aBR
Review Article

Strategies for Securing Key Raw Materials for Secondary Batteries through Battery Recycling: Case Studies on Battery Materials and Manufacturing Companies

DaeSeung, Seo 1,*

Received: 07 January 2025
Revised: 15 May 2025
Accepted: 30 November 2025
Published: 27 February 2026

1 Where617@naver.com

* Correspondence: Where617@naver.com

Abstract: Background/Purpose: The rapid growth of electric vehicles (EVs) and energy storage systems (ESS) has driven explosive demand for secondary batteries. Key raw materials—lithium, nickel, and cobalt—face mounting supply-chain risks and resource-depletion concerns, making sustainable procurement strategies an urgent priority. This study explores how battery recycling can ensure a stable supply of these critical materials and proposes practical strategies derived from leading-company case analyses. **Study Design/Methodology/Approach:** A qualitative, multi-case study methodology was applied, examining three global recycling leaders—SungEel HiTech, Ecopro, and Umicore—alongside four intercompany collaboration cases (Samsung SDI–SungEel HiTech; Ultium Cells–Li-Cycle; CATL–Volvo; Japan–EU). Data were gathered from corporate disclosures, industry association reports, and media coverage through 2024. **Findings:** Each firm leverages distinct technical capabilities to recover high-value metals from spent batteries. SungEel HiTech operates an integrated pre- and post-treatment system targeting high-purity metal recovery. Ecopro maximises efficiency through a closed-loop eco-system linking lithium hydroxide, precursor, cathode, and recycling stages. Umicore combines pyrometallurgical and hydrometallurgical processes to maximise recovery rates while pursuing ESG-aligned innovation. Cross-company collaborations demonstrate that supply-chain partnerships are essential for economic viability. The global end-of-life battery market is projected to grow from approximately 44 GWh (2025) to 338 GWh (2030) and 1,329 GWh (2040). **Originality/Value:** This study provides a structured 4-company/4-collaboration analysis of battery recycling strategies in a rapidly evolving regulatory landscape (EU Battery Regulation, US Recycling and Environmentally Friendly Battery Act), offering actionable strategic and policy insights for industry practitioners and policymakers seeking to advance the secondary battery circular economy.

Keywords: battery recycling; secondary battery; lithium; nickel; cobalt; circular economy; end-of-life battery; supply chain; SungEel HiTech; Ecopro; Umicore

1. Introduction

1.1. Research Background and Objectives

The rapid proliferation of electric vehicles (EVs) and energy storage systems (ESS) has generated exponential growth in secondary battery demand. Secondary batteries depend critically on lithium, cobalt, and nickel—materials that are geographically concentrated, environmentally costly to mine, and subject to price volatility and supply-chain disruption. Against this backdrop, battery recycling has emerged as a strategic imperative: it recovers valuable metals from spent batteries, reduces dependence on primary mining, lowers the carbon footprint of battery production, and supports the transition toward a circular economy.

This study aims to (1) examine the technological and strategic approaches of leading battery recycling firms; (2) analyse intercompany collaboration models for securing recycled raw materials; and (3) derive strategic and policy recommendations for industry participants and governments. The analysis contributes to three domains:

sustainable development by addressing resource depletion and environmental concerns; practical strategy by illustrating real-world recycling business models; and economic competitiveness by demonstrating how recycling generates cost advantages and new revenue streams.

1.2. Research Scope and Methodology

This study employs a qualitative, multi-case design. Three recycling-specialist firms were selected based on technological leadership, operational scale, and global market influence: SungEel HiTech (South Korea), Ecopro (South Korea), and Umicore (Belgium). Four intercompany collaboration cases were additionally examined to illustrate supply-chain partnership models. Data were gathered from company annual reports and disclosures, industry association statistics (SNE Research, AEM), government and regulatory documents (EU Battery Regulation, US Recycling Act, EU CRMA), and credible media coverage through 2024.

2. Business Environment: Drivers of Battery Recycling

2.1. Necessity of Battery Recycling for Raw Material Security

Secondary batteries are composed of high-value-added metals—primarily lithium, nickel, and cobalt—that directly determine energy density, cycle life, and electrochemical stability. Global demand for these materials is increasing rapidly, yet supply is constrained by geographic concentration (e.g., over 60% of cobalt reserves are located in the Democratic Republic of Congo) and environmentally damaging extraction processes.

Battery recycling addresses these challenges by recovering metals from spent cells and reintroducing them into manufacturing supply chains, thereby reducing primary mining dependence, mitigating price volatility exposure, and decreasing greenhouse gas emissions relative to virgin-material production. Advances in recycling technology also link directly to national carbon-neutrality goals, since energy consumption in pyrometallurgical and hydrometallurgical recovery is substantially lower than that of mineral extraction and refining.

2.2. Global Policy Environment

2.2.1. Policy Changes in Europe and North America

The European Union introduced the European Battery Regulation in late 2020, establishing lifecycle environmental obligations covering design, manufacture, use, and disposal. Key targets include recycling rates for lithium, nickel, and cobalt of 70%, 95%, and 95%, respectively, by 2030. These obligations function as market-access conditions, compelling manufacturers to integrate recycled content and establish collection infrastructure.

In North America, the United States enacted the Recycling and Environmentally Friendly Battery Act in 2021, mandating strict environmental standards for battery manufacturers and recyclers, and providing federal support for recycling technology R&D and infrastructure. Canada complemented this with its Battery Innovation Strategy, incentivising technology development and investment attraction. In March 2024, the EU adopted the Critical Raw Materials Act (CRMA), targeting a reduction of dependence on any single third country to below 65% of total EU strategic raw material consumption by 2030.

2.2.2. Implications for Industry

European regulations require manufacturers to incorporate recyclability from the design stage, spurring materials innovation and process reconfiguration, though imposing compliance costs—particularly on SMEs with limited infrastructure. North American policy creates market expansion opportunities, especially for start-ups and recycling specialists, but simultaneously raises the performance bar for incumbents. Across jurisdictions, regulatory tightening accelerates structural change in global battery supply chains and rewards early movers in recycling technology.

2.3. Characteristics and Requirements of Recyclable Key Materials

Recyclable raw materials recovered from spent batteries face several quality challenges. Lithium purity is difficult to maintain during hydrometallurgical recovery due to interference from other dissolved ions. Cobalt requires careful management given both its toxicity and the ethical issues associated with artisanal primary mining. Nickel recovery efficiency is sensitive to battery chemistry (NMC vs. LFP) and the pre-treatment approach adopted.

Four dimensions must be satisfied for commercially viable material recovery: (1) chemical purity sufficient to meet cathode-material specifications; (2) minimal environmental impact throughout the recovery process, including waste-water treatment, energy consumption, and emissions; (3) economic efficiency, achievable through scale economies, process optimisation, and favourable input material pricing; and (4) ethical and social responsibility in procurement, particularly the avoidance of supply chains associated with child labour or environmental destruction—an area where recycled materials hold an inherent advantage over mined equivalents.

2.4. End-of-Life Battery Treatment and Market Scale

2.4.1. Treatment Pathways

Spent batteries are addressed through two primary pathways. Recycling involves physical and chemical processing to recover metals: a pre-treatment stage (discharge, crushing, shredding, black-mass production) followed by a post-treatment stage using pyrometallurgical and/or hydrometallurgical processes. Reuse repurposes batteries retaining 60–80% of original capacity for less demanding applications such as stationary energy storage, golf carts, or agricultural equipment.

The two principal recycling processes are compared in Table 1. Pyrometallurgy (dry process) offers high throughput and process simplicity but generates significant CO_2 emissions and is limited in lithium recovery. Hydrometallurgy (wet process) achieves high selectivity and lithium recovery but involves complex, time-intensive process steps less suited to very high-volume feedstreams. Industry practice is increasingly converging on hybrid approaches that combine both methods to exploit complementary strengths.

Table 1. Comparison of pyrometallurgy and hydrometallurgy processes for battery recycling.

공정방식 (Process)	주요 특징 (Characteristics)	장점 (Advantages)	단점 (Disadvantages)
건식공정 (Pyrometallurgy)	폐배터리를 고온에서 용융하여 금속을 회수	대량 처리 가능; 공정이 단순	높은 초기 투자 비용; 리튬 회수 제한
습식공정 (Hydrometallurgy)	화학 용액으로 금속을 용해 및 분리	다양한 금속 회수 가능; 비교적 낮은 초기 투자 비용; 리튬 회수율 높음	공정 복잡·시간 소요; 대량 처리 부적합

Source: Eco Plant Newsroom, ESG Column (2023.10.05); News1 (2024.07.25).

2.4.2. End-of-Life Battery Market Scale

According to SNE Research (2023), the global end-of-life battery volume is projected to grow from approximately 44 GWh in 2025 to 338 GWh by 2030 and 1,329 GWh by 2040, driven by the EV adoption wave of 2018 onwards and typical battery replacement cycles of 7–10 years. The Korean AWP battery recycling rental market alone was estimated at USD 530 million in 2023 (SPHERICAL INSIGHTS, 2024). This growth trajectory identifies battery recycling as a high-priority sector for both environmental value creation and economic opportunity.

2.5. Recycling Process Technology

The integrated battery recycling process proceeds through four stages. Pre-treatment physically prepares spent cells: discharge removes residual charge to eliminate fire and explosion risk; shredding and crushing produce black mass (electrode active material); and purification removes non-electrode constituents. Post-treatment applies chemical processes to the black mass: acid leaching dissolves metal ions; selective precipitation and solvent extraction separate individual metals; and refining produces battery-grade compounds.

Pyrometallurgical post-treatment smelts pre-treated material in a high-temperature furnace to yield a metal alloy, which is then refined. Hydrometallurgical post-treatment dissolves black mass in acid solution, separates metal ions via precipitation and extraction, and recovers high-purity metal compounds. The combined approach—smelting first, then wet refining of slag—enables recovery of a broader range of metals including lithium, which is poorly captured by pyrometallurgy alone.

3. Case Analysis: Leading Recycling Companies

The following analysis examines three globally significant battery recycling specialists, each representing a distinct national and technological context. Table 2 provides a comparative overview.

Table 2. Summary comparison of the three case companies.

Company	Country	Core Process	Key Strategy	Notable Partnership
SungEel HiTech	South Korea	Integrated pre- & post-	Global production network;	Samsung SDI, SK On

(성일하이텍)		treatment (hydrometallurgy)	Gen3 membrane zero-wastewater system	
Ecopro (에코프로)	South Korea	Hydrometallurgy; closed-loop eco-system	EV battery recycling expansion; overseas capacity (Hungary, Canada)	Kia, Hyundai Glovis, Ascend Elements
Umicore	Belgium	Combined pyro- & hydrometallurgy	'RISE 2030' & 'Let's Go for Zero' ESG strategy	LG Energy Solution, Samsung SDI, SK Innovation

Source: Authors' compilation based on corporate disclosures and industry reports.

3.1. SungEel HiTech

3.1.1. Company Overview

SungEel HiTech, headquartered in South Korea, is a specialist in battery and electronic waste recycling. The company is distinguished by its fully integrated pre- and post-treatment system—the only such integrated domestic capability in Korea—enabling it to process spent batteries from physical preparation through to high-purity metal compound production.

3.1.2. Recycling Technology

SungEel HiTech's pre-treatment process comprises discharge, mechanical shredding and crushing to produce black powder, and impurity removal. The post-treatment stage applies hydrometallurgy (wet refining): acid leaching of black powder extracts metal ions, which are separated and refined to recover lithium, nickel, cobalt, and copper. A key forthcoming innovation is the 'Gen3' membrane system (planned from 2026), which will recycle 100% of process wastewater, eliminating liquid discharge and substantially reducing waste-treatment costs.

The company is also developing LFP (lithium iron phosphate) battery recycling technology, which presents greater recovery challenges than NMC chemistries due to lower cobalt and nickel content. Successful LFP recycling would significantly expand the addressable feedstream as LFP-based EVs—common in China and increasingly globally—reach end of life.

3.1.3. Business Strategy and Partnerships

SungEel HiTech pursues global scale through production facilities in Georgia and Indiana (USA) and a planned 'Euro Hydro Centre' in Europe, supplementing its domestic base including a third plant in Gunsan (New Saemangeum Industrial Complex) with monthly processing capacity of 2,900 tonnes. The company operates a closed-loop model with battery manufacturers—notably Samsung SDI and SK On—receiving manufacturing scrap and end-of-life batteries and supplying recovered metal compounds back into cathode production. The Gunsan plant targets annual output of 600 tonnes of cobalt, 5,300 tonnes of nickel, and 6,000 tonnes of lithium—sufficient for approximately 300,000 EVs.

3.1.4. Performance and Outlook

SungEel HiTech currently recovers approximately 4,200 tonnes of valuable metals annually and is positioned as a global leader in integrated battery recycling. The Gen3 membrane technology and LFP recycling capability are expected to enhance both environmental credentials and economic competitiveness. Ongoing global network expansion and deepening manufacturer partnerships support continued growth.

3.2. Ecopro

3.2.1. Company Overview

Ecopro is a leading South Korean cathode material manufacturer that has vertically integrated battery recycling through its subsidiary Ecopro CnG (established 2020). The company's strategic differentiation lies in its 'Closed-Loop Eco-System,' which links lithium hydroxide production, precursor manufacturing, cathode material output, and recycling in a continuous circular flow.

3.2.2. Recycling Technology and Capacity

Ecopro CnG employs hydrometallurgical processing: black mass from spent batteries is dissolved in acid, and lithium is separated from precipitates, achieving higher lithium recovery rates than pyrometallurgy. As of October 2023, annual processing capacity stands at approximately 30,000 tonnes. A second plant is planned to become operational in Q1 2025, and overseas lines in Hungary and Canada are targeted to bring total capacity to 61,000 tonnes by 2027.

3.2.3. Business Strategy and Partnerships

Ecopro's strategy operates across three dimensions. First, EV battery recycling expansion: the company is extending beyond manufacturing-scrap recycling to end-of-life EV batteries, forming a 'Battery Ecosystem Alliance' with Kia and Hyundai Glovis (October 2023). Second, global market entry: Ecopro has signed an MOU with US-based Ascend Elements for battery recycling cooperation and entered the European market through SK Ecoplant and its subsidiary TES. Third, the closed-loop system: manufacturing scrap and spent batteries are recycled to recover raw materials that feed directly back into cathode production, reducing both input costs and environmental burden.

In June 2024, Ecopro signed an agreement with Hyundai Glovis covering EV battery recycling, value-chain strengthening, and manufacturing logistics automation, reinforcing its integrated supply-chain model.

3.2.4. Performance and Outlook

The global battery recycling market is projected to grow from approximately KRW 27 trillion (2025) to KRW 272 trillion (2040). Ecopro's combination of high lithium-recovery hydrometallurgy, closed-loop system, and strategic overseas expansion positions it to capture a significant share of this growth. The company's deep integration across the battery materials value chain provides a competitive moat that pure recyclers cannot easily replicate.

3.3. Umicore

3.3.1. Company Overview

Umicore, headquartered in Belgium, is a global materials technology and recycling company with a technologically leading position in battery recycling. The company applies a proprietary combination of pyrometallurgical and hydrometallurgical processes to recover cobalt, nickel, lithium, and other metals from spent batteries at up to 95% recovery rates. Its operations span the full battery value chain, from cathode material supply to end-of-life recycling.

3.3.2. Recycling Technology

Umicore's pyrometallurgical stage melts spent batteries in a high-temperature smelter, yielding a metal alloy (primarily cobalt and nickel) and a slag phase. The slag is then processed hydrometallurgically to recover lithium and other metals that are not efficiently captured in the initial smelt. This combined approach maximises overall metal recovery while maintaining the throughput advantages of pyrometallurgy for large-volume feedstreams.

3.3.3. Business Strategy

Umicore's strategic framework is articulated in its 'Umicore 2030 – RISE' programme, which targets sustainable and profitable growth through three pillars: strengthening circularity of critical metals; accelerating global mobility innovation; and meeting growing demand for advanced materials. This is complemented by the 'Let's Go for Zero' ESG strategy, which commits to zero greenhouse gas emissions, zero hazardous substances, and zero inequality across operations.

Globally, Umicore has established production and export hubs across Asia–Pacific, leveraging strong manufacturing infrastructure and supply-chain relationships. It maintains strategic partnerships with Korea's major battery producers—LG Energy Solution, Samsung SDI, and SK Innovation—covering the full production-to-recycling lifecycle. In April 2021, Umicore secured a cathode supply-to-recycling agreement with these Korean majors, positioning itself as a preferred recycling partner as EV-driven battery volumes scale.

3.3.4. Performance and Outlook

Umicore's 2023 integrated annual report reflects strong cash flow and margins despite challenging market conditions, supported by its diversified business model. The 'RISE 2030' strategy provides a forward-looking roadmap anchored in sustainability and innovation. The company's established technology base and long-term manufacturer relationships position it well to benefit from the growing end-of-life battery volumes expected from 2028 onwards.

4. Corporate Strategies for Securing Recyclable Raw Materials

Section 3 establishes that individual company capabilities, while important, are insufficient on their own to ensure stable raw material supply across a rapidly scaling market. Supply-chain collaboration between battery manufacturers, automakers, and recyclers is a structural necessity. Table 3 summarises the four key collaboration cases examined in this section.

Table 3. Summary of intercompany collaboration cases in battery recycling.

Collaboration	Parties	Key Mechanism	Outcome / Target
Samsung SDI – SungEel HiTech	Battery maker + recycler	Closed-loop scrap recovery → cathode re-input	Recycled metal use rate: 12% (2023) → 26% (2030 target)
Ultium Cells – Li-Cycle	GM/LG JV + recycler	~95% waste stream recycled from battery production	Long-term Ni supply; LG invested KRW 60 bn for 2.6% stake
CATL – Volvo	Battery maker + automaker	Certified end-of-life battery collection → metal extraction → new battery	Volvo target: 30% recycled materials by 2030, 35% thereafter
Japan – EU	National/multilateral	'Uranos Ecosystem' + 'Catena-X' platform data sharing	Reduce Chinese supply dependency; EU CRMA: <65% reliance by 2030

Source: Authors' compilation based on corporate disclosures and media reports (2021–2024).

4.1. Supply Chain Collaboration Cases

4.1.1. Samsung SDI and SungEel HiTech

Samsung SDI has established a closed-loop system with SungEel HiTech wherein manufacturing scrap is recovered, metals extracted via wet refining, and the resulting metal compounds reintroduced into cathode production. By 2023, Samsung SDI achieved a recycled metal utilisation rate of 12%, with a target of 26% by 2030. The model is being extended to overseas manufacturing hubs in Malaysia, Hungary, China, and the US. SungEel HiTech's new Gunsan third plant (operational July 2023) directly strengthens this partnership through increased wet-smelting capacity.

4.1.2. Ultium Cells and Li-Cycle

Ultium Cells—the GM/LG Energy Solution joint venture operating battery plants in Ohio and Tennessee—partnered with Li-Cycle, North America's largest battery recycler, to recover cobalt, nickel, and lithium from production waste streams. The collaboration enables approximately 95% of battery manufacturing waste to be recycled. LG Chem and LG Energy Solution each invested KRW 30 billion in Li-Cycle (total KRW 60 billion for a 2.6% stake) and signed a 10-year offtake agreement for 20,000 tonnes of nickel beginning 2023—sufficient for approximately 300,000 high-capacity (80 kWh) EV batteries. Li-Cycle's hydrometallurgical process generates no dust and recycles 100% of process water, strengthening LG's ESG credentials.

4.1.3. CATL and Volvo

In April 2024, CATL and Volvo signed a memorandum of understanding for strategic sustainability partnership. Under this model, Volvo collects end-of-life batteries and delivers them to certified sub-suppliers for metal extraction; CATL uses the recovered materials to produce new batteries for Volvo EVs—a closed-loop circular economy model spanning two continents. Volvo has committed to achieving 30% average recycled battery materials across its full EV fleet by 2030, rising to 35% thereafter. CATL has described the partnership as a landmark in establishing battery recycling business models in China.

4.1.4. Japan–EU Cooperation

Japan and the EU are building interoperable battery mineral traceability platforms to enable cross-border data sharing on mineral origins and supply chains, targeting a functioning framework by 2025. Japan's 'Uranos Ecosystem' involves approximately 50 companies including Toyota, Nissan, Honda, and Denso; the EU operates the 'Catena-X' platform led by automakers. The linkage aims to track battery minerals throughout their lifecycle, prevent resource leakage, and reduce both regions' dependence on China's dominant processing and refining capacity (lithium: 65%; cobalt: 76%; graphite: 70% of global supply, per IEA). The EU's CRMA (adopted March 2024) directly supports this objective by mandating diversification of strategic raw material supply below 65% from any single third country.

4.2. Spent Battery Collection Models and Economic Viability

Effective collection of end-of-life batteries is the foundational prerequisite for all recycling activity. Leading firms have adopted structured collection approaches: Ecopro operates regional collection networks; CATL co-ordinates with EV manufacturers and local governments; and the Japan–EU initiative develops cross-border digital traceability. EV manufacturer partnerships—as exemplified by all four cases above—provide structured flows of end-of-life batteries that improve feedstream predictability and quality.

The economic viability of battery recycling is driven by the market value of recovered metals relative to processing costs. Rising cobalt and lithium prices increase the economic incentive for recycling. Firms like Redwood Materials (USA) have demonstrated substantial revenue from lithium recovery. Cost minimisation strategies include optimising recovery yields (reducing metal loss per tonne processed), achieving scale economies through capacity expansion, and reducing energy consumption via process innovation such as Ecopro CnG's hydrometallurgical approach and SungEel HiTech's Gen3 zero-wastewater system.

4.3. Strategic Recommendations for Industry

International partnership strengthening: Firms should establish multi-party agreements covering feedstock supply, metal offtake, and technology sharing across the battery value chain, reducing exposure to single-source supply risk.

Recycling technology innovation: Continuous improvement in metal recovery rates, particularly for lithium and LFP battery chemistries, is critical to economic competitiveness. Investment in membrane technology, solvent extraction optimisation, and direct cathode recycling (DCR) should be prioritised.

Collection network development: Robust end-of-life battery collection, enabled by partnerships with EV manufacturers, dealership networks, and public collection infrastructure, is a prerequisite for scalable recycling operations. Early-mover advantage in establishing collection relationships will be difficult for later entrants to replicate.

Regulatory navigation and advocacy: Firms should engage proactively with evolving regulatory frameworks (EU Battery Regulation, US Recycling Act, CRMA) to shape implementation details, secure compliance advantages, and leverage available policy incentives for recycling technology investment.

4.4. Policy Recommendations

Financial and R&D support: Governments should expand recycling technology R&D funding, provide tax incentives for end-of-life battery collection infrastructure investment, and support pilot programmes for novel recycling chemistries (e.g., direct lithium extraction, solid-state battery recycling).

Regulatory harmonisation: International regulatory alignment—particularly between the EU, USA, Japan, and Korea—on battery material traceability, recycled content requirements, and collection targets would reduce compliance complexity for global operators and strengthen cooperative supply-chain frameworks.

Market environment creation: Policy design should ensure that recycled materials can compete fairly with primary materials in market pricing, potentially through differentiated carbon pricing or procurement standards that account for the lifecycle environmental advantages of recycled inputs.

5. Discussion

The three company cases and four collaboration cases examined in this study converge on several cross-cutting insights. First, technical integration across pre- and post-treatment stages is a decisive competitive advantage: both SungEel HiTech's domestic integrated system and Umicore's combined pyro-hydrometallurgical process demonstrate that single-process approaches leave value on the table, particularly for lithium recovery. Second, closed-loop partnerships with battery manufacturers—as exemplified by Samsung SDI/SungEel HiTech, Ultium Cells/Li-Cycle, and Ecopro's manufacturer alliances—generate feedstock security and strategic alignment that pure market-based feedstock procurement cannot replicate.

Third, the COVID-19 pandemic and associated supply-chain disruptions of 2020–2022 accelerated the strategic shift from recycling as a niche environmental activity to recycling as a core procurement strategy, as manufacturers experienced first-hand the risks of single-source primary material dependence. The regulatory environment, particularly the EU Battery Regulation and CRMA, institutionalises this shift by mandating recycled content and collection targets that transform recycling from optional to obligatory.

Fourth, the Japan–EU cooperation case highlights the emerging geopolitical dimension of battery recycling: reduced dependence on China's refining dominance is an explicit policy goal, and recycling—by creating domestic or allied-nation supply chains—is a direct instrument of resource security. This dimension is likely to intensify as EV adoption and battery volumes scale through the 2030s.

6. Conclusions

This study has examined battery recycling as a strategic mechanism for securing critical raw materials—lithium, nickel, and cobalt—for the secondary battery industry. The principal findings are as follows:

- Battery recycling has evolved from an environmental compliance activity to a core strategic tool for raw material security, cost reduction, and circular economy advancement, driven by both regulatory mandates and commercial imperatives.
- The three leading recyclers examined—SungEel HiTech, Ecopro, and Umicore—each occupy differentiated technological niches (integrated pre/post-treatment; closed-loop cathode ecosystem; combined pyro-hydrometallurgy) that reflect their distinct competitive contexts and corporate strategies.
- Intercompany collaboration—between battery manufacturers, automakers, and recyclers—is a structural necessity for achieving stable feedstock supply and economic viability at scale. The Samsung SDI/SungEel HiTech, Ultium Cells/Li-Cycle, CATL/Volvo, and Japan–EU cases each illustrate distinct but complementary partnership architectures.
- Governments must provide enabling policy frameworks—R&D support, collection infrastructure incentives, regulatory harmonisation, and fair market conditions for recycled materials—to allow the recycling ecosystem to scale at the pace required by the energy transition.

Battery recycling is not a peripheral sustainability initiative but a structural component of the future secondary battery industry. Firms that invest early in recycling technology, build deep supply-chain partnerships, and engage constructively with the regulatory environment will secure durable competitive advantages in raw material procurement as primary supply constraints tighten through the 2030s.

6.1. Research Limitations and Future Directions

This study relies primarily on publicly available disclosures and secondary industry data; proprietary operational and financial data from the case companies were not directly accessible. The qualitative multi-case design, while suited to exploring strategy and context, does not enable quantitative generalisation. Future research should apply quantitative lifecycle assessment and techno-economic modelling to compare recycling process alternatives; extend the analysis to additional recycling specialists (e.g., Redwood Materials, Li-Cycle, Retriev Technologies); and examine the long-term effects of specific policy instruments on recycling investment and market structure across jurisdictions.

References

Ecopro (n.d.). *Official corporate website.* Retrieved from https://www.ecopro.co.kr

IEA [International Energy Agency] (2023). *Global EV Outlook 2023.* IEA.

KDB Industrial Bank (2019, November). *Re-use and recycling of spent lithium secondary batteries: Industry and technology status (Report No. 768).* pp. 70–71.

LG Business Research Institute (2023, September). *Battery recycling ecosystem: Preparation required for full-scale expansion.* Retrieved from https://www.lgbr.co.kr

Jeong, H. C., et al. (2023). Current status and prospects of recycling spent lithium-ion batteries (LIB) by hydrometallurgical processes. *Resources Recycling, 32*(4), 4–15.

SNE Research (2023). *Recycling/Reuse: Technology trends and market outlook.* SNE Research.

SPHERICAL INSIGHTS (2024). *Korea Aerial Work Platform (AWP) Rental Market Insights, Forecast to 2033.* Spherical Insights & Consulting.

SungEel HiTech (n.d.). *Official corporate website.* Retrieved from https://www.sungeelht.com

Umicore (n.d.). *Official corporate website.* Retrieved from https://www.umicore.com

Umicore (2023). *Integrated Annual Report 2023.* Umicore.

Samsung SDI Newsroom (2024, November 26). *Recycled metal utilisation rate and 2030 targets.* Retrieved from https://news.samsungsdi.com/ko/articleView?seq=231