

Giving Electric Vehicle Batteries a Second Life: Navigating Standards and Regulations for Energy Storage in the United States

Zhi Cao, Shengyu Jia, Naser Vosoughi Kurdkandi, Chris Mi

Abstract

The rapid growth of electric vehicles presents both a significant opportunity and a challenge: what happens to batteries after they are no longer on the road? These "second-life" batteries, typically retaining 70-80% of their original capacity, are ideal for less demanding stationary energy storage applications. This article explores the evolving standards and regulatory landscape in the United States for this repurposing. We examine the three primary reuse pathways, including the pack, module, and cell-level, and detail the critical safety and certification standards established by organizations such as Underwriters Laboratories and the National Fire Protection Association. The article identifies key challenges, including regulatory fragmentation, data accessibility, and economic hurdles, while drawing lessons from international approaches in the European Union and China. Finally, we propose a path forward for harmonized standards that can unlock the economic and environmental potential of second-life batteries, supporting a more circular economy and a resilient grid.

Keywords

Second-life batteries, battery energy storage systems, standards, regulation, circular economy.

1. Introduction: From Mobility to Stationary Energy Storage

Electric mobility is accelerating. As illustrated in Figure 1, more than six million electric vehicles (EVs) (including both battery electric vehicles and plug-in hybrid electric vehicles) have been sold in the United States, and projections suggest this number will exceed 30 million by 2030. Each of these packs has an energy storage capacity ranging from 20 to 100 kilowatt-hours. Even when an EV battery can no longer meet the rigorous demands of the road, it often retains 70-80% of its original capacity. Instead of heading straight to recycling, these batteries can power a second life in stationary energy storage, where performance requirements are less stringent. This repurposing approach offers compelling advantages: it reduces the environmental footprint of battery production, provides cost-effective storage for the grid, and delays the resource-intensive recycling process. The market is poised for

significant growth, with industry estimates suggesting that 40 gigawatt-hours of EV battery packs will retire annually in the United States alone by 2030¹.

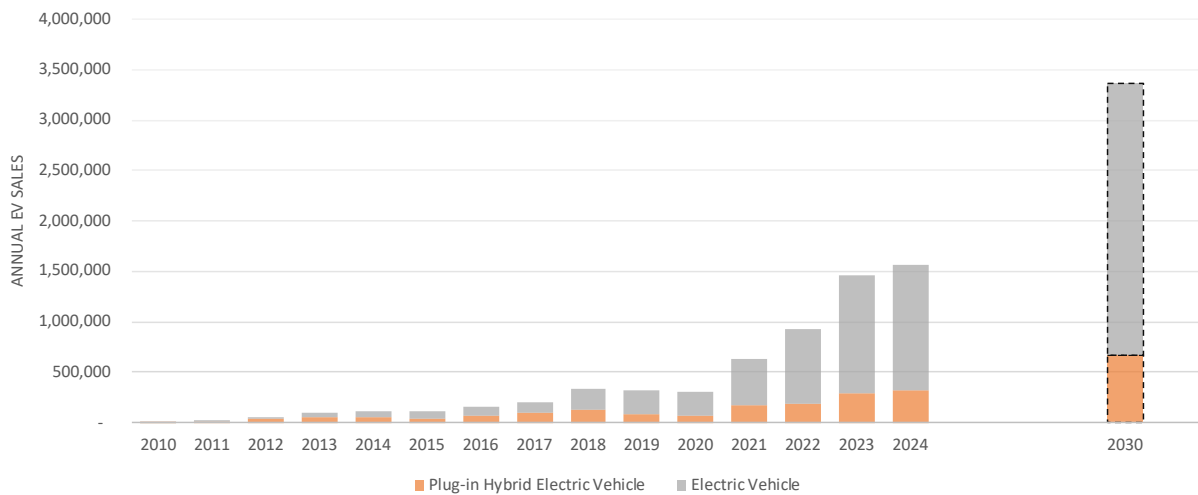


Figure 1: Electric vehicle growth in the United States (Data source: Argonne National Laboratory, Light Duty Electric Drive Vehicles Monthly Sales Updates).

This transition is already underway. Second-life battery deployment is gaining momentum across the United States, with a concentration in states that have supportive clean energy policies. The geographic distribution of these pioneering projects across the United States is mapped in Figure 2. California leads with several commercial installations, including B2U Storage Solutions' 28 MWh facility in Lancaster, which utilizes approximately 1,300 repurposed Honda and Nissan packs and represents the first large-scale second-life system to achieve UL 9540 certification². Texas has emerged as another major hub, with Element Energy's 53 MWh facility utilizing 900 repurposed batteries, supported by the U.S. Department of Energy³. The scale of deployment continues to grow, with Nevada now home to a landmark 63 MWh project by Redwood Energy, the world's largest second-life deployment to date, powering a high-demand AI data center⁴. Figure 3 shows a 362-kWh experimental second-life EV battery energy storage system developed by San Diego State University. These deployments are crucial, as they

¹ Source: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage> (accessed November 4, 2025)

² Source: <https://www.utilitydive.com/news/B2U-storage-solutions-ev-batteries-second-life/642107/> (accessed November 4, 2025)

³ Source: <https://elementenergy.com/element-energy-announces-commissioning-of-worlds-largest-second-life-battery-storage-project/> (accessed November 4, 2025)

⁴ Source: <https://www.ess-news.com/2025/06/27/redwood-crusoe-deploy-second-life-batteries-at-data-center-for-63-mwh-storage/> (accessed November 4, 2025)

provide real-world operational data and regulatory lessons needed to inform the development of broader standards and market expansion.

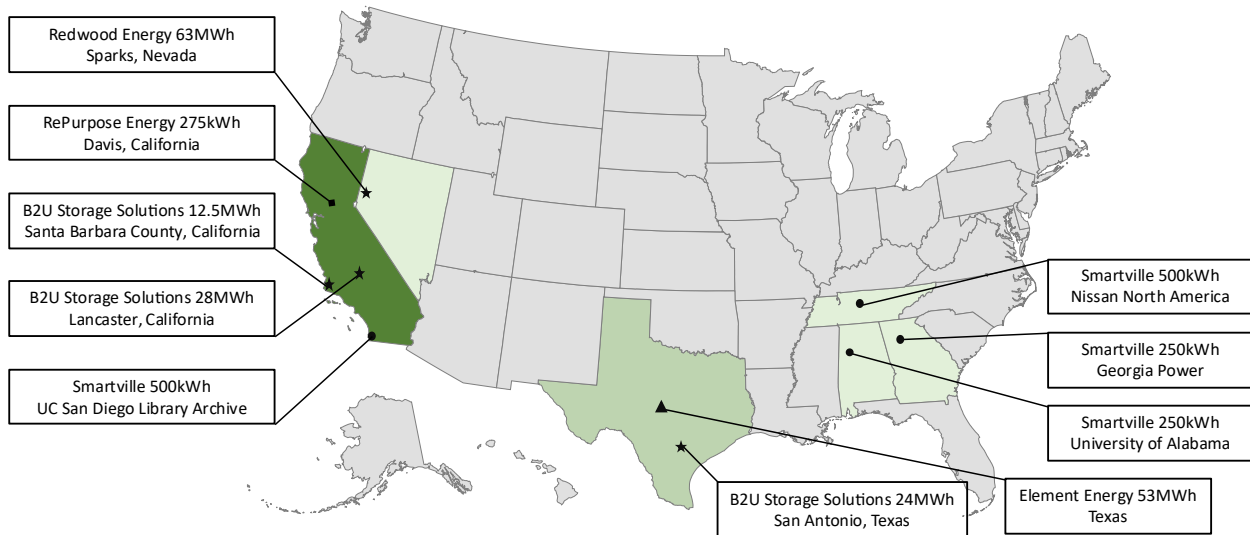


Figure 2: Second-life battery deployment activities across the United States.

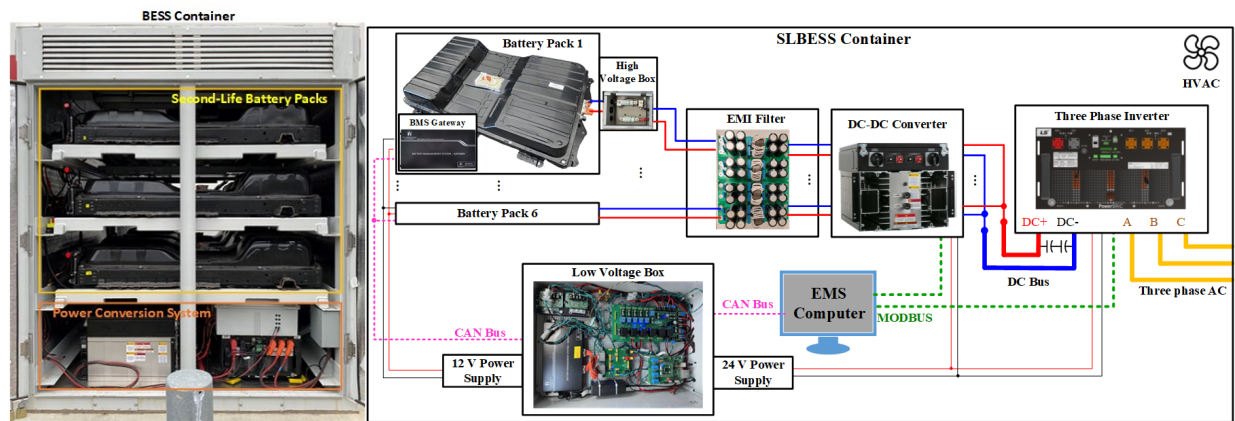


Figure 3: A 362-kWh experimental second-life EV battery energy storage system developed by San Diego State University, deployed at a commercial building in San Diego, California. The system utilizes repurposed retired Nissan Leaf Gen3 battery packs, demonstrating the practical implementation of second-life technology for commercial-scale energy management.

However, giving these batteries a second life is not as simple as plugging them into the grid. They arrive with varied histories and unknown degradation patterns. The U.S. regulatory framework, a patchwork of standards and codes, must ensure safety and reliability while encouraging innovation. This article explores the standards and regulatory codes governing second-life battery energy storage systems in the United States. It explains which agencies and organizations set the rules, what standards currently apply, where gaps remain, and how lessons from other regions may guide future progress.

2. Understanding Second-Life Batteries

A second-life battery refers to a lithium-ion pack originally designed for an EV that is reused in a different application after removal from the vehicle. Before these batteries can be repurposed, they must undergo a rigorous evaluation to determine their health and suitability for a second life. Assessing whether a retired battery is viable for reuse depends on two key performance metrics: state of health (SOH) and internal resistance.

State of health is the most critical indicator, measuring the battery's remaining capacity against its original, new condition. It is calculated as:

$$\text{SOH} = \frac{\text{Current Maximum Capacity (Ah)}}{\text{Original Nominal Capacity (Ah)}} \times 100\%$$

SOH is measured by fully charging the battery, letting it rest, and then discharging it at a constant current to determine the total capacity it can still deliver.

Internal resistance, measured in milliohms, increases as the battery degrades. Higher resistance reduces efficiency by causing energy loss as heat and limits power delivery. We measure it by applying a short current pulse and calculating the instantaneous voltage drop using Ohm's law: $R = \Delta V / I$. Tracking this growth helps predict future performance and identify potential safety issues. Figure 4 illustrates the typical laboratory procedure for determining battery capacity and internal resistance.

Beyond these core metrics, a comprehensive qualification includes several additional assessments. Visual inspection identifies physical damage such as swelling, cracks, or electrolyte leakage. Engineers review battery management system data to understand operational history, checking for exposure to extreme temperatures, overcharging events, or other stress factors. Self-discharge monitoring over 24-hour periods detects internal faults that could indicate safety risks. High-voltage isolation testing ensures electrical safety and prevents dangerous short circuits.

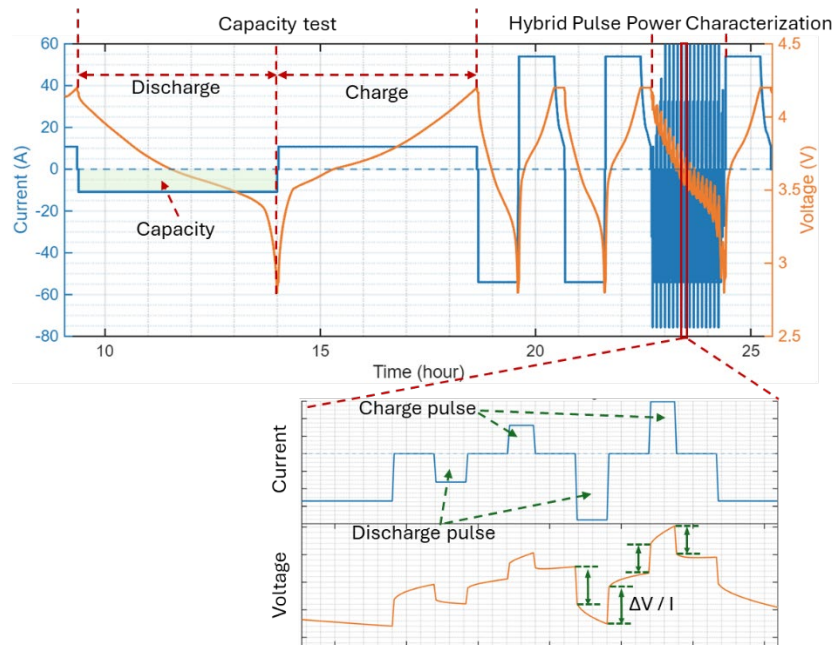


Figure 4: Measurement of battery capacity and internal resistance. The upper graph shows current (blue) and voltage (orange) during controlled charge-discharge cycling. Capacity is determined from the total discharge current integrated over time, while internal resistance ($R = \Delta V / I$) is derived from the voltage response to short charge or discharge pulses, as illustrated in the zoomed region.

Once a battery passes these tests, it is ready for one of three primary repurposing pathways, as illustrated in Figure 5.

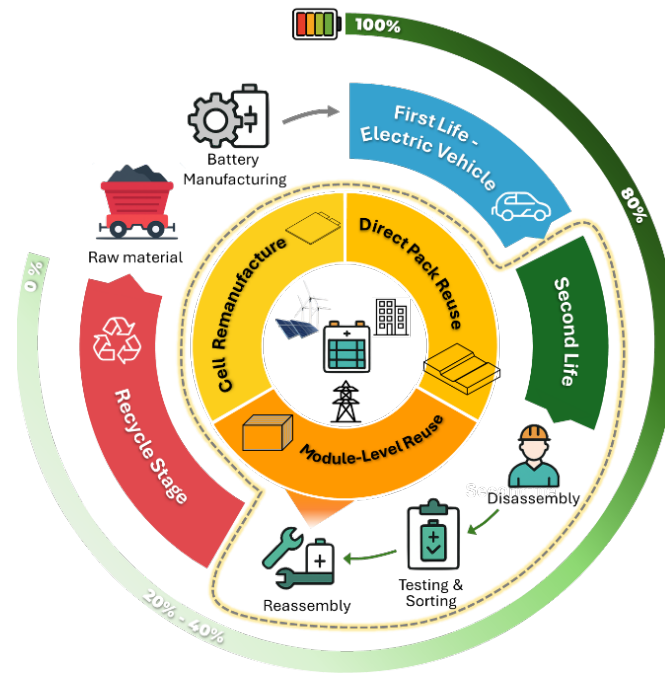


Figure 5: Battery lifecycle and second-life pathways.

Direct Pack Reuse

The simplest approach involves removing the entire battery pack from the vehicle and installing it into a stationary energy storage system with minimal modifications. This method preserves the original battery management system and safety features designed by the vehicle manufacturer. The pack's housing, cooling system, and cell interconnections remain intact.

Direct pack reuse offers several advantages: it requires less labor and processing, maintains the manufacturer's safety engineering, and can be implemented relatively quickly. However, it also means working with batteries designed for automotive rather than stationary applications, which may not be optimized for the new use case and require validation of the compatibility and safety for the battery management system.

Module-Level Reuse

Many EV batteries are constructed from distinct modules, each containing multiple cells connected in series and parallel. In module-level reuse, packs are disassembled into modules, and individual modules

are tested and reconfigured into new pack architectures optimized for stationary use. These systems may incorporate new enclosures, thermal management, and battery management systems.

Module-level reuse provides greater flexibility in system design and can improve overall performance by creating more uniform battery banks. Different modules from various vehicle packs can be combined if they have compatible electrical characteristics. However, it requires more extensive testing, new housing and cooling systems, and custom battery management systems designed specifically for the new configuration.

Cell-Level Remanufacturing

The most intensive approach involves complete disassembly to the individual cell level. Cells are extracted, thoroughly tested, sorted by capacity and health, and reassembled into entirely new battery systems. This process most closely resembles manufacturing new batteries, albeit with used cells.

Cell-level remanufacturing offers maximum flexibility and can create optimized systems for specific applications. Cells can be precisely matched for uniformity, and system designers have complete freedom in voltage, capacity, and configuration choices. However, it is labor-intensive, requires sophisticated testing equipment, and presents the greatest regulatory challenges since the final product bears little resemblance to the original automotive battery.

These three distinct approaches are summarized in **Table 1**, which compares their key characteristics such as processing complexity, labor requirements, and typical applications.

Table 1: Comparison of the second-life battery reuse pathways.

Characteristic	Direct pack reuse	Module-level reuse	Cell-level remanufacturing
Processing complexity	+ Low	++ Medium	+++ High
Labor requirements	+ Minimal	++ Moderate	+++ Extensive
Design flexibility	+ Limited	++ Moderate	+++ Maximum
Time to deployment	+ Short	++ Medium	+++ Long
Testing requirements	Pack-level	Module-level	Individual cell
Original safety features	Retained	Partially retained	New design

3. The U.S. Regulatory Framework

3.1. Key Players

The U.S. regulatory landscape is decentralized, involving federal agencies, state regulators, and industry standards organizations. The cornerstone of safety is set by independent standards, which are then referenced by building and fire codes adopted by local authorities. **Table 2** summarizes key organizations and their roles.

Table 2: U.S. Agencies and Organizations relevant to second-life battery energy storage system regulation.

Agency / Organization	Primary role
Underwriters Laboratories (UL)	Safety and performance standards for batteries and energy storage systems (UL 1973, UL 9540, UL 9540A, etc.).
National Fire Protection Association (NFPA)	Codes and standards related to fire safety, electrical installations, and building requirements (NFPA 855, NFPA 70).
Institute of Electrical and Electronics Engineers (IEEE)	Technical standards for grid interconnection (IEEE 1547) and performance characterization (IEEE 1679).
International Code Council (ICC)	Model building and fire codes adopted and amended by jurisdictions (International Building Code, International Fire Code).
State and local authorities	Have ultimate authority for permitting and inspection. They adopt and enforce building/fire codes, review UL listings and fire test reports, and grant approval for installation and interconnection.

Navigating this landscape requires understanding a sequential compliance pathway, where standards from organizations like Underwriters Laboratories and the National Fire Protection Association build upon one another to ensure safety from the repurposing facility to the final grid-connected system.

3.2. Key Standards and Codes

The regulatory framework for second-life battery energy storage systems builds upon standards originally developed for new battery installations, supplemented by emerging standards specifically addressing repurposed batteries. **It is critical to define the scope of this analysis. A multitude of standards govern the broader battery lifecycle, including those for cell manufacturing (e.g., UL 1642), original EV traction pack safety (UL 2580), transportation (e.g., UN Manual of Tests and Criteria, Part III, subsection 38.3), and grid interconnection (e.g., IEEE 1547).** This article focuses on the core set of safety and installation standards that are pivotal, and often present unique challenges, for the specific act of repurposing a retired EV battery into a stationary, grid-connected system. These standards address the process of repurposing, the safety of the repurposed unit, its integration into a system, and the mitigation of fire hazards. These steps collectively establish the legitimacy of a second-life EV battery energy storage system. Other standards, while essential for a functioning project, are generally agnostic to the battery's prior use and apply equally to new and second-life systems. The key standards within our defined scope are detailed below.

3.2.1. UL 1974: Repurposing Facility and Process Certification

IEEE Electrification Magazine

UL 1974 is the cornerstone standard for repurposing used EV batteries. It defines how facilities must grade, test, and document used batteries before reuse. The latest revision has been expanded to include remanufactured batteries and clarifies that repurposed components beyond their original design life must undergo verification. Importantly, UL 1974 certifies the repurposing process and facility, but does not make batteries "grid-ready"; therefore, additional certifications remain necessary.

UL 1974 provides a pathway for second-life batteries to achieve safety certification even when a complete usage history is unavailable. However, the standard sets conservative requirements for testing and documentation, which can increase the cost of repurposing operations.

3.2.2. UL 1973: Battery Pack Safety Certification

UL 1973 has emerged as the primary product safety standard for battery energy storage systems in the United States. Originally developed for new battery systems, it tests electrical safety, fire resistance, mechanical integrity, and environmental tolerance for battery packs and modules.

Once batteries have been repurposed, UL 1973 governs their use in stationary applications. UL 1973 certification ensures that the repurposed pack meets equivalent safety standards as a new battery product.

3.2.3. UL 9540: System-Level Safety for Energy Storage Systems

UL 9540 applies to the complete energy storage system, including power conversion equipment, controls, and system integration. This system-level standard is particularly relevant for second-life applications because it addresses how batteries integrate with other components.

UL 9540 requires evaluation of:

- Complete system safety under normal and fault conditions.
- Battery management system adequacy for specific battery configuration.
- Integration between the battery, inverter, and control systems.
- System response to grid abnormalities.
- User interface and safety labeling.

The latest edition (2023) maintains identical requirements for new and second-life systems. A UL 9540-certified second-life energy storage system means that the entire assembly (repurposed batteries, controls, and enclosure) is evaluated for safety as a system. Energy storage system units must be UL 9540-listed to be accepted under U.S. building codes.

3.2.4. UL 9540A: Thermal Runaway Evaluation

UL 9540A establishes a standardized test method for evaluating fire propagation in battery energy storage systems. The test examines whether a fire in one battery module or unit will spread to adjacent units and assesses the effectiveness of the fire suppression system.

For second-life batteries, fire testing becomes more complex because cell degradation may affect thermal runaway behavior. Currently, most UL 9540A testing focuses on new battery systems. The

industry is still developing consensus on appropriate testing protocols for second-life systems, particularly regarding sample selection and the need for aging simulation.

UL 9540A is a test method, not a certification. Results guide fire code compliance. Authorities are increasingly requiring UL 9540A test data for lithium-ion systems to inform fire safety measures such as spacing, fire suppression, and whether the system can be installed indoors or near buildings.

3.2.5 Installation and Operation Codes

Beyond product certification, second-life battery energy storage systems must comply with fire codes and building regulations that govern their installation and operation. These requirements significantly affect where and how second-life systems can be deployed.

NFPA 855: Installation of Stationary Energy Storage Systems

NFPA 855 is the standard for the installation of energy storage systems adopted by most U.S. jurisdictions. NFPA 855 establishes requirements for system spacing, ventilation, fire detection and suppression, and emergency response procedures. The 2023 edition explicitly references second-life batteries, requiring refurbishment in accordance with UL 1974 and installation in accordance with UL 9540 and UL 9540A data.

The standard includes prescriptive requirements based on battery technology and capacity, as well as performance-based options where fire testing (per UL 9540A) demonstrates adequate safety. This flexibility can benefit second-life installations where innovative designs may not fit prescriptive requirements but can demonstrate equivalent safety through testing.

International Building Code (IBC) and International Fire Code (IFC)

Most U.S. jurisdictions adopt building and fire codes based on the International Code Council's model codes, which increasingly reference NFPA 855 and UL standards for energy storage systems. Local amendments create variations, making it essential to research specific jurisdictional requirements early in the project planning process.

State and Local Regulatory Variations

While national standards provide a framework, actual implementation varies significantly across states and localities. These variations reflect different policy priorities, regulatory maturity, and local experiences with energy storage deployments. For instance, the California Fire Code Section 1207 explicitly states: "Storage batteries previously used in other applications, such as EV propulsion, shall not be reused in applications regulated by Chapter 12, unless approved by the fire code official and unless the equipment is refurbished by a battery refurbishing company approved in accordance with UL 1974." California authorities typically require comprehensive certification, including UL 1974 facility certification, UL 9540 system listing, full UL 9540A fire testing documentation, and detailed emergency response planning coordinated with local fire departments.

The standards detailed in Sections 3.2.1 through 3.2.5 represent the core pathway where second-life EV batteries encounter requirements distinct from new battery systems. In contrast, grid interconnection standards (IEEE 1547 series), inverter certification (UL 1741), electrical installation codes (National

Electrical Code Article 706), and workplace safety practices (NFPA 70E Article 320) apply uniformly regardless of battery origin. Similarly, transportation regulations (UN 38.3, 49 CFR 173.185) govern movement of retired batteries to repurposing facilities, and performance evaluation methodologies (IEEE 1679 series) provide technical guidance for assessing any battery technology. These standards, while essential to the complete regulatory ecosystem, do not present unique barriers or requirements specific to second-life applications and thus fall outside the primary focus of this analysis.

The interconnected nature of these standards and codes is visualized in Figure 6.

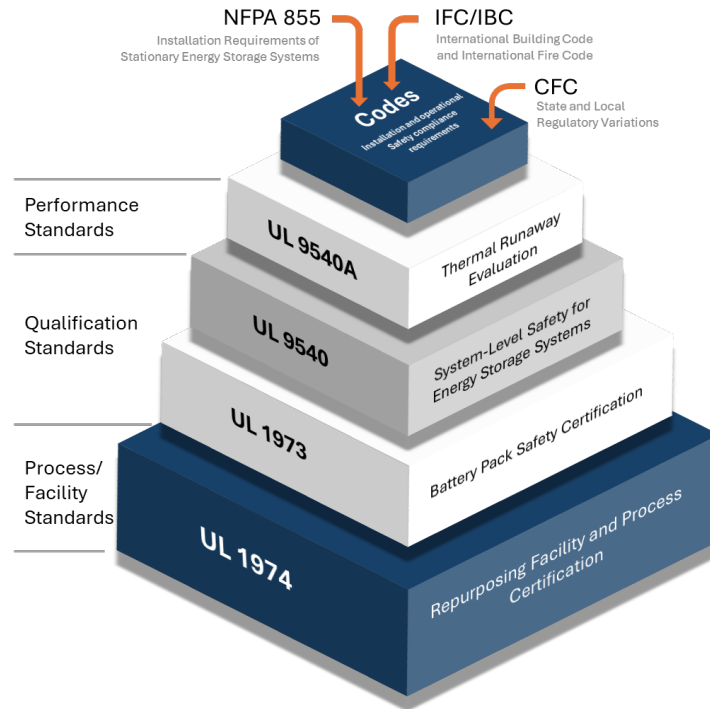


Figure 6: Standards hierarchy and dependencies.

4. The Compliance Journey

All second-life battery energy storage systems, regardless of processing method, must navigate the same fundamental regulatory sequence, as visualized in Figure 7. The journey for a second-life system typically follows this sequence: A facility certified to UL 1974 repurposes the batteries. The resulting packs or modules are evaluated against UL 1973. They are then integrated into a complete system that is listed to UL 9540. Data from UL 9540A testing is often required by authorities to approve the installation under NFPA 855 and local fire codes.

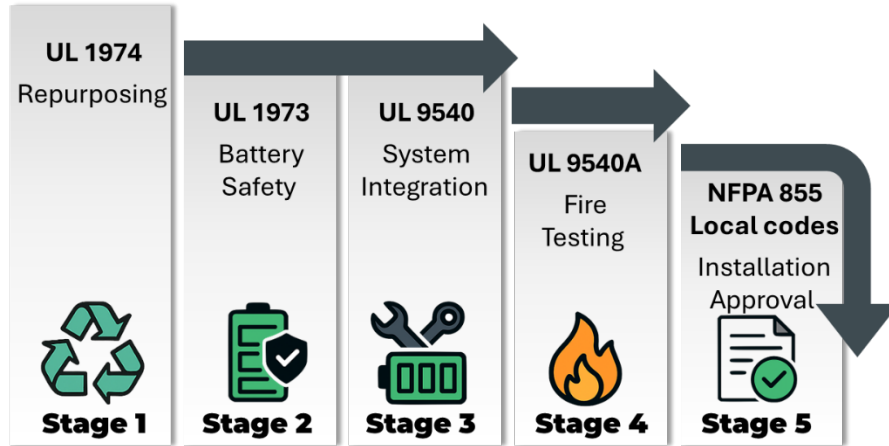


Figure 7: Regulation compliance pathway of second-life battery energy storage systems.

The regulatory pathway is sequential, but its complexity depends heavily on the approach used for repurposing.

- Pack-level reuse leverages the original automotive safety engineering. Certification focuses on verifying that the battery management system and safety features remain functional in a stationary setting. This pathway can be relatively streamlined, as it builds upon the extensive validation already performed by the vehicle manufacturer.
- Module-level reuse requires qualifying a new system. Since modules are rearranged with new housing and controls, the entire assembly must be certified as a new product. First principles must prove the safety of the new pack architecture and custom battery management system.
- Cell-level remanufacturing follows a path nearly identical to that of manufacturing a new battery. Every cell is tested and assembled into a new system that must demonstrate full compliance from the ground up. This approach carries the highest certification burden but offers the greatest design freedom.

This progression in regulatory effort mirrors the increasing technical departure from the battery's original, certified automotive form.

5. Key Challenges

Despite progress, significant challenges remain that affect deployment and regulatory certainty. These challenges fall into three primary categories: technical uncertainties, gaps in standards development, and regulatory coordination issues.

5.1. Technical Uncertainties

The fundamental challenge lies in dealing with batteries of unknown history and variable condition. Each retired EV battery arrives with unique degradation patterns shaped by its previous usage, such as different charging habits, operating temperatures, and potential abuse history. While modern standards

provide testing frameworks, establishing appropriate acceptance criteria remains challenging without access to the proprietary operational data collected by vehicles during their first life.

Limited long-term performance data compounds these challenges. Questions remain about degradation rates in stationary applications, whether automotive usage accelerates subsequent decline, and failure modes specific to second-life systems. This data gap forces standards developers to balance conservative safety approaches against economic viability.

The complexity of fire safety assessments is particularly critical. Thermal runaway behavior may differ in degraded cells due to internal lithium plating or damage to the separator. Additionally, third-party repurposers face systematic barriers. Industry feedback suggests that non-original manufacturers conducting thermal runaway tests may struggle to achieve full UL 9540A classification, even when following identical procedures, resulting in certification disadvantages compared to original equipment manufacturer-led programs.

5.2. Standards Development Gaps

Although UL 1974 provides a foundation for repurposing, significant gaps remain in standardized testing protocols. Specific methods for capacity testing, health assessment, and accelerated aging lack uniformity across certification bodies. Most existing standards were originally developed for new batteries, creating ambiguity when applied to repurposed systems and forcing each project to approach compliance as a custom engineering effort.

The integration of automotive certification data remains problematic. Despite extensive safety validation during vehicle development, no clear pathway exists to leverage this testing for stationary applications. Additionally, current standards offer insufficient guidance on critical operational questions, such as acceptable tolerances for matching cells of different ages or from various manufacturers.

5.3. Regulatory Coordination Issues

High certification costs, which can reach \$3 million per project⁵, threaten the economic viability of second-life batteries, particularly in light of steadily declining prices for new batteries. This cost burden is exacerbated by insurance market uncertainty, where limited actuarial data on second-life failure rates makes insurers cautious about providing coverage at reasonable rates.

Regulatory fragmentation creates further complications. Local interpretation varies significantly. This inconsistency among fire marshals, building officials, and electrical inspectors generates uncertainty for multi-state operations. Unlike the European Union or China, the U.S. lacks integrated federal approaches, such as extended producer responsibility or battery passport programs, leaving critical policy gaps in data sharing and incentives for reuse.

⁵ Cost estimate based on interviews with second-life battery system developers. Actual costs vary based on system configuration, testing scope, and certification pathway.

The interconnected nature of these technical, standards, and regulatory challenges is captured in Figure 8. Addressing these hurdles requires a collaborative focus on three critical needs: reliable battery history to reduce testing burdens, optimized certification pathways that maintain safety while reducing costs, and consistent standards interpretation across jurisdictions. Solving these interconnected challenges is essential for building a robust second-life battery ecosystem.

6. Learning from Global Approaches

While the U.S. navigates its regulatory challenges, other regions have implemented comprehensive frameworks that offer valuable lessons.

- **European Union:** comprehensive lifecycle regulation. The European Union's Battery Regulation mandates a "battery passport" from 2026, ensuring critical data on composition, history, and state of health is available to repurposers. It also establishes clear extended producer responsibility, making manufacturers accountable for the entire battery lifecycle, thus creating built-in incentives for designing batteries that are easier to repurpose. The lesson for the U.S. is the power of data transparency and lifecycle governance to lower barriers to entry and create a more coherent ecosystem.
- **China:** producer responsibility and tiered use. China's framework centers on holding manufacturers accountable for collection and end-of-life management. It also features a "tiered use" framework that explicitly defines which second-life applications (e.g., backup power, grid storage) are suitable for batteries in different conditions. This provides much clearer guidance for repurposers than exists in the U.S. The lesson is the value of application-specific guidance and manufacturer-led integration to reduce market uncertainty.

International regulatory approaches offer complementary lessons for U.S. standards development, as summarized in **Table 3**. The U.S. market-driven approach encourages innovation from a diverse set of companies, from automakers to startups. Adopting the best ideas from abroad, particularly on data sharing and providing clear application tiers, could address critical gaps while preserving the competitive strength and diversity of the American market.

Table 3 International comparison of second-life battery regulatory approaches.

Region	Regulatory philosophy	Key features	Strengths	Relevant lessons for the U.S.
European Union	Comprehensive lifecycle management	Battery passports, performance standards, and extended producer responsibility	Data availability, traceability, clear lifecycle framework	Adopt battery passport concepts, enhance data sharing requirements

China	Producer responsibility, tiered use	Manufacturer accountability, explicit use tiers, and pilot programs	Integrated pathways, data access assured, clear application guidance	Develop tiered use guidance, consider incentives for manufacturer participation
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7. A Path Forward

To realize the immense potential of second-life batteries, coordinated action is needed from industry, government, and standards bodies. Based on the challenges and international lessons, we recommend a focused path forward:

- **Promote data access:** encourage or mandate manufacturers to provide secure access to battery state-of-health data for repurposers, perhaps through a standardized "battery passport" model. This single action would do the most to reduce testing costs and uncertainty.
- **Optimize and harmonize certification:** develop risk-based certification pathways that maintain safety while reducing costs for well-understood repurposing models; simultaneously, work towards greater consistency in how states and local authorities interpret and apply national standards to create a more predictable market.
- **Clarify roles and incentivize design:** establish clearer extended producer responsibility frameworks to define roles in the end-of-life chain; support policies that encourage "design-for-repurposing" principles, such as modular architectures and standardized components, making future batteries easier and safer to reuse.
- **Support enabling innovation:** direct research funding toward advancements in rapid testing technologies, semi-automated disassembly processes, and data-driven degradation modeling; overcoming these technical hurdles is key to improving the economics of the second-life industry.

Figure 8 outlines the pathway to a mature market, requiring the coordinated implementation of solutions that address the interconnected challenges identified throughout this article.

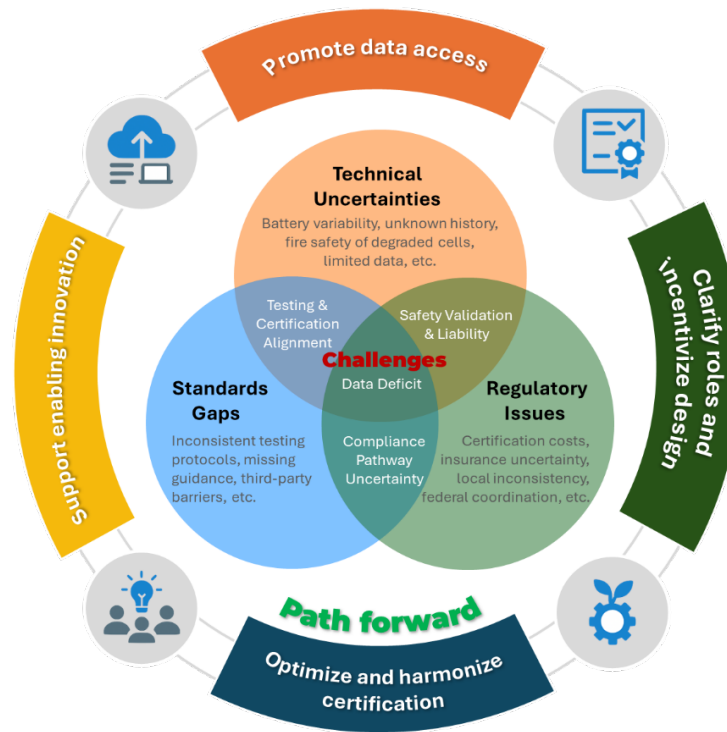


Figure 8: Challenges and Path Forward for Second-Life Battery Standards.

8. Conclusion

Repurposing EV batteries for energy storage is more than a technical curiosity; it is a powerful opportunity to build a more circular and sustainable economy. The United States has laid a crucial foundation with critical safety standards from UL and NFPA, and real-world projects are already proving the concept's technical and commercial feasibility. The path forward is now clear: we must overcome the interconnected challenges of data accessibility, economic viability, and regulatory harmony. By learning from global peers and fostering collaboration across the entire battery value chain, we can create a robust framework that ensures safety, unlocks economic value, and allows these batteries to support a clean, resilient, and efficient energy grid for years to come. The journey to a circular economy for batteries is underway. With the right standards and collaborative spirit, second-life batteries are poised to power a more sustainable and resilient energy future.

For Further Reading

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