The Technologies Needed to Build a Successful, Sustainable Circular Battery Economy

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In our previous Earth Day blog[1], we discussed the sustainable technologies needed to achieve the Net Zero Emissions 2050 (NZE2050) targets. In its NZE2050 roadmap for the global energy sector, the International Energy Agency stated, “All the technologies needed to achieve the necessary deep cuts in global emissions by 2030 already exist.”[2]

Since that assessment, the electric vehicle and battery energy storage industries have grown significantly. Other sectors, including marine, aerospace, and industrial applications, are also embracing electrification. In addition, recent research on batteries already in the field suggests that they last longer than previously thought.

For lithium-ion batteries and their individual cells to be truly sustainable, they must operate within a circular economy that encourages remanufacturing and reuse through next-life applications before eventual recycling for material recovery. This approach maximizes their use, and helps minimize their lifetime carbon footprint. To support this goal, global regulations are increasingly focused on battery tracking to create a trusted supply chain that supports a circular economy.

	European Union	China	South Korea	United States	India	Australia	Japan
Primary Regulation	EU Battery Regulation (2023/1542)	Interim Provisions for NEV Battery Traceability + Digital ID rollout	EV Battery Safety & Traceability Rules	Inflation Reduction Act (IRA), state & federal supply chain rules	Battery Waste Management Rules (EPR)	Product Stewardship & Lifecycle Responsibility laws	Circular Economy & Recycling Laws
Battery Passport / Digital ID	Mandatory Digital Battery Passport	National traceability codes + digital IDs emerging	Mandatory unique battery ID	Not mandated	Under development / proposed	Registration & stewardship tracking (not passport)	Not mandatory
Lifecycle Coverage	Full lifecycle (materials → recycling → reuse → repurposing)	Strong focus on use, retirement, and recycling lifecycle	Production → use → safety traceability	Primarily supply chain & sourcing	Focus on end-of-life & recycling	Focus on disposal & stewardship	Mainly recycling & reuse
Unique Battery Identifier	Required	Required	Required	Not universally required	Under development	Partial via registration	Limited / voluntary
Supply Chain Traceability	Extensive mandatory reporting	Required via national tracking platform	Required supplier disclosure	Required for tax credit eligibility	Growing EPR-based requirements	Stewardship-based	Industry-driven traceability
Data Accessibility	Multi-tier access via QR-linked passport	Centralized national reporting platforms	Regulatory authority access	Manufacturer/IRS compliance documentation	Limited structured data systems	Stewardship organizations	Mostly industry or program-level
Recycling / EPR Integration	Fully integrated	Strongly integrated & enforced	Integrated via safety & waste management	State-level & voluntary programs	Core regulatory driver	Regulatory focus	Regulatory focus
Implementation Timeline	2024–2031; Passport required 2027+	Traceability since 2018; digital ID expansion mid-2020s	Implementation beginning 2025	Active since 2022	Expanding mid-2020s	State-based rollout mid-2020s	Longstanding but evolving

A breakdown of global battery traceability regulations in major regions.

Global Battery Regulatory Differences in Major Regions

Global approaches to battery traceability and lifecycle tracking are evolving, with major regions developing distinct regulatory models. The EU has established the most comprehensive framework through the EU Battery Regulation (2023/1542)[3], which mandates a Digital Battery Passport for batteries over 2 kWh starting in 2027.

This system assigns each battery a unique identifier and records detailed lifecycle data, including raw material sourcing, manufacturing, performance, repair history, repurposing, and recycling outcomes. By integrating sustainability, safety, circular economy objectives, and supply chain transparency, the EU is promoting a standardized digital infrastructure.

China has implemented a similarly robust but structurally different approach that focuses primarily on electric vehicle batteries. Its Interim Provisions on Traceability Management, introduced in 2018, require manufacturers, vehicle producers, and recyclers to submit battery data to centralized national traceability platforms. China is further expanding this system through standardized digital battery identifiers designed to monitor batteries across production, use, second life applications, and recycling. Although the framework emphasizes environmental protection, recycling accountability, and resource recovery, it prioritizes regulatory reporting and centralized oversight rather than public data accessibility.

In contrast, the United States relies on incentive-driven traceability mechanisms instead of a unified digital passport system. Revised rules in July 2025 more strictly focus on US-based materials, technology and manufacturing, and prefer state-level action for clean energy manufacturing and recycling policies to incentivize electrification. Embracing standards such as SAE J3327[4] can promote supply chain accountability and domestic manufacturing objectives, but the distributed approach does not yet establish standardized lifecycle tracking or comprehensive digital battery identification comparable to the EU or Chinese frameworks.

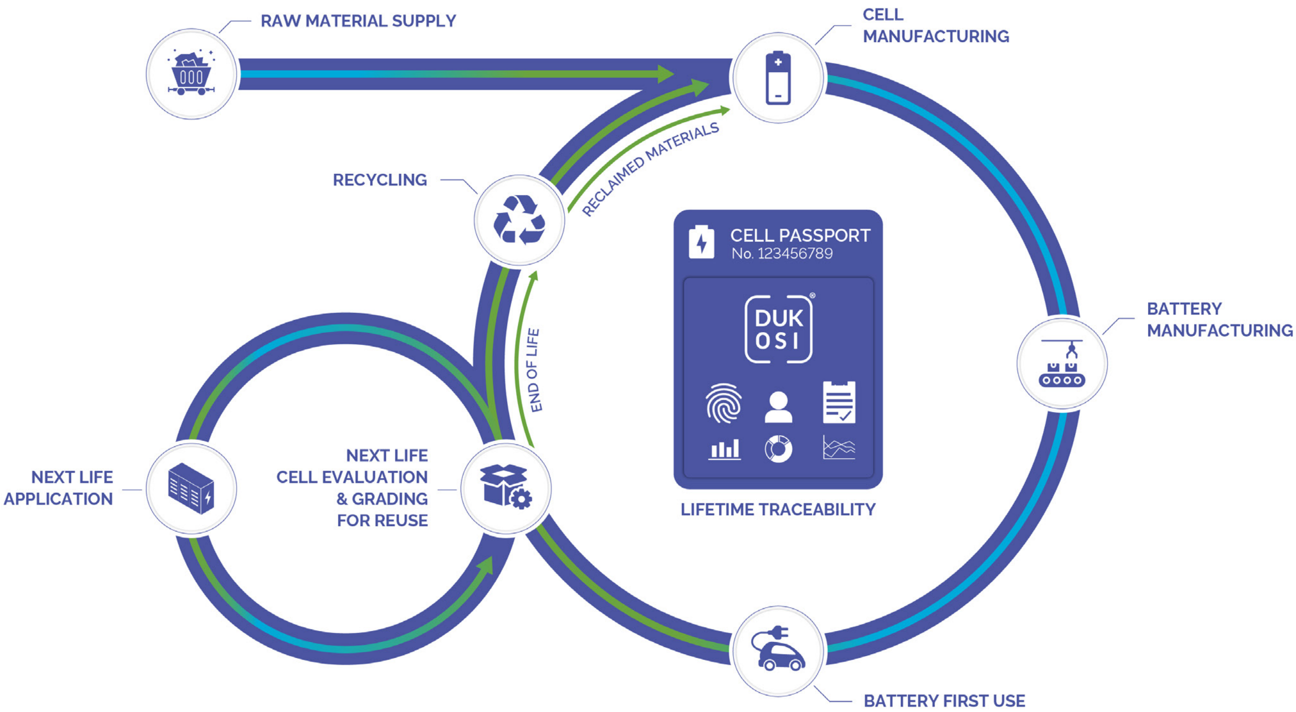
Creating a Circular Economy

Consideration of material use and manufacturing is essential to achieving NZE2050, especially as data shows that battery cells produced using recycled raw materials generate only 25 percent of the carbon emissions compared with cells made from newly mined materials.[5]

Because cells deteriorate at different rates, traditional battery architectures limit the ability to determine the condition of individual cells. If individual cells can be easily analyzed and graded for reuse, rather than having their fate grouped together with hundreds of others in a single battery pack, the potential of the circular economy can be unlocked.

For example, a commonly proposed reuse pathway is transitioning batteries from highly demanding applications such as electric vehicle batteries to 'less demanding' applications such as battery energy storage systems. However, the respective system designs differ significantly. On the surface, electric vehicle batteries typically use 400-800 V architectures, whereas battery energy storage systems can operate at up to 1500 V. And while electric vehicles have a confined range of shape/capacities, the variety of stationary energy storage installations is much greater; utility-grade BESS often use container storage, whereas new wave of AI Datacenters[6] often require highly specialized battery installations that meet the specific power demands of this application.

Therefore, it is necessary to streamline the extraction, grading, and reapplication of each cell into a new battery pack that is precisely designed for its next-life application.



A sustainable, circular battery economy, enabled by Dukosi cell passport technology[7].

Promoting the Economics of Reuse and Remanufacturing Over a Full Battery Replacements

When a battery is damaged, fails, or reaches its assumed end of life, it is often considered more economical to replace and recycle the entire pack rather than open it to test and replace individual cells or modules, despite the significant cost difference between replacing the full pack and replacing individual cells. This assumption largely stems from the complexity, cost, and time required to safely dismantle and reliably reassemble a battery with a complex wiring harness, as well as the challenge of identifying weak or failing cells among hundreds.

Autocraft's 2024 analysis of 559 commercial EV battery repairs[8] revealed that often replacing just one of the modules was enough to return packs to full performance. The findings also showed that 92% of modules in most failed packs were still suitable for automotive use, making full pack replacement rarely necessary.

This highlights the first advantage of the Dukosi Cell Monitoring System (DKCMS™). Even before the battery pack is opened, DKCMS can pinpoint the exact cell with degraded or failing performance and identify its precise location within the pack.

A second advantage is lifetime traceability at the individual cell level. Each DK8102 Cell Monitor integrates embedded processing, data storage, and RF communication. Its on-chip memory can store a comprehensive cell passport that includes static supply chain data, dynamic usage history, and potentially State of Health information, eliminating the need for a cost-intensive grading process.

Using Dukosi's proprietary communication protocol C-SynQ®[9], every Cell Monitor is synchronously connected through secure, reliable near field communication to the DK8202 System Hub, which pairs with the BMS host processor. By removing the complex wiring harness and integrating contactless cell communications into the battery housing itself, its architecture simplifies and accelerates disassembly, replacement, and reassembly, minimizing cost and time while promoting the economics of repair and reuse over pack replacement. Thanks to its flexibility and adaptability, DKCMS can be applied to a wide range of electrified applications across diverse global markets.

A Regulatory-ready, Sustainability-focused Battery Management Solution: Dukosi DKCMS™ and STMicroelectronics STSAFE™ Create a Secure Solution for Cell-to-Cloud Battery Passport Protections

Dukosi recently collaborated with STMicroelectronics to create a battery passport demonstrator based on DKCMS with C-SynQ® and STSAFE™ Secure Element. The demonstrator showed how an overheating cell can be easily identified and replaced. The overheating event can be stored as part of the dynamic data in the battery passport and, together with regulatory static data, is stored in the Dukosi Cell Monitor's non-volatile memory. In addition, the unique ID of each Cell Monitor is stored in the STSAFE-A120 to ensure data encryption and validation. The demonstrator also provides a GUI to display battery passport management, data encryption, and secure validation processes.

When an individual cell is removed and replaced, the system detects a mismatch in the new cell's unique ID on the network. This mismatch flags a potential tampering anomaly and restricts access to data from other cells and system operations. An authorized maintenance procedure can also be simulated, where valid credentials allow the registration and replacement of the new cell by authorized service personnel (PLI). Learn more about this DKCMS and STSAFE cell-to-cloud, battery passport ready BMS solution, which demonstrates industry-leading flexibility, repairability, safety, and security in a turnkey battery management solution.

Conclusion

The technologies needed to build a successful, sustainable and circular battery supply chain are already available today. By capitalizing on cutting-edge battery solutions, battery designers and application developers can stay ahead of regional regulatory requirements while also benefiting from cost efficiencies throughout the battery supply chain. Dukosi DKCMS improves first-life battery usage and maintainability, streamlines the cost-effectiveness of next-life opportunities, and enables an effective circular economy, accelerating the journey toward achieving NZE2050.

	European Union	China	South Korea	United States	India	Australia	Japan
Data Sources	Regulation 2023/1542 (Battery Passport) European Commission Global Battery Alliance	Interim Provisions on the Traceability Management of Power Battery Recycling Ministry of Industry and Information Technology China Automotive Technology and Research Center	Ministry of Environment Ministry of Trade, Industry and Energy	Inflation Reduction Act Internal Revenue Service U.S. Securities and Exchange Commission U.S. Department of Energy	Battery Waste Management Rules Ministry of Environment, Forest and Climate Change Industry white papers	Product Lifecycle Responsibility Act Australian Government Department of Climate Change, Energy, the Environment and Water B-cycle	Act on Promotion of Effective Utilization of Resources Basic Act for Establishing a Sound Material-Cycle Society Ministry of Economy, Trade and Industry

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