacity, state of health and recycling history.

- **Require standardised labelling** with capacity, composition, lifespan, and disposal information.

Strengthen Institutional Coordination and Compliance

- **Support the development of accredited testing and certification infrastructure** for BESS, including facilities for state of health (SoH) assessment, safety testing, and recyclability evaluation, to enable compliance verification and second-life qualification.
- **Develop training programmes** for the safe handling, transport, dismantling, and recycling of BESS modules, supported by a **personnel certification scheme** for technicians and recyclers.

Importance of Circularity in BESS in India

Battery energy storage systems (BESS) are critical enablers of the global energy transition, providing flexibility, reliability, and grid stability for renewable energy sources such as solar and wind. As use scales up rapidly, so too do concerns about the environmental and resource impacts of manufacturing and disposing these systems. A circular approach to BESS is therefore vital.

To meet international climate targets, the global installed capacity of stationary battery storage must grow more than 25-fold by 2030. Without circularity, this growth could result in a substantial waste burden and increased demand for finite raw materials (IEA, 2023a). Scaling up BESS production without recycling could increase pressure on critical minerals, many of which are geographically concentrated and subject to supply risks. A circular economy can mitigate these pressures and enhance system resilience (World Bank, 2020).

In 2025, the Indian Government launched the National Critical Mineral Mission (NCMM) to build self-reliance in the critical minerals sector. The NCMM aims to secure and sustainably manage critical minerals essential for the global renewable energy transition (lithium, cobalt, nickel, rare earths). Regarding BESS, batteries directly depend on these materials for performance, safety, and reliability.

India is one of the fastest-growing markets for renewable energy, and BESS are set to play a pivotal role in achieving its national sustainability and energy security goals. As the country accelerates the use of solar and wind power, large-scale BESS installations are projected to expand rapidly. This growth presents significant opportunities for enhancing grid stability and renewable integration, but also introduces potential environmental and resource-management challenges in the absence of robust circular economy practices. The following points outline the key trends, opportunities, and risks shaping India's BESS landscape.

- **Increasing Use of BESS**: India is expected to add up to 160 GWh of BESS capacity by 2030 to support its renewable energy targets. Without a plan for endof-life management, this could lead to substantial environmental and logistical challenges (Government of India, Ministry of Power, 2023).

- **Limited Domestic Resources**: India imports most of the raw materials used in BESS, making it strategically important to recover and reuse materials through recycling and second-life applications (CII Blog, 2023).
- **Alignment with Energy Access and Affordability**: Reusing EV batteries in offgrid or behind-the-meter renewable energy applications can support rural electrification and improve affordability for decentralised systems (Xynteo, 2025).
- **Policy Alignment and EPR**: India's Battery Waste Management Rules (2022) establish extended producer responsibility (EPR) for all types of batteries, including BESS. However, specific guidance for stationary storage systems and design for circularity is still lacking (MoEFCC, 2022).
- **Environmental and public health risks**: Improper disposal of stationary BESS—often used in remote or industrial areas—can lead to soil and groundwater contamination. A circular strategy would mitigate these risks and ensure safer endof-life handling (TERI, 2020).
- **Second life of batteries**: Research is underway to develop a "Battery Aadhaar" system to track details such as manufacturer, material composition, durability, performance, and recyclability, enabling more efficient second-life applications. While EV batteries can be repurposed for powering EV charging stations or utilityscale storage, challenges such as diverse battery chemistries, pack designs, and the absence of standardised reuse frameworks increase the cost and complexity of recycling and repurposing (PSA, 2024).

Regulations and Standards for BESS in India

Current Regulatory and Standardisation Landscape in India

India's push toward high shares of renewable energy makes large-scale use of BESS inevitable. While the policy environment has begun to take shape, notably on safety and waste management, there are still important gaps. Most current documents address only the operational life of batteries, while issues related to end-of-life (EoL) handling, second-life use, and circularity remain underdeveloped. A coherent regulatory and standards framework covering the full lifecycle of BESS is critical if the sector is to scale sustainably.

Major existing instruments include Central Electricity Authority (CEA) reports and drafts of technical standards, Bureau of Indian Standards (BIS) documents and the Battery Waste Management (BWM) Rules, 2022.

The CEA has published reports and draft technical standards that touch on energy storage in the context of distributed generation and grid connectivity (CEA, 2019). These drafts mainly focus on the safety of electrical interfaces, system performance, and grid stability. The draft technical standards are proposals for regulation, circulated for public or stakeholder comment. They are voluntary in nature until finalised and officially announced. Importantly, they stop short of setting binding, sector-wide safety requirements for utility-scale stationary BESS.

BIS standards relevant to batteries today are largely adopted from international IEC standards. The IS 16046 series, which has been harmonised with IEC 62133, provides safety requirements for sealed, portable secondary lithium systems (BIS, 2018). A few other standards cover testing and performance evaluation. However, these documents are directed at consumer electronics and small batteries rather than large stationary BESS.

The BWM Rules introduced a mandatory extended producer responsibility (EPR) framework under which manufacturers and importers must collect, recycle, or refurbish used batteries (MoEFCC, 2022). The rules cover all chemistries and applications from portable cells to EV packs. They set collection and material recovery targets for critical resources like lithium, cobalt, and nickel. However, they also remain broad: they do not provide detailed protocols for handling and certifying degraded large-format BESS modules, nor do they address safe on-site decommissioning or logistics for transport of high-energy units.

Gap Analysis on Standards and Regulations for BESS

The review above identifies several areas where India’s (voluntary) standardisation and (mandatory) regulatory ecosystem does not yet align with the requirements of a circular battery economy:

1. **Second-life applications are not standardised.** India currently has no national standard for evaluating the state of health (SoH) of used BESS modules, nor for testing and certifying them for repurposed use. In the absence of such standards, operators face high uncertainty, and a second-life market—an important pillar of circularity—cannot develop.
2. **No incentives for design for disassembly.** Manufacturers currently do not have requirements or incentives to design BESS for safe disassembly, module replacement, or material recovery. This increases EoL processing costs and reduces recycling efficiency.
3. **Traceability and data gaps.** India lacks a “battery passport” or equivalent mechanism. A system such as the one defined in the EU Battery Regulation (Regulation (EU) 2023/1542) would record key data on battery chemistry, origin, usage history, and SoH, providing essential information for recyclers and second-life assessors.
4. **Insufficient technical detail on EoL management.** While the BWM Rules establish responsibility, they do not provide specific technical guidelines for safe site-level dismantling, interim storage, or cross-state transport of utility-scale BESS at EoL.
5. **Standards limited to small cells/portable devices.** Currently, there are no Indian Standards (IS) for utility-scale applications that address safety, design for recycling, documentation or end-of-life.
6. **Limited institutional coordination and capacity.** The recycling infrastructure in India is currently not sufficient to cover the expected number of batteries that will need to be recycled in the future. A roadmap to develop such infrastructure by involving the relevant public and private entities is lacking. Joint development plans would also be required for the state of health and recycling laboratory capacity, as well as the implementation of a certification or verification scheme on EPR compliance, of BESS. Institutional cooperation in training programmes is required to increase knowledge on the safe handling, transport, and dismantling of BESS modules.

Key components of circularity of BESS

Circularity in battery energy storage systems (BESS) involves a comprehensive approach to designing, utilising, and managing BESS to maximise resource efficiency, minimise environmental impact, and extend their lifecycle. This involves the entire battery value chain, from initial design to EoL management.

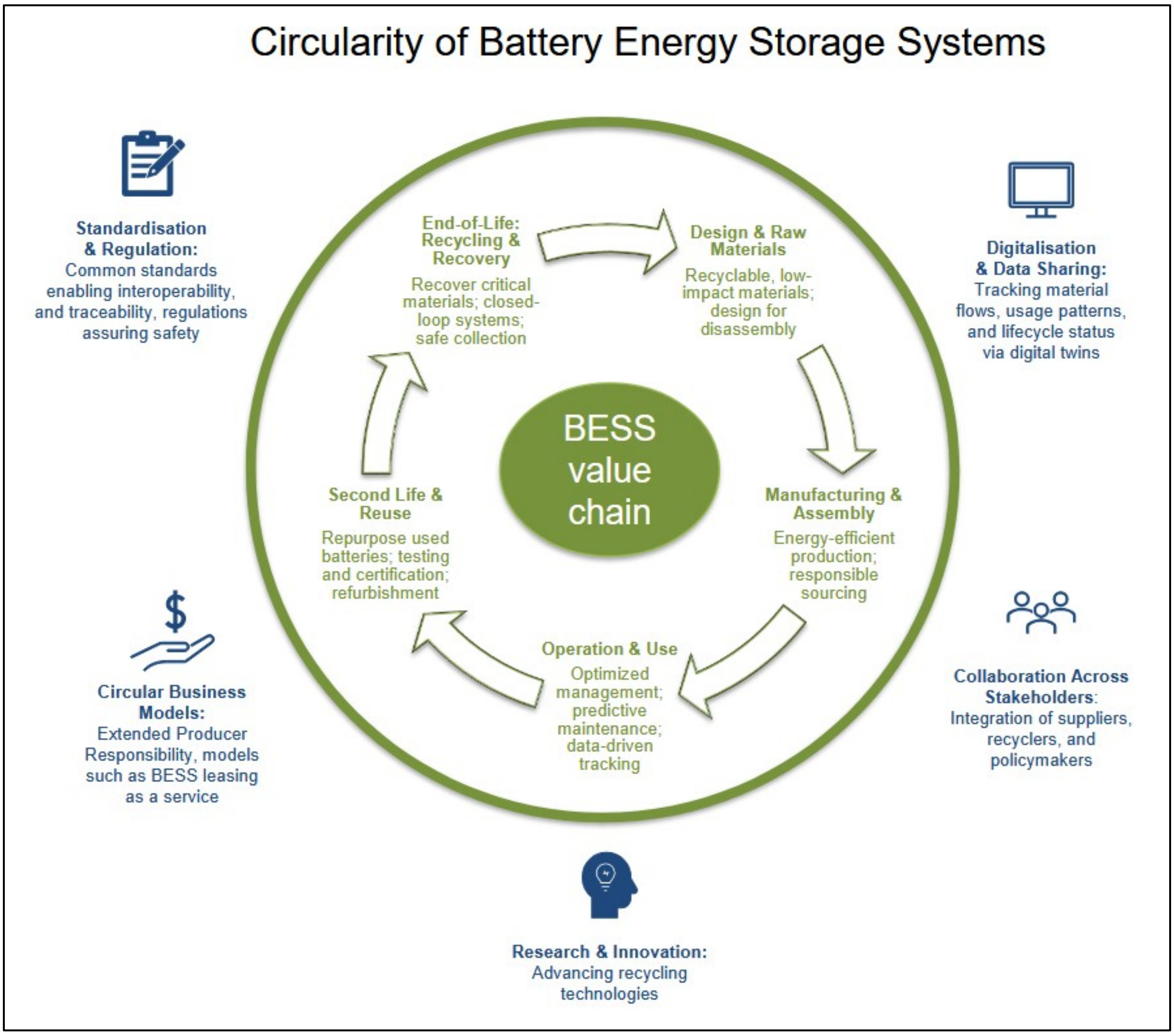

Figure 1: Key components of BESS circularity.

Key components of BESS circularity include elements of value creation (centre of Figure 1) and transversal elements that support them. Core elements represent the main stages of the battery lifecycle, while transversal elements are cross-cutting enablers that ensure the system functions effectively and sustainably.

Elements of Value Creation

- **Design and Materials**: Circularity in BESS begins with batteries engineered for safe disassembly, repair, and material recovery. This involves selecting less-toxic materials that are recyclable and abundant, and structuring packs for modularity and ease of dismantling, which improves recycling efficiency and reduces labour requirements (Thompson et al., 2020; Stena Recycling, 2023; CIC energiGUNE, 2021).
- **Manufacturing and Assembly:** Sustainable production is supported by responsible sourcing and designs that minimise waste throughout assembly. Incorporating materials with established recycling pathways and understanding performance trade-offs helps ensure that environmental gains do not compromise functionality (CIC energiGUNE, 2021).
- **Operation and Use:** During operation, effective lifecycle management—including monitoring battery health, predictive maintenance, and optimised usage patterns—enhances safety and extends the functional life of storage assets. These practices also allow targeted interventions to reduce environmental hotspots identified through lifecycle assessments (LCAs).
- **Second-Life and Reuse**: Batteries that no longer meet electric vehicle performance thresholds can be repurposed for stationary storage, such as grid services, microgrids, or commercial backup systems. This second-life stage increases the return on material and energy inputs, improves affordability, and supports wider energy access (Wired, 2021).
- **End-of-Life - Recycling and Recovery**: Innovative processes such as hydrometallurgy and bioleaching enable the recovery of valuable materials like lithium, cobalt, and nickel from end-of-life batteries. Efficient recycling mitigates environmental risks from improper disposal and supports a secure, circular supply of critical materials (The Guardian, 2024).

Transversal Elements

- **Standardisation and Regulation**: Common standards in design, safety, and data protocols—supported by tools like battery passports and accessible diagnostic information—facilitate interoperability and improve the economic viability of circular business models. Mandatory regulations ensure safety and environmental compliance. As a good practice, they refer to internationally recognised criteria defined in standards for technical details. Together, standards and regulations streamline the integration of second-life batteries into new applications while supporting safe and efficient circular practices (Frontiers in Sustainability, 2024).

- **Circular Business Models:** Mechanisms such as extended producer responsibility and battery leasing models create economic incentives for reuse, refurbishment, and recycling. Circular business models reinforce the closed-loop approach, promoting resource efficiency and long-term sustainability (Thompson et al., 2020).
- **Digitalisation and Data Sharing:** Digital twins and lifecycle tracking systems like the battery passport allow stakeholders to monitor product and material flows, usage patterns, and battery health. Data-driven insights support maintenance, second-life integration, and recycling strategies, enhancing operational and environmental outcomes (Frontiers in Sustainability, 2024).
- **Collaboration Across Stakeholders:** Effective circularity requires coordinated efforts among manufacturers, recyclers, policymakers, and researchers. Collaboration accelerates innovation, streamlines processes, and strengthens the sustainability of battery value chains (Thompson et al., 2020).
- **Research and Innovation**: Ongoing innovation in areas such as advanced recycling techniques, alternative chemistries, and improved LCA methodologies helps reduce environmental burdens and enhances resilience across the BESS lifecycle.

Integrating these components can help establish a circular system in which batteries are designed with their entire lifecycle in mind. This in turn supports sustainable development, reduces environmental burdens, and contributes to the resilience of India’s energy storage sector.

International Framework

Building on the Indian perspective, this section outlines key regulatory models that guide sustainable battery management worldwide.

EU Extended Producer Responsibility (EPR) Framework

Extended producer responsibility (EPR) is a core framework in the EU that places the financial and operational burden of post-consumer waste management on manufacturers and importers rather than on society (Katona & Partners, 2025). Rooted in the "polluter pays" principle, EPR requires producers to finance or organise the collection, treatment, and recycling of products at the end of their life (European Commission, 2025; Katona & Partners, 2025). The concept was formally introduced through the Waste Framework Directive (2008/98/EC), particularly Article 8, which mandates that Member States ensure producers take back used products and cover associated waste management costs (Bird & Bird, 2023). This transfer of costs from governments to industry incentivises eco-design, encouraging producers to develop more durable, repairable, and recyclable products (European Parliament & Council of the European Union, 2012).

Within this framework, specific waste streams operate under mandatory EPR schemes. The Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU), for instance, requires producers to establish free take-back and recycling systems. Consumers must be able to return waste electrical and electronic equipment at no charge, while producers finance its collection, treatment, recovery, and disposal (European Parliament & Council of the European Union, 2012). By harmonising these obligations across Member States, the EU ensures that the cost of e-waste management shifts from taxpayers to manufacturers and helps prevent illegal waste exports.

EPR is a central instrument in the EU's Circular Economy Action Plan, as it keeps materials circulating in the economy, reduces virgin material use, and promotes product innovation. This principle is further reinforced in the EU's Batteries Regulation (EU 2023/1542), which represents the most advanced global framework integrating EPR across all battery types.

Benefits: EPR ensures that producers bear the cost of EoL management, encourages eco-design, and keeps materials circulating in the economy. It reduces environmental impact and promotes sustainable product innovation.

Recommendation: **Align more closely.** India could align its EPR framework for BESS, requiring manufacturers and importers to fund collection, recycling, and disposal. Local targets and incentives for eco-design could be included to strengthen circularity and resource efficiency.

EU Batteries Regulation (EU) 2023/1542

Adopted in July 2023, the EU Batteries Regulation establishes a comprehensive, lifecycle-based legal framework addressing the environmental and circularity requirements of batteries (European Parliament & Council of the European Union, 2008; European Parliament & Council of the European Union, 2012). It embeds EPR, requiring manufacturers to finance the collection, treatment, and recycling of used batteries, including those repurposed for second-life applications, with cost-sharing mechanisms that avoid penalising reuse (European Commission, 2023a). The regulation sets progressively higher collection and recycling targets, such as portable battery collection rates rising to approximately 73% by 2030 and stringent recovery efficiency levels, to drive the development of dedicated take-back systems and secure critical raw materials (IEA, 2023a; Deutsche Recycling, 2025; Flash Battery, 2025; VDE Renewables, 2024).

In addition to EPR obligations, the regulation introduces design and information requirements to enhance circularity. From 2027, consumers must be able to remove or replace portable batteries, and all batteries will feature a QR-coded label and a digital battery passport containing data on origin, capacity, state-of-health, and composition (Deutsche Recycling, 2025). Importantly, the Regulation explicitly recognises stationary BESS as a distinct category, requiring compliance with safety and durability standards (Article 12) and reporting of remaining capacity—measures that enable second-life reuse and safe recycling of large-scale storage units (European Commission, 2023a; TÜV SÜD, 2024).

Benefits: The regulation mandates producer take-back through EPR, sets high recycling efficiency levels (targeting >80% recovery of lithium, cobalt and nickel) and enforces material recovery, carbon footprint limits, durability, safety, and a digital battery passport to track batteries throughout their lifecycle.

Recommendation: **Adopt key features and use as reference.** India could adopt key features such as eco-design mandates, minimum recycled content, and digital tracking systems for stationary and second-life batteries.

EU Battery Regulation Implementation Guidelines

These guidelines provide the technical framework needed to apply the Batteries Regulation (EU) 2023/1542 in practice. They define detailed procedures and metrics for assessing recyclability, calculating recycled content, measuring the carbon footprint of battery production, and implementing the digital battery passport. Together, these implementing acts ensure consistent application of circularity and sustainability requirements across all EU Member States (European Commission, 2023b).

Benefits: The guidelines above offer clear, consistent methods for measuring sustainability performance, ensuring transparency and comparability across battery supply chains.

Recommendation: **Use as reference**. India can draw on these methodologies when defining its own technical requirements for recyclability, recycled content verification, and digital traceability in the BESS sector.

China's Regulatory Framework for Battery Recycling

China has established a comprehensive framework requiring EV manufacturers to ensure the collection and recycling of end-of-life power batteries. Although the regulations primarily target the mobility sector, they are increasingly being extended to second-life applications in stationary BESS. Since August 2024, lithium-ion and sodium-ion energy storage batteries have been subject to mandatory registration under the China Quality Certification Center's (CQC) national battery product registration platform, strengthening oversight and compliance (MPR, 2025). The framework combines design for recycling guidelines, producer responsibility obligations, and digital traceability systems to ensure accountability and maximise material recovery (IEA, 2023a/b; IEA, 2024). A pilot programme in Shenzhen tested digital take-back and traceability mechanisms, providing insights for national-scale implementation.

Benefits: The framework extends EPR principles to multiple battery sectors, promotes efficient collection and recycling, and establishes digital traceability to track batteries through their lifecycle.

Recommendation: **Use as reference. Be informed about these other approaches**. India could adopt a phased EPR approach with integrated traceability systems to structure its national framework for BESS circularity and EoL management.

United States – Standards and Incentive-Based Approach

The United States does not have a single national law on battery circularity, but promotes it through coordinated federal initiatives and frameworks. The Department of Energy's ReCell Centre and the National Blueprint for Lithium Batteries (2021–2030) prioritise design for recycling, second-life applications, and domestic recovery of critical materials (ReCell, 2025; FCAB, 2021). In addition, state-level extended producer responsibility (EPR) schemes are emerging (e.g., California, New York).

Benefits: Encourages private investment in recycling infrastructure and promotes the safe reuse of batteries through technical standards (e.g. UL 1974, UL 1973), advancing a market-driven path to circularity.

Recommendation: **Use as reference**. **Be informed about these other approaches**. India could adopt a similar model that blends standards-based governance with fiscal incentives, encouraging manufacturers to invest in local recycling and second-life applications for BESS.

Japan and South Korea – Integrated Circularity and Resource Security Models

Japan and South Korea embed battery circularity within their broader resource security and industrial strategies. Japan's battery recycling guidelines and South Korea's Act on the Promotion of Resource Circulation (2018) mandate traceability, collection, and recycling obligations for producers (IEEP, 2023; MDPI, 2025). Both countries maintain digital battery tracking systems and promote industry consortia for material recovery and second-life use.

Benefits: Strengthens supply chain resilience and ensures efficient recovery of critical minerals while reducing waste and emissions.

Recommendation: **Use as reference.** India could draw on these models to integrate battery traceability platforms, producer consortia, and recycling targets within its national BESS and EV circular economy policies.

Important international stakeholders

At the global and regional levels, collaborative initiatives and alliances are driving innovation, digital traceability, and harmonised standards for sustainable batteries. The following section highlights leading European and international frameworks that exemplify best practices in circular battery systems.

European Battery Alliance (EBA)

The EBA promotes strategic autonomy and environmental responsibility in the battery supply chain. It aligns EU member states on sustainable production, circularity, and standards, and supports investment in recycling and second-life applications (EBA, 2022).

International Energy Agency (IEA)

The IEA provides global insights on BESS use, second-life use of EV batteries, recycling markets, and policy instruments. Its frameworks support lifecycle optimisation and policy design for sustainable energy storage systems (IEA, 2023b).

Joint Research Centre (JRC), European Commission

The JRC provides scientific and technical evidence to inform EU policies on battery design, recyclability, and digital traceability. Its methodologies underpin sustainability assessment and standardisation in the battery value chain (JRC, 2023).

Fraunhofer Battery Alliance (Germany)

A network of research institutes pioneering applied research on battery recycling, ecodesign, and second-life applications. It collaborates with industry to advance circular BESS solutions (Fraunhofer, 2023).

Global Battery Alliance (GBA)

A multi-stakeholder platform bringing together governments, companies, and NGOs to promote sustainable, circular, and traceable battery value chains. The GBA developed the battery passport framework for global digital traceability (GBA, 2022).

Battery 2030+ (European Research Initiative)

A large-scale EU research initiative focussed on developing next-generation sustainable batteries with recyclability, durability, and safe design at the core of innovation. It complements circularity efforts by targeting long-term material and system innovation (Battery 2030+, 2025).

References

Battery 2030+ (2025). Sustainable Batteries of the Future. [Online] Retrieved from: https://battery2030.eu/

Bird & Bird (2023). Waste in the textile industry: the EU Commission's strategy on Extended Producer Responsibility. [Online] Retrieved from: https://www.twobirds.com/en/insights/2023/global/waste-in-the-textile-industry-theeu-commissions-strategy-on-extended-producer-responsibility

Bureau of Indian Standards (BIS). (2018). IS 16046 (Part 2): Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes — Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from Them, for Use in Portable Applications: Part 2 Lithium Systems. New Delhi: BIS.

Central Electricity Authority (CEA). (2019). Report of Committee on Preparation of Technical Standards for Connectivity of Distributed Generation Resources. Ministry of Power, Government of India.

CEN (2025). EN 18061:2025. Road vehicles - Rechargeable batteries with internal energy storage. [Online] Retrieved from: https://standards.cencenelec.eu/dyn/www/f?p=205:110:0::::FSP_PROJECT:77366&cs=1517E65B35C19FD4A320EDCF27E977EFE

China State Council (2016). https://www.iea.org/policies/25069-plan-for-theimplementation-of-the-extended-producer-responsibility-system

CIC energiGUNE (2024). Recycling lithium-ion batteries: key to a sustainable energy transition. [Online] Retrieved from: https://cicenergigune.com/en/blog/recyclinglithium-ion-batteries-sustainable-energy-transition

CII Blog (2023). Battery recycling in the era of electric vehicles (EVs) and battery energy storage systems (BESS). [Online] Retrieved from: https://ciiblog.in/batteryrecycling-in-the-era-of-electric-vehicles-evs-and-battery-energy-storage-systemsbess

Deutsche Recycling (2025). EU Battery Regulation: Everything You Need to Know (Update 2025). [Online] Retrieved from: https://deutsche-recycling.com/blog/batteryregulation/

EBA (2022). Strategic Action Plan for Batteries. European Commission, European Battery Alliance.

European Commission (2023a). Regulation (EU) 2023/1542 of the European Parliament and of the Council Concerning Batteries and Waste Batteries. Official Journal of the European Union.

European Commission (2023b). Draft implementing acts and guidance documents for Regulation (EU) 2023/1542.

European Commission (2025). Waste Framework Directive. [Online] Retrieved from: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-frameworkdirective_en

European Parliament & Council of the European Union (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives. *Official Journal of the European Union*, L 312, 3–30. [Online] Retrieved from: http://data.europa.eu/eli/dir/2008/98/oj

European Parliament & Council of the European Union (2012). Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast). *Official Journal of the European Union*, L 197, 38–71. [Online] Retrieved from: http://data.europa.eu/eli/dir/2012/19/oj

FCAB, 2021. National Blueprint for Lithium Batteries (2021 – 2023), Federal Consortium for Advanced Batteries. [Online] Retrieved from: https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf

Flash Battery (2025). From production to recycling: a comprehensive guide to the new European Battery Regulation 2023/1542. [Online] Retrieved from: https://www.flashbattery.tech/en/blog/eu-battery-regulation-obligations-updates/

Fraunhofer (2023). Battery Alliance: Research and Innovation in Recycling and Second-Life Applications.

Frontiers in Sustainability (2024). Advancing sustainable development through circular economy and skill development in EV lithium-ion battery recycling: a comprehensive review. [Online] Retrieved from: https://www.frontiersin.org/journals/sustainability/articles/10.3389/frsus.2024.1409498/full

GBA (2022). “Battery Passport Green Paper.” Global Battery Alliance, World Economic Forum.

GBA (2023). Battery 2030: Resilient, sustainable, and circular. [Online] Retrieved from: https://www.globalbattery.org/media/publications/battery-2030-resilientsustainable-and-circular.pdf

Government of India, Ministry of Power (2023). National Framework for Promoting Energy Storage Systems. [Online] Retrieved from:

https://powermin.gov.in/sites/default/files/National_Framework_for_promoting_Energy_Storage_Systems_August_2023.pdf

IEA (2023a). Batteries and Secure Energy Transitions. International Energy Agency. [Online] Retrieved from: https://www.iea.org/reports/batteries-and-secure-energytransitions/executive-summary

IEA (2023b). “Global EV Outlook” and “Tracking Energy Storage.” International Energy Agency.

IEA (2024). Plan for the Implementation of the Extended Producer Responsibility System. [Online] Retrieved from: Plan for the Implementation of the Extended Producer Responsibility System – Policies - IEA

IEC (2022). IEC 62619:2022. Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications. [Online] Retrieved from: https://webstore.iec.ch/en/publication/64073

IEC (2023a). IEC 62933-4-4:2023. Electrical energy storage (EES) systems - Part 44: Environmental requirements for battery-based energy storage systems (BESS) with reused batteries. [Online] Retrieved from: https://webstore.iec.ch/en/publication/66365

IEC (2023b). IEC 62933-5-3:2023. Electrical energy storage (EES) systems - Part 53: Safety requirements for grid-integrated EES systems – Performing unplanned modification of electrochemical based system. [Online] Retrieved from: https://webstore.iec.ch/en/publication/66697

IEC (2024a). IEC 63338:2024 — General Guidance on Reuse and Repurposing of Secondary Cells and Batteries. [Online] Retrieved from: https://webstore.iec.ch/en/publication/66675

IEC (2024b). IEC 62933-1:2024. Electrical energy storage (EES) systems - Part 1: Vocabulary. [Online] Retrieved from: https://webstore.iec.ch/en/publication/64642

IEEP (2023). Managing waste batteries from electric vehicles: The case of the European Union and Japan. [Online] Retrieved from:

https://ieep.eu/wpcontent/uploads/2023/05/Managing-waste-batteries-from-EVs-JP-and-EU-May-
2023.pdf

ISO (2023). ISO 59004 and ISO 59010 – Circular Economy Standards. International Organization for Standardization.

JRC (2023). “Science for Policy on Batteries and Energy Storage.” Joint Research Centre, European Commission.

Katona & Partners (2025). Extended Producer Responsibility (EPR) - Draft EU Legislation and Updates to Guidance on Packaging Data and What to Collect, Including Drinks Containers. [Online] Retrieved from: https://www.lexology.com/library/detail.aspx?g=f59fa80c-7b7e-49da-906742a2d49fc9f1#:~:text=Extended%20Producer%20Responsibility%20,of%20their%20 products%20and%20packaging

MDPI (2025). Global Regulations for Sustainable Battery Recycling: Challenges and Opportunities *Sustainability* 2025, *17*(7), 3045; [Online] Retrieved from: https://doi.org/10.3390/su17073045

Ministry of Environment, Forest and Climate Change (MoEFCC) (2022). Battery Waste Management Rules, 2022. G.S.R. 655(E). The Gazette of India. [Online] Retrieved from: https://moef.gov.in
MPR, 2025. MPR China Certification: China enforces Mandatory Registration for Energy Storage Batteries. [Online] Retrieved from: https://www.chinacertification.com/en/china-enforces-mandatory-registration-for-energy-storagebatteries/

NCSL, 2023. Extended Producer Responsibility – Batteries. National Conference of State Legislatures. [Online] Retrieved from: https://www.ncsl.org/environment-andnatural-resources/extended-producer-responsibility#batteries

PSA (2024). eMobility R&D Roadmap for India. [Online] Retrieved from: https://psa.gov.in/CMS/web/sites/default/files/psa_custom_files/Printing%20Updated%20eMobility%20R%26D%20Roadmap%20document_11072024.pdf

ReCell, 2025. Advanced Battery Recycling. [Online] Retrieved from: https://recellcenter.org

Stena Recycling (2023). Designing batteries for circularity. [Online] Retrieved from: https://www.stenarecycling.com/news-insights/insights-inspiration/guidesarticles/designing-batteries-for-circularity

TERI (2020). Managing India's clean energy waste: A roadmap for the solar and storage industry. [Online] Retrieved from: https://www.teriin.org/article/managingindias-clean-energy-waste-roadmap-solar-and-storage-industry

The Guardian (2024). Bacteria helping to extract rare metals from old batteries in boost for green tech. [Online] Retrieved from: https://www.theguardian.com/environment/article/2024/aug/25/bacteria-helping-toextract-rare-metals-from-old-batteries-in-boost-for-green-tech

Thompson et al. (2020). The importance of design in lithium-ion battery recycling – a critical review. Green Chemistry. [Online] Retrieved from: https://pubs.rsc.org/en/content/articlehtml/2020/gc/d0gc02745f

TÜV SÜD (2024). An Overview of EU Battery Regulation. [Online] Retrieved from: https://www.tuvsud.com/en-us/-/media/regions/us/pdf-files/whitepaper-report-ebooks/tuvsud_overview-of-eu-battery-regulations.pdf

UL (2023a). UL 1974: Standard for Evaluation for Repurposing Batteries. UL Standards.

UL (2023b). UL 9540A - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems. [Online] Retrieved from: https://www.ul.com/services/ul-9540a-test-method

VDE Renewables (2024). EU Battery Regulation - (EU) 2023/1542. [Online] Retrieved from: https://www.vde.com/renewables/newsroom/eu-battery-regulation

Wired (2021). These Batteries Can't Power a Car—but They Can Light Up a City. [Online] Retrieved from: https://www.wired.com/story/batteries-cant-power-car-lightcity

World Bank (2020). Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. [Online] Retrieved from: https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

Xynteo (2025). *Your EV battery's second act can power India's future*. [Online] Retrieved from: https://xynteo.com/your-ev-batterys-second-act-can-power-indiasfuture

Annex: Comparative table of key international documents

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
Regulation (EU) 2023/1542 on Batteries and Waste Batteries (European Commission, 2023a). Regulation - 2023/1542 - EN - EUR-Lex	Regulation	Full life-cycle law: imposes extended producer responsibility on battery makers (must finance end-of-life collection/recycling. Sets gradually tighter recycling targets (e.g., >80% material recovery) and carbon footprint limits. Requires data reporting and declarations.	Includes a digital battery passport (mandatory for EV/industrial batteries by 2027); explicit rules for second-life reuse and cost-sharing; substance restrictions and eco-design criteria.	Adapt – integrate EPR (producer take-back) and clear targets into Indian regs; incorporate a battery registry/passport concept to track BESS and materials.
EU EPR Framework – Waste & Electronics:	Regulation	The EU Waste Framework Directive (2008) introduced Extended Producer Responsibility (Art. 8) as a	- **Producer take-back:** Producers (including importers) must register and ensure financing of	India's Battery Waste Management Rules (2022) already embrace EPR: producers (including

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
EU Directives (WFD 2008/98/EC & WEEE 2012/19/EU) (European Parliament & Council of the European Union, 2008; European Parliament & Council of the European Union, 2012). Directive - 2008/98 - EN - Waste framework directive - EUR-Lex Directive - 2012/19 - EN - EUR-Lex		principle, allowing Member States to require producers to bear financial/organisational responsibility for end-of-life products (European Commission, 2025). The WEEE Directive (2012) implements EPR for electronics: it mandates that producers of electrical/electronic equipment finance the separate collection, treatment, recycling and disposal of e-waste.	collection and treatment of WEEE. - **Collection & take-back:** Retailers must accept very small WEEE (≤25 cm) back free of charge from consumers. - **Targets:** High collection rates (e.g., ≥65% of EEE by 2019) and minimum recycling/recovery rates (50–85%, depending on category) apply.	importers) of all battery types must finance collection and recycling of end-of-life batteries. However, India's approach diverges in some ways. For instance, the rules define EPR targets by battery life span, whereas the EU's WEEE scheme sets weight-based targets by equipment category. To align more closely with EU practice, India could consider setting clear collection/recycling quotas

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
			- **Product rules:** EEE must be labelled (crossed-bin) and producers provide manuals or online info on product disassembly and hazardous components. - **Eco-design incentives:** Member States may ecomodulate EPR fees, giving lower fees to eco-designed or highly recyclable products.	and introducing fee modulation to reward easier-to-recycle battery designs. The planned CPCB EPR portal echoes the EU's national registers, but India currently lacks explicit labelling or repairability criteria for batteries. Strengthening design-for-durability and public take-back schemes (similar to EU retailer take-back) would further harmonise India's regime with EU circular economy principles.

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
UL 9540A (2023) – Test Method for BESS Fire Propagation (UL, 2023b). UL 9540A Test Method for Battery Energy Storage Systems (BESS) | UL Solutions	Standard	US/Canada safety test for stationary battery energy storage systems. Specifies how to evaluate and contain thermal runaway propagation in large BESS, under extreme (exceedance) conditions.	The only consensus standard cited in US/Canadian codes (NFPA 855) for large-scale fire testing. Critical for showing system-level safety under failure.	Reference – use UL 9540A (or equivalent test protocols) for certifying India's large-scale BESS fire safety.
UL 1974 – Evaluation for Repurposing Batteries (UL, 2023a). UL 1974 | UL Standards & Engagement | UL Standard	Standard	US standard for second-life of EV batteries: covers the sorting, grading, testing process to repurpose used battery packs. Defines criteria for safe reuse and reconfiguration of modules into new applications.	Provides certified procedures for repurposing EV battery packs safely. Addresses a key circularity step (second life) with rigorous testing.	Reference – adopt its protocols for validating reused BESS packs, or require repurposing facilities to meet similar criteria.

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
IEC 62619:2022 – Secondary Lithium Batteries (Industrial) (IEC, 2022). [IEC 62619:2022 | IEC]	Standard	International safety standard for rechargeable industrial Li-ion cells and batteries (stationary use). Specifies design and testing requirements to ensure cell/battery safety and performance under abuse conditions.	Recognised benchmark for industrial battery safety (used by manufacturers worldwide).	Adapt to an Indian Standard for certification of BESS battery units.
IEC 63338:2024 — General Guidance on Reuse and Repurposing of Secondary Cells and Batteries (IEC, 2024a). https://webstore.iec.ch/en/publication/66675	Standard	IEC 63338 is an international standard that provides general guidance on the reuse and repurposing of secondary lithium-ion and nickel-metal-hydride cells and batteries after they are removed from their original application. It sets out principles	Provides a harmonised framework for safe and traceable reuse of batteries, ensuring quality, safety, and sustainability in second-life applications.	Adapt to an Indian standard for safe and traceable repurposing of used batteries.

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
		for assessing safety, traceability, environmental risk, and re-use eligibility.		
IEC 62933 (series) – Electrical Energy Storage Systems (IEC, 2023a; 2024b). https://webstore.iec.ch/en/publication/64642	Standard	IEC standards for grid-connected energy storage: includes terminology, general and safety requirements for ESS systems and subsystems. Defines second-life terms and testing procedures for system integration.	Harmonises BESS definitions and safety criteria internationally (e.g. requirements for repurposed batteries in grid use).	Adapt to an Indian standard (safety, interoperability, second-life integration).
IEC 62620:2014 Secondary cells and batteries containing	Standard	IEC 62620:2014 specifies marking, tests and requirements for lithium secondary cells and		Adapt to an Indian standard on secondary cells and batteries.

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications		batteries used in industrial applications including stationary applications.		
EN 18061: 2025 – Road vehicles - Rechargeable batteries with internal energy storage (CEN, 2025). https://www.dinmedia.de/en/standard/sn-en-18061/395252635	Standard	EN 18061:2025 is a European standard published by the European Committee for Standardization (CEN) that sets out steps, conditions and protocols for the safe repair and reuse and preparation for repurposing of modules and batteries originally designed for EV applications.	Establishes standardised procedures for the safe repair and reuse of EV batteries, improving reliability and promoting circular design practices.	Reference – India is recommended to use this as a guiding reference for remanufacturing, reusing, and repurposing battery systems, packs, and modules made for electric vehicle applications.

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
ISO 59000 Series – Circular Economy Framework (ISO, 2023).	Standard	The ISO 59000 series establish a systems-based framework for applying circular economy principles across industries. They define common terminology and tools for integrating reuse, recycling, and sustainable design into production and supply chains.	Provides a structured methodology for embedding circularity in BESS design, use, and end-of-life management, reducing waste and improving resource efficiency.	Adopt progressively – India can align BESS manufacturing and recycling practices with ISO 59000 principles to strengthen sustainability credentials and competitiveness in global markets.
"Battery 2030: Resilient, Sustainable and Circular" (GBA, 2023). https://www.globalbattery.org/media/publications/battery-2030-resilient-	Guidance	Vision/analysis report on battery value chain to 2030. Highlights the need for circular approaches (maximal reuse/recycle). Projects high global demand and stresses sustainability/loop economy.	Advocates a global 80% recycling target by 2030. Emphasises life-extension ("tight loops") via second-life before recycling.	Reference – provides aspirational targets and circularity strategies (reuse emphasis) for policy goal-setting (e.g. setting high recovery goals for BESS).

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
sustainable-and-circular.pdf				
"Batteries and Secure Energy Transitions" (IEA, 2024). Batteries and Secure Energy Transitions	Guidance	In-depth IEA analysis of batteries in clean energy. Covers raw material supply, recycling, EPR policies, and climate impact. Recommends actions for governments to support sustainable battery growth.	Highlights the EU's EPR scheme (manufacturers' take-back) and its role in creating collection centres. Endorses reuse/second-life to enhance circularity and suggests recycled-content mandates/tradable recycling credits.	Reference – use IEA's evidence and recommendations when designing India's policies (e.g. set recycled content requirements, incentivise second-life use).

Title and Source (with reference)	Type	Key Content (relevant to BESS circularity)	Notable Features / Innovations	India Recommendation (Adopt/Adapt/Reference)
“Plan for the Implementation of the Extended Producer Responsibility System” (IEA, 2024).	Policy / Guidance	National strategy extending EPR to key sectors (electronics, autos, batteries, etc.). Aims to finalise EPR laws by 2025. Emphasises eco-design and reuse.	Requires EV/battery makers to establish recovery networks via sales/service channels, implement product coding and tracking for batteries. Sets staged recycling rate targets (40% by 2020, 50% by 2025) for key wastes.	Reference – useful model of a phased EPR rollout including EV batteries. India can study its mandates (collection networks, coding) but tailor timelines and targets to national context.

Imprint

Published by
Physikalisch-Technische Bundesanstalt
Bundesallee 100
38116 Braunschweig
Germany

Responsible
Dr Marion Stoldt
+49 531 592-9300
marion.stoldt@ptb.de
www.ptb.de/q.3/en

Text
Niels Ferdinand, Stephanie Binks,
Dr Venkatasailanathan Ramadesigan,
Maria Llauradó

As of January 2026

Contact

Physikalisch-Technische Bundesanstalt
International Cooperation
Dr Marion Stoldt
Phone +49 531 592-9300
marion.stoldt@ptb.de
www.ptb.de/q.3/en

Here you can find this
publication online: