RECIRCULATE

Making Battery Second Life Work at Scale in Europe

WHITE PAPER

The RECIRCULATE project is an EU-funded initiative focused on advancing the circular economy for lithium-ion batteries' second life. Its goal is to improve efficiency, transparency, and value creation across the entire battery lifecycle, especially for second-life applications and recycling. tackled a problem that has slowed Europe's battery circularity ambitions for years: many electric-vehicle batteries still hold value after their first automotive use, but that value is hard to recover when condition is unclear, logistics are risky, dismantling is slow, and transaction data cannot be trusted. The project's core contribution was to treat second life not as a side route after recycling, but as an operating model built around fast decisions, safe handling, reliable data, and credible end markets.

Its most important insight is that battery second life is not one binary choice. It is a chain of decisions: assess the battery quickly, route it safely, dismantle only when needed, reuse or remanufacture wherever viable, and recycle only when residual value is genuinely exhausted. That sounds simple on paper. In practice, it forces technical, commercial, and regulatory pieces to work together. Recirculate makes a strong case that the weak links are usually not chemistry alone, but the hand-offs between diagnosis, transport, sorting, reuse, and sale.

The strongest public results sit in speed, visibility, and trust. Rapid diagnostics reportedly reduced one assessment path to under five minutes with error below 2 per cent, while another qualification pathway cut capacity gauging from hours to minutes. In parallel, the project developed monitored logistics, AI-assisted dismantling, second-life storage integration, Digital Battery Passports, and a marketplace model for more informed transactions. Some outputs appear close to commercial uptake, while others remain earlier-stage.

For Europe's circular battery supply chain, the wider implication is clear. Scaling second life will require more than better recycling capacity. It will require faster triage, monitored reverse logistics, easier disassembly, common data structures, and enough market confidence for used batteries to be priced and traded as assets rather than treated as liabilities. Recirculate shows what that operating system can look like.

The challenge Recirculate set out to solve

Europe's battery challenge is often framed as an end-of-life problem. Recirculate reframes it more accurately as a value-retention problem. Once batteries leave their first life in vehicles, the central question is not simply how to dispose of them safely, but how to decide, quickly and credibly, whether they should be reused, remanufactured, or recycled. That shift matters because the biggest missed opportunity in circularity is often not the final recycling step. It is the failure to keep usable value in circulation for longer.

The project addressed six overlapping dimensions at once. It confronted policy and standards gaps that make every pilot feel bespoke, market distrust that suppresses pricing and demand, technical bottlenecks in battery assessment and dismantling, logistical complexity in reverse flows, stakeholder fragmentation across OEMs, logistics providers, integrators, and recyclers, and an environmental imperative to preserve embedded value by extending useful life wherever safe and economic.

The comparison below condenses the project's challenge-response logic.

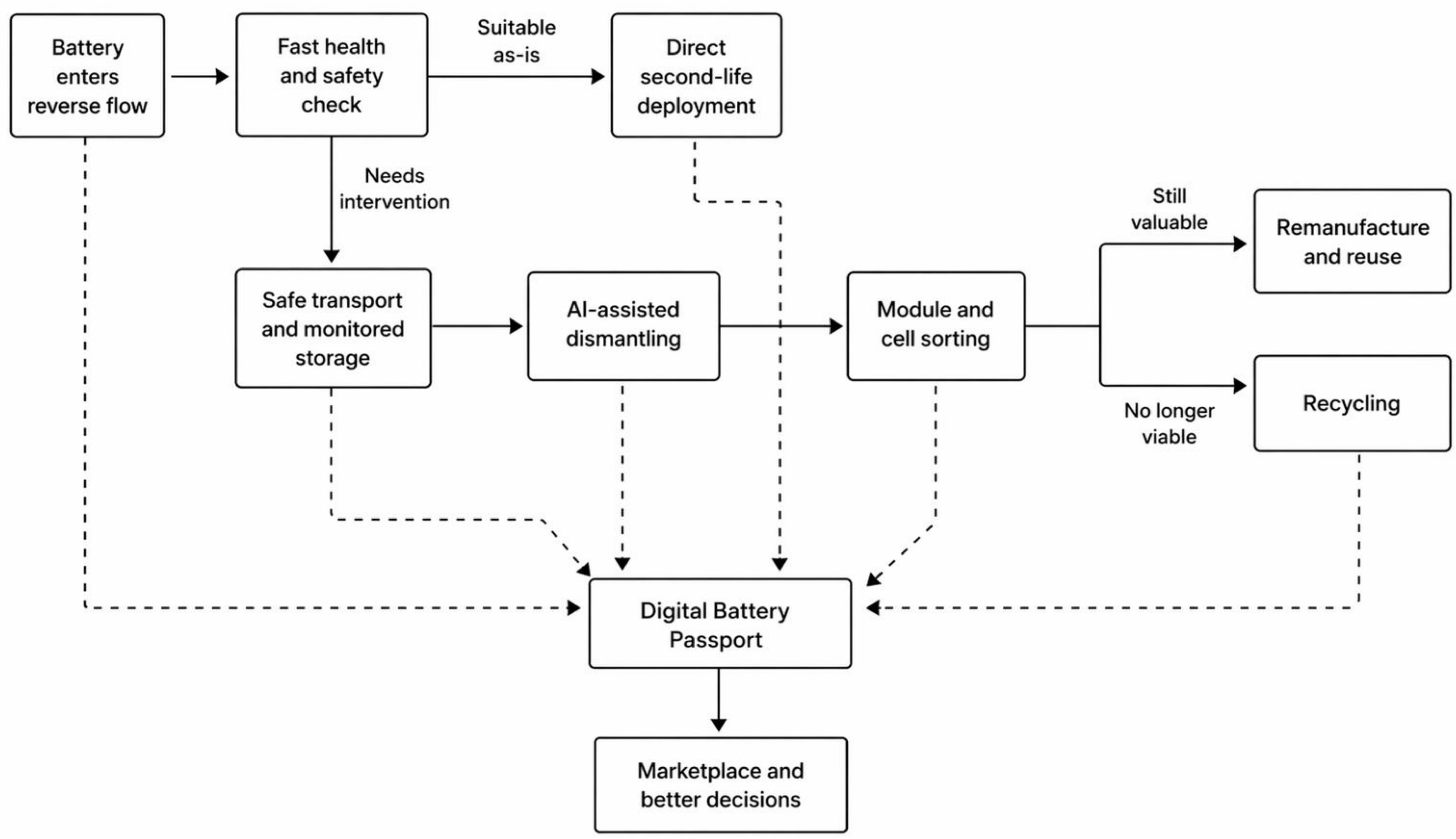
Challenge dimension	Why it constrained scale	Recirculate's response
Policy and standards	Without common rules for classification, qualification, and data exchange, second-life routes remain one-off exercises rather than repeatable industry practice.	The project treated standardisation, reusable guidance, and common data logic as foundations for scale, especially around qualification procedures and Digital Battery Passports.
Market trust	Buyers will not pay for residual value they cannot verify. Thin data creates thin markets.	A Digital Battery Passport and marketplace model were developed to make relevant battery information portable, accessible, and usable at the point of transaction.
Technical diagnostics	Conventional capacity testing can take hours, which inflates cost before any value can be recovered.	Fast diagnostic methods and EIS-based qualification were designed to cut assessment time from hours to minutes.
Logistics and safety	Reverse battery flows are fragmented, compliance-heavy, and potentially hazardous.	The project combined sensing, telematics, alerts, visibility tools, and practical transport guidance to create monitored logistics rather than opaque hand-offs.
Dismantling and labour	Manual disassembly is slow, expensive, and difficult to scale safely.	AI-assisted robotic dismantling used vision, defect classification, and multiple end-effectors to automate key handling and separation tasks.
Stakeholder coordination	OEMs, transport providers, repurposers, buyers, and recyclers often act on incomplete or inconsistent information.	The project linked assessment, transport, dismantling, reuse, recycling, and data into one operating chain, reducing decision friction between actors.
Environmental value retention	Much of a battery's environmental burden sits upstream in materials and manufacturing.	The project prioritised life extension, remanufacture, and reuse before material recovery, arguing that recycling should come after higher-value options where safe and viable.

Viewed together, these barriers explain why the project did not treat circular batteries as a single technology problem. It treated them as a systems problem, where weak trust, slow decisions, or unsafe logistics can destroy value just as effectively as poor electrochemistry.

The project’s operating model and solutions

Recirculate’s defining strength is that it joined previously separate steps into one practical cascade. Instead of asking every used battery the same blunt question, it created a routing logic: qualify first, decide the most suitable path second, dismantle only when necessary, recover intact modules or cells where possible, and recycle only when no higher-value route remains. The Digital Battery Passport sits across this whole chain, not as a compliance afterthought, but as the information layer that makes each decision more credible.

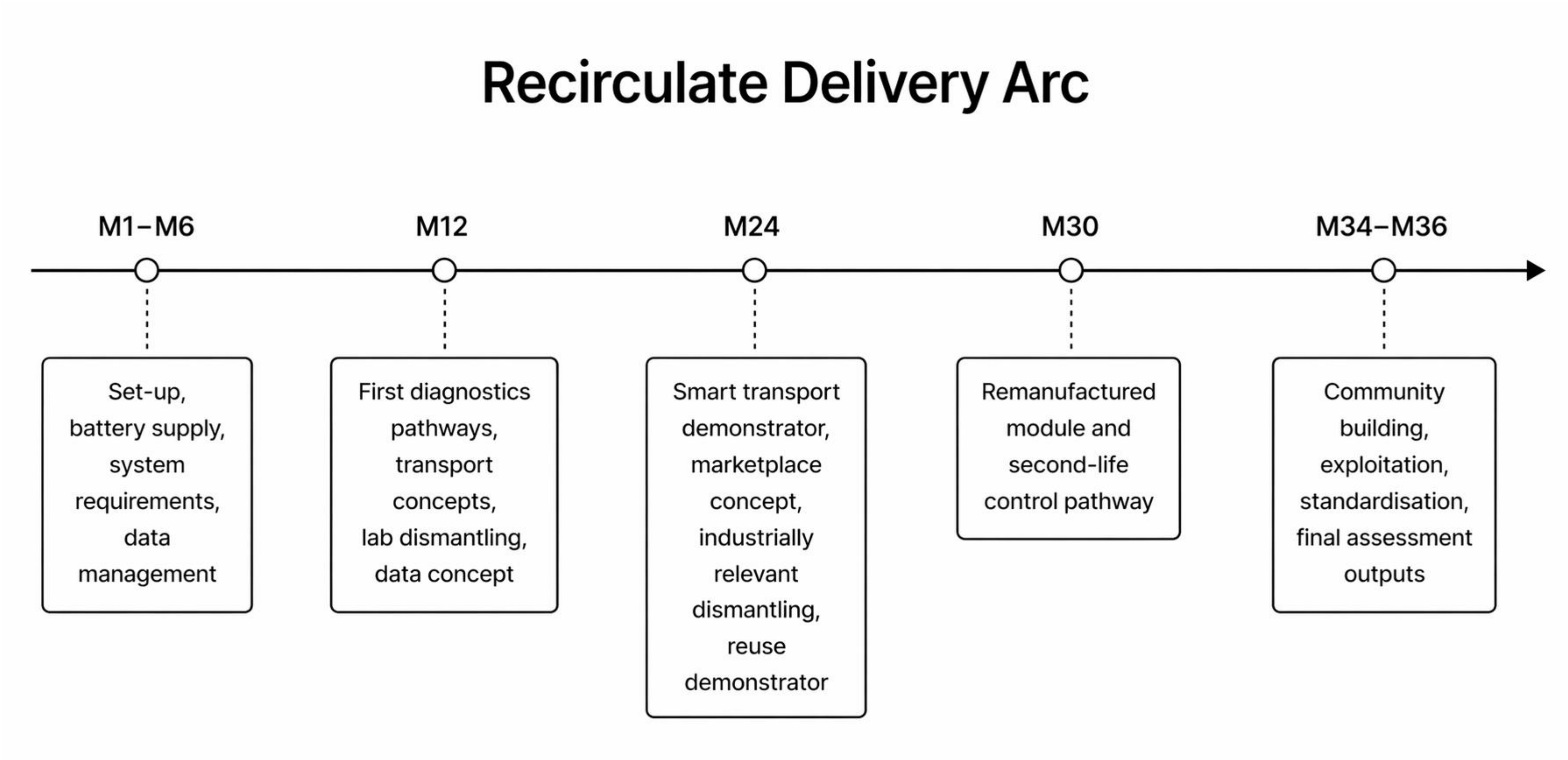
The operating model can be visualised as follows.



The crucial point is that every stage improves the next one. Faster triage reduces unnecessary handling. Better transport visibility reduces risk. Easier dismantling improves recovery quality. Trusted data makes trading more efficient. It is a chain designed to preserve optionality rather than collapse everything prematurely into recycling.

This systems approach depended on an intentionally mixed partnership spanning research, industrial validation, logistics, automation, safety, and digital infrastructure. Automated dismantling and coordination sat with Centria University of Applied Sciences, with industrialisation support from Probot Oy. Rapid diagnostics came from Eurecat and CSEM. Direct second-life storage work came through Eco Stor. The Digital Battery Passport and marketplace layer came from Minespider. Monitored transport came through DHL Supply Chain, OEM validation through Ford Otosan, pack integration through Libattion, fire-safety support through Gelkoh, and standardisation and exploitation support through Iconiq Innovation Limited. Across 36 months and 11 partners, that mix allowed the project to test not just components, but the interfaces between them.

The project's implementation path was equally pragmatic. It began with set-up, battery supply, system requirements, and data management; moved into early diagnostics, transport concepts, and laboratory dismantling; then advanced into demonstrators for logistics, marketplace functions, reuse, and industrially relevant dismantling; and finally closed with exploitation, standardisation, and final assessment outputs. That sequence matters because scale-up in circular batteries rarely happens through one big leap. It happens by validating each hand-off and then connecting them.



The scale-up logic was therefore twofold: prove that the chain can work end to end, and advance the most mature elements toward post-project deployment without pretending that every output is equally ready. That is a sensible strategy in a field where overclaiming is common and operational edge cases are never far away.

Results, outcomes, and lessons learned

The clearest quantitative result is in diagnostics. One rapid assessment method reportedly achieved results in under five minutes with error below 2 per cent. A separate qualification route based on electrochemical impedance spectroscopy reduced capacity gauging from hours to a few minutes. Those numbers matter well beyond laboratory performance. In second life, every extra minute spent diagnosing an asset eats into the value that asset can still deliver. By reducing triage time, the project improved not only technical workflow but economic feasibility.

The logistics and safety work is also notable because it moved the conversation from paperwork to operational visibility. Publicly stated figures include 30 participants in the human-factors study, 32 EEG channels, 160 telemetry variables, six workload dimensions, four battery categories, and a seven-step checklist. Even where some research elements remain exploratory, the practical direction is unmistakable: safe battery transport in a circular economy should be monitored, not guessed at.

On the hardware and systems side, the project established an AI-assisted dismantling cell with machine vision and multiple tool types, a reuse pathway that can connect directly to batteries and read key parameters without opening every pack, a second-life battery management system with high-precision sensing and cell-level balancing, a residential-scale second-life storage demonstrator, a remanufactured module pathway, and an online marketplace concept that was developed and refined over the course of the project. The thread connecting these outputs is practical reduction of friction: less intrusive inspection, safer handling, better control, and more credible routing choices.

Qualitatively, the lessons are just as important as the metrics. First, speed changes economics. Second, trust infrastructure matters as much as electrochemical testing. Third, transport is not a neutral middle step; it can either preserve value or destroy it. Fourth, disassembly must be designed for scale, not heroics. Fifth, reuse and remanufacture only become credible when diagnostics, logistics, and data travel together. In other words, circularity succeeds when the operating model is coherent.

The maturity picture is mixed in a productive way. Digital Battery Passports are positioned furthest along at TRL 8. The marketplace MVP and second-life energy storage route sit at TRL 7. DigiTruck is placed at TRL 6, with a route to TRL 7 to 8 through warehouse deployment. Rapid diagnostics and AI-assisted dismantling are placed around TRL 5, while the OEM decision-support workflow is positioned at TRL 6. That spread suggests a healthy portfolio, with some outputs ready for near-term deployment and others needing translational support before they can scale.

What the results mean for Europe's circular battery supply chain

For Europe's circular battery supply chain, Recirculate points to a more demanding but more realistic model of scale. Circularity will not be unlocked by recycling capacity alone. It will depend on the speed and quality of upstream decisions: how quickly batteries can be assessed, how safely they can be moved, how economically they can be opened or preserved, and how reliably they can be described in digital form. The project's wider message is that second-life batteries become viable industrial assets only when information asymmetry and handling risk are reduced together.

The table below links the project's main results to their broader European implications.

Result or outcome	Immediate significance	Broader implication for Europe
Under-five-minute assessment with error below 2 per cent	High-throughput triage becomes more feasible and less costly.	Faster triage lowers transaction costs and helps make second-life routing commercially credible.
Qualification reduced from hours to minutes	Sorting for reuse can happen at operational speed rather than laboratory speed.	Repurposing markets become easier to price, schedule, and integrate into industrial workflows.

Result or outcome	Immediate significance	Broader implication for Europe
Monitored logistics through sensing, telematics, alerts, and guidance	Transport becomes more observable and less opaque.	Policy and industry practice should shift from compliance-only thinking to monitored operations as a safety baseline.
AI-assisted dismantling with machine vision and multiple end-effectors	Disassembly can become safer, more consistent, and more scalable.	Automation can reduce one of the toughest labour and safety bottlenecks in battery circularity.
Digital Battery Passports and marketplace logic	Battery data becomes more useful at the point of transaction.	Trusted digital infrastructure is not optional. It is the precondition for liquid second-life markets.
Life-extension prioritised before recycling	Residual value can be retained for longer.	Circular policy should reward higher-value retention pathways wherever safe and economically justified.
Mixed TRL maturity across outputs	Near-term deployment can begin while earlier-stage work continues to mature.	Investment strategies should be staged, with different capital and policy tools for TRL 5, 6, 7, and 8 outputs.
Incomplete public KPI roll-up	Evidence is strongest at the component and demonstrator level.	Future programmes should improve whole-chain reporting so investors and policymakers can compare performance more easily.

What makes this especially relevant for Europe is its replication logic. The model is transferable wherever used batteries arrive with patchy information, reverse logistics are heavily constrained, and demand exists for second-life stationary storage. Replication would still need local adaptation in classification rules, transport compliance, and buyer confidence in digital records. Even so, the underlying sequence is robust: diagnose quickly, move safely, dismantle only when necessary, preserve value where possible, and let trusted data travel with the asset.

From a policy perspective, this implies stronger emphasis on common qualification logic and interoperable Digital Battery Passport data fields. From an industry-practice perspective, it points to monitored logistics, modular reuse pathways, and design-for-dismantling as competitive necessities rather than nice-to-haves. From an investment perspective, it supports a staged thesis: back the mature digital and system-integration layers now, while continuing to finance translational development for diagnostics and dismantling automation.

Recommendations and next steps

The project's takeaways should focus less on proving that second life is possible and more on making the strongest elements repeatable, investable, and hard to ignore in day-to-day operations.

1 Regulators and standard setters should codify qualification logic and core Digital Battery Passport fields.

Market growth will remain slower than it needs to be if every actor describes battery condition differently. Common qualification rules and portable data fields would reduce ambiguity, lower transaction risk, and make second-life decisions easier to audit and trust.

2 OEMs should design packs for non-intrusive diagnosis and easier dismantling.

Recirculate makes plain that opening every pack to understand it is expensive, slow, and sometimes risky. Future battery and pack design should assume that rapid diagnosis, selective disassembly, and downstream reuse are normal requirements, not edge cases.

3 Logistics operators and safety authorities should treat monitored transport as the emerging baseline.

Reverse flows for used batteries are too consequential to be handled as blind transfers between sites. Practical monitoring, sensing, alerting, and visibility tools should become part of standard operating practice, especially where safety and compliance intersect.

4 Repurposers and system integrators should build for throughput, not bespoke craftsmanship.

Fast diagnostics, modular reuse pathways, and better control systems are what turn circularity from endless pilots into an industrial routine. The operational objective should be scalable triage and repeatable assembly, not one beautiful project at a time.

5 Investors and public funders should back integrated chains rather than isolated components.

Funding diagnostics without logistics, or dismantling without trusted data, will slow learning and reduce commercial relevance. End-to-end pilots that connect assessment, transport, dismantling, reuse, and digital market infrastructure are more likely to produce bankable evidence.

6 Digital infrastructure providers should treat trusted data exchange as market infrastructure.

Digital Battery Passports and marketplaces should not be positioned as compliance tools. Their real role is to capture and communicate key data, reduce information asymmetry, support more confident pricing, and let battery knowledge travel across lifecycle transitions.

7 Programme owners should separate near-term deployables from longer-horizon research tracks.

Some outputs are ready to move into operational environments sooner than others. Europe will benefit more from honest staging, with mature tools pushed into deployment quickly and promising earlier-stage technologies supported through focused follow-on development rather than bundled into a single vague scale-up story.

Recirculate's most durable contribution is not one device, one demonstrator, or one digital tool. It is a working blueprint for how Europe can keep more battery value in circulation: diagnose early, see the risks, trust the data, automate the painful steps, and reserve recycling for the point where higher-value options are no longer sensible. That is what battery second life looks like when it stops being a concept and starts behaving like an industry.

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