Singapore Battery Consortium

2021 Q4 Newsletter

Understanding curation of recent industry developments and technology news

Recent industry developments and technology news are specifically curated based on the relevance to the progression of the industry. Each news event is categorized based on importance and area of focus (see below for description for both).

SK innovation

15 January 2020

SK Innovation announces 10 GWh exp(1)sion of factory in U.S.

Very (3)rtant | Ener(4)orage

SK Innovation will build its second U.S. factory in Georgia, from which it intends to ship another 9.8 GWh to VW in Tennessee. Its total production goal of 100 GWh by 2025 outpaces its publicly known manufacturing projects, so expansions near already-planned facilities will likely be a forthcoming trend. In the Southeast U.S., automotive manufa(2)ers are nearby: VW is in Tennessee, Daimler has factories in South Carolina and Alabama, where Hyundai also is, and Volvo, BMW, and Kia are located in Georgia. Clients should expect SK Innovation to ramp up production near customers and keep chipping away at its 2025 goal.

1. **Link**: Hyperlink to original news article. Note some news articles may be behind paywall.
2. **Analysis**: Writeup of the news event as it relates to industry development and recommendations for action.
3. **Importance**: Take on the potential importance of the event from "Truly Disruptive" to "Ignore"
4. **Area of Focus**: Category of the news event based on the to the topic.

Importance	Description
Truly Disruptive	A game-changing, landmark development
Very Important	Significant news that will have strong implications
Average Importance	Worth noting, but not likely to be too important or disruptive
Low Importance	An over-hyped development, which is not worth monitoring closely
Ignore	Misleading or irrelevant development, worth being cautious about

Area of Focus	Description
Built environment energy use	Hardware and software technologies for commercial and residential energy consumption
Business models and regulations	Novel business models for energy production, consumption, and distribution, as well as policies with transformational impact on new energy technology development
Energy for mobility	Energy sources for powering road, rail, aviation, and marine – includes movement of goods and people
Energy storage	Various forms electrochemical energy storage, such as Li-ion and solid-state batteries
Stationary storage	Utility-scale and long-duration energy storage for grid services, renewables integration and backup, and microgrid support

Companies continue to expand activity upstream of the battery supply chain

29 September 2021

Redwood Materials announces intention to become cathode material supplier

Very Important | Energy storage

The company will begin utilizing the materials it recovers by producing both copper current collectors and cathode active materials (CAMs). This announcement comes on the heels of a $700 million funding round. Redwood plans to scale to producing 100 GWh of CAM by 2025, then 500 GWh by 2030. Clients should expect its business in recycling manufacturing scrap to contribute significantly to its CAM production and note that its existing partnerships are integral to further integration in cathode manufacturing.

30 September 2021

Hyundai and LG Energy Solution will build 10 GWh battery manufacturing plant in Indonesia

Average Importance | Energy for mobility

The Indonesian government previously banned the export of nickel ores, forcing mining companies to set up refineries domestically; this move is likely a way to curb future discussions of stricter export policy. As one of the world's top producers of nickel, Indonesia has leverage to establish itself as a battery production hub, and LG Energy Solution can use the facility to source batteries to the rest of Southeast Asia. Building up a local battery value chain will prove to be less difficult due to the country's proximity to chemical suppliers and automotive companies; however, clients shouldn't expect this to be replicable in more remote areas with significant battery materials resources.

1 October 2021

BASF and Shanshan Technology to form cathode materials joint venture in China

Very Important | Energy storage

The partnership, called BASF Shanshan Battery Materials, will focus on consumer electronics applications and electric vehicles, with EVs being a priority. With an emphasis on cathode materials, the partnership is aiming to have a production of 90 kilotons by 2022. Following negotiations with the Canadian government to tap Canada's reserves to develop a raw material supply chain, BASF has now set goals in China. This does not come as a surprise, as BASF has been aggressive and pursuing multiple avenues of collaboration with battery material manufacturers across the globe. By establishing a partnership in China, which is also a first for a company from Europe, BASF has become a leader in the global battery materials value chain.

Innovative companies look to address today’s raw material challenges with novel recovery technologies

Saltworks

12 October 2021

Saltworks produces battery-grade lithium from wastewater containing as little as 70 mg/L lithium

Very Important | Energy storage

Saltworks is likely targeting oil and gas produced waters in the U.S. or SAGD wastewater operations in Canada. While most commercial operations tend to be profitable above 200 mg/L, Saltworks can produce battery-grade lithium from as little as 70 mg/L. The company uses adsorbents that selectively remove Li from wastewater to produce a concentrated LiCl solution. It then uses a proprietary electrolysis or crystallization step to produce LiOH or Li_2CO_3. Clients should note that as a turnkey solutions provider, Saltworks can potentially design and engineer a low-cost extraction plant using its own technologies.

Li-Cycle™ | KOCH

13 October 2021

Li-Cycle secures $100 million in funding to rollout its battery recycling technology

Very Important | Energy storage

The funding helps Li-Cycle expand its operations with new pre-processing plants or "spokes" (which produce the black mass from shredding batteries) it has announced in Alabama and Arizona and accelerate the building of its centralized hydrometallurgical plant in New York. Li-Cycle plans to tap into the broader Koch Industries ecosystem, where it can access EPC services and building and shipping of modular plants to regions outside North America. Koch will leverage Li-Cycle's technology as the missing link in its Li-ion battery value chain, with previous investments in battery production, EVs, and renewable energy storage.

ESS INC | SB Energy SoftBank Group

25 October 2021

ESS Inc. lands 2 GWh order from SB Energy

Very Important | Stationary storage

The iron-flow battery developer will supply batteries to SB Energy's projects across the U.S. through 2026, starting with a commissioned project of unnamed size in California in October 2021. ESS Inc. announced it would go public earlier in 2021, primarily raising funds to increase manufacturing capacity. Despite the accelerating need for large-scale energy storage, non-Li-ion technologies still struggle to land sizable projects. ESS's partnership with SB Energy will be a springboard for increased implementation, providing important benchmark performance data, a necessity for energy storage technologies looking to build a business case for long-duration storage; future projects with SB may hinge on successful metrics from the first project.

Companies continue to develop next-generation battery technologies despite Li-ion's dominance today

1 November 2021

Tesla introduces LiFePo cathodes for all its standard-range vehicles

Very Important | Energy for mobility

The announcement comes amid the rising nickel and cobalt prices across the globe. Tesla's switch to LFP can be viewed as a move toward cheaper production costs and mitigating supply chain risks in rare earth metals like nickel and cobalt. It should not be a surprise, as Tesla offers the LFP-based batteries for the Model 3 in China and has seen a rapid increase in production and sales. Although LFP-based cells are less energy-dense, their long cycle life and lower costs are the key factors for Tesla to switch to a cobalt-free cathode.

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16 November 2021

SES to produce 1 GWh/year of Li-metal batteries in Shanghai and reveals first 107 Ah battery

Very Important | Energy storage

SES has unveiled the first 100 plus Ah Li-metal battery and announced plans to produce 1 GWh/year of such batteries in Shanghai. CEO Qichao Hu said that its Shanghai factory had a capacity of 100,000 cells per month but was limited to 8,000 per month due to constraints in Li-metal anode production, which amounts to approximately 3.5 MWh/year. Li-metal anodes have yet to be produced at the scale that SES is proposing, but the company is one of the more experienced companies producing the technology. The technology has yet to reach A-sample testing for automotive and commercial implementation will take years despite these compelling announcements.

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16 November 2021

SK Innovation invests $30 million in Solid Power

Very Important | Energy storage

SK Innovation and Solid Power have signed a memorandum of understanding to jointly develop solid-state batteries for precommercial production. Solid Power's automotive partners will use cells produced under the agreement for validation testing. SK Innovation will license the technology and buy electrolyte material from Solid Power for production. Although production volumes will probably be small during the automotive-validation period, this partnership is significant as one of the few public collaborations between a battery startup and major cell manufacturer. The real value of SK Innovation's involvement will be to demonstrate solid-state battery production using existing manufacturing processes.

Entering the electric vehicle supply chain requires significant funding and a global network of partners

RETRIEV TECHNOLOGIES
HERITAGE Battery Recycling

19 November 2021

Heritage Battery Recycling and Retriev Technologies combine for comprehensive battery management

Very Important | Energy storage

The combination of Heritage Battery Recycling and Retriev Technologies will allow the further development of an inclusive recycling and reuse battery management platform under the Retriev Technologies brand. Included in the partnership was Retriev's acquisition of the xEV Strategies division of Kinsbursky Brothers, which had built a system of testing, refurbishment, and storage for end-of-life batteries. Retriev also struck up a strategic partnership with Marubeni in early 2021 to use the recycled materials. Retriev continues focused on preexisting technologies and waste management systems as part of its market strategy.

JM

29 November 2021

Johnson Matthey cites increasing commoditization as key reason for pulling out of batteries business

Very Important | Energy storage

Previously, Johnson Matthey (JM) had pursued commercialization of lithium-nickel oxide cathodes, investing roughly $200 million in R&D to date. In an abrupt move, JM announced it would exit the battery business, citing two key reasons. First and foremost, being competitive with other cathode manufacturers required a significant scale of investment, but the increasing commoditization of cathodes meant returns on this significant investment would be minimal. In Europe specifically, acquiring JM's assets should be a high consideration, as the EU is incentivizing building a local battery supply chain; however, recognize the price for cathodes will be closely tied to nickel prices.

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ample
UBER

29 November 2021

Ample expands into Europe to leverage fresh funding and its partnership with Uber

Very Important | Energy for mobility

While Ample had previously leveraged a partnership with Eneos to explore opportunities in Japan, it is currently leveraging this recent financing round to expand into Europe through a deepened partnership with Uber. Ample's battery-swapping solution is well-suited to fleet applications like ride-hailing, where Lux has found battery-swapping solutions to be competitive on costs and to enable greater uptime in its fleet. Look for further announcements about Ample's partnership with Uber, which will require a vehicle using Ample's solution to be developed before scaling up — an announcement that could arise from its partnership with Arrival.

Oil and gas continues to diversify its retail offerings with EV charging and battery swapping partnerships

2 December 2021

U.S. Department of Energy announces $209 million in funding for advanced battery research

Average Importance | Energy for mobility

The U.S. Department of Energy (DOE) announced funding of $209 million for 26 new projects, with most projects emphasizing solid-state batteries and advanced battery research. The list also includes Li-bridge, a public-private partnership with Argonne National Laboratory that focuses on the domestic supply chain. It may not come as a surprise as the DOE has been working aggressively on strategies to reduce importing materials for batteries. With the demand for batteries at an all-time high, clients interested in this development should expect more initiatives and projects by DOE to help boost domestic battery manufacturing and the mineral supply chain.

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3 December 2021

O&G investments in battery swapping continue with BP and Shell announcements

Average Importance | Energy for mobility

Shell and Nio have partnered to deploy battery-charging and -swapping facilities across China with planned pilot stations across Europe, while BP invested in Aulton, which provides stations to network operators. Clients should take note of increasing investments in battery-swapping networks from oil and gas companies, specifically those with retail operations. Shell and Eneos previously invested in Ample, while Sinopec co-invested in Nio's battery-swapping network. While Nio and Aulton are focused primarily on passenger vehicle applications, battery-swapping solutions for commercial fleets are most promising for oil and gas companies looking for a transition of their retail operations

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9 December 2021

BP acquires Amply Power to bolster its EV charging infrastructure portfolio

Very Important | Energy for mobility

During the second half of 2021, BP showed its intention to play a bigger role in the power sector by offering other energy services for buildings and owners of distributed energy resources through its acquisitions of Blueprint Power and Open Energi. However, electric mobility remains the key area to focus on for oil and gas majors. BP definitely gets it: Last month the company showed interest in battery swapping through its investment in Aulton, and now it's looking to provide charging infrastructure as a service with the acquisition of Amply Power. BP is clearly betting on alternative ways to power electric fleets.

Automakers must move upstream to meet electrification targets and avoid supply chain disruptions

15 December 2021
Cummins taps Sion Power for lithium metal batteries

Average Importance | Energy storage

Sion Power will supply batteries using its metallic lithium anode battery technology to Cummins for commercial vehicles. Lithium anodes offer much higher energy densities than incumbent anodes, but poor cycle life, safety, and limited production capacity remain large barriers to commercial adoption. Despite the technical hurdles for widespread adoption, Cummins' use of Sion Power's technology will provide the company an early market opportunity in applications where payload is a concern. The partnership highlights how companies interested in electrification can incorporate new technology without waiting for commercial-scale production.

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16 December 2021
GM invests in its EV supply chain, focusing on battery cathodes and rare earth magnets

Very Important | Energy for mobility

GM made two notable announcements in its supply chain for electric vehicle (EV) components. First, a joint venture with Posco to build a cathode manufacturing plant in North America, and next a second supply agreement with MP Materials to ensure access to rare earth magnets used in motors. While we've seen several automakers invest in upstream battery materials production and sign offtake agreements for raw materials, the investment in rare earth magnets is one of the first for an automaker. China's control over rare earth magnets has pushed many automakers to move toward less efficient induction motors.

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16 December 2021
VW announces slew of investments highlighting concerns over battery supply chains

Very Important | Stationary storage

VW announced an offtake deal with Vulcan Energy Resources for CO2-neutral lithium, a joint venture with Umicore to produce cathode materials, and an investment in semisolid battery developer 24M. VW's investment in 24M is a long-term one, with the potential to adopt 24M's technology toward the end of the decade, but the most notable partnerships are the two upstream-materials-focused ones with Vulcan and Umicore. Electric vehicle adoption has accelerated rapidly, causing shortages and price spikes in raw materials, and the largest companies are investing further upstream in not only batteries but also electrode and raw materials production. A rapid increase in automakers investing in upstream battery materials is expected to continue.

Key drivers for the battery recycling market

By the end of 2020, 17.6 GWh of Li-ion batteries had reached their end of life; by 2035, this figure will grow to more than 140 GWh. However, existing battery recycling infrastructure is not optimized to either handle end-of-life battery capacity or meet critical materials demands placed on the market as electrification ramps up.

While China's dominance in battery manufacturing gives it a head start in recycling, North America and Europe are seeing increasing capacities to ensure future materials security by establishing a local recycling infrastructure.

Based on these factors, new technology developments improving the recovery of materials from spent batteries are emerging. In addition, collaborations across the value chain are creating new business opportunities for automotive OEMs, cathode manufacturers, chemicals and materials companies, and waste management companies.

Source: Redwood Materials

Battery recycling will play a crucial role as the first generation of battery vehicles comes off the road

More than 100 GWh of Li-ion batteries were deployed in BEVs and PHEVs in 2020, and that number is expanding rapidly. As those batteries reach their end of life, they represent a large environmental risk and contain valuable metals that can be recovered via recycling.

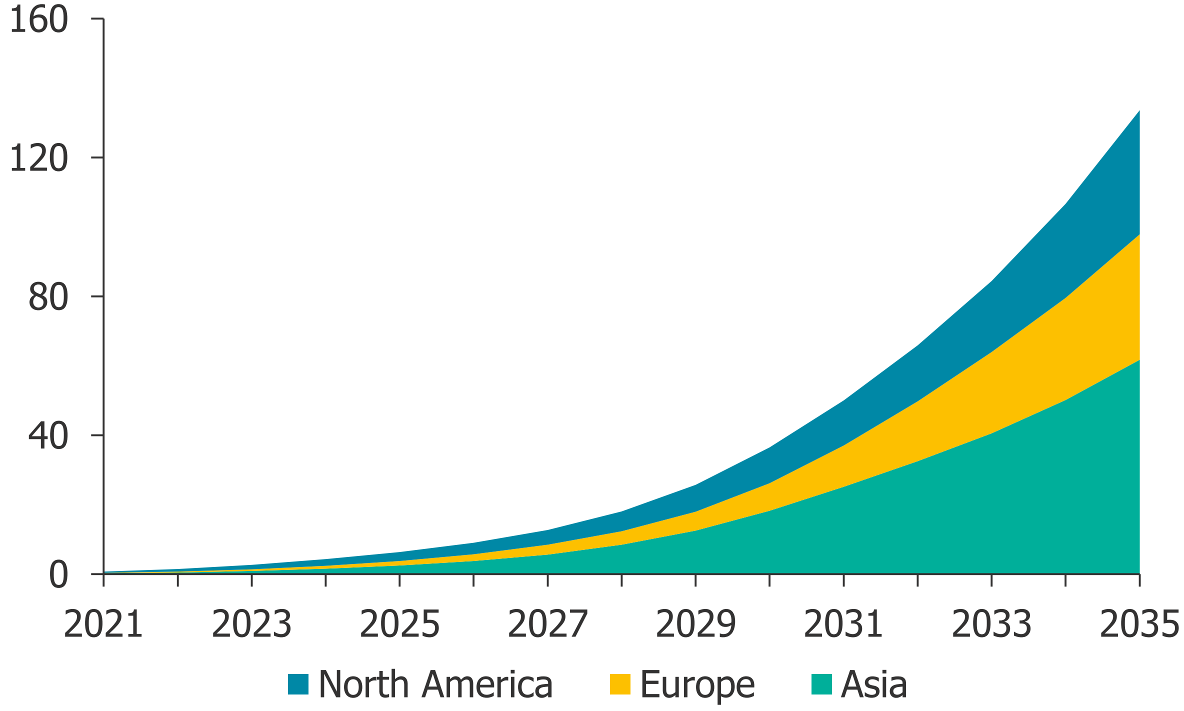
By the end of 2020, more than 100,000 tons (17.6 GWh) of batteries reached their end of life; by 2030, this will represent more than 1 million tons (about 150 GWh).

Although the supply of waste batteries only represents 2% to 3% of cumulative energy storage demand, it still creates an opportunity for OEMs, cathode producers, and chemicals companies to create value from end-of-life Li-ion batteries.

However, existing battery recycling infrastructure capacity is neither well-suited to effectively recover valuable metals found in lithium-ion batteries or of sufficient capacity to handle the volumes of batteries that will be placed on the market as electrification ramps up.

Forecast of Retired BEV and PHEV Li-ion batteries

GWh



BATTERY RECYCLING: KEY DRIVERS

The driving factors for recycling development are numerous

While Li-ion batteries can be recycled using the traditional smelting methods common for other battery chemistries, many players in the value chain have moved to establish specific technologies to recover a larger percentage of the battery at a higher quality. Supply chain constraints are only a very small portion of what's driving today's battery recycling industry; we've identified the top three factors contributing to its accelerated development:

- **Policy** is emerging as an important safeguard against environmental hazards associated with battery disposal. In most geographies, end-of-life Li-ion batteries are categorized as hazardous materials. Only in the past decade have countries begun to outline more specific regulations for Li-ion waste disposal and recycling.
- **Economic development** of recycling will benefit almost all players along the battery value chain. Regions without access to raw materials can take advantage of battery recycling by capturing waste batteries and reinjecting them into local battery ecosystems. Recycling activates involvement with various types of companies, which encourages further battery production network development.
- **Technology** for Li-ion battery recycling has improved in recent years, such that recyclers claim recovery rates upward of 98%. Companies are filing patents at an accelerated rate, and startups with improved recycling technology are raising substantial funding to scale up.

Regulators determine responsibility, while industry players will bank on economic and technological development

POLICY

In 2018, **China** introduced national policy outlining responsibilities for BEV battery recycling, assigning responsibility to automakers to find end-of-life solutions. The **European Commission** proposed a comprehensive battery recycling policy in 2020, which defines battery collection obligations and will require a minimum content of recycled material in new Li-ion batteries in the future. The **U.S.** continues to lag in establishing federal policy for Li-ion battery recycling; instead, each state is responsible for its own regulations.

ECONOMIC DEVELOPMENT

Li-ion battery recycling offers opportunities to regional economies by retaining materials for a supply loop. In Asia, where battery manufacturing dominates, recycling is located close to both the waste stream and customers. Most recently, Europe has been the most active in organizing partnerships across industry sectors. **The beneficiaries of such economic development are present throughout the value chain.** Battery recycling engages with precursor chemical producers, cathode manufacturers, cell suppliers, and automotive OEMs.

TECHNOLOGY

A growing number of end-of-life BEV batteries pose a technical challenge for battery recyclers to maximize recovery and efficiency. Recovered materials have a high value and can be sold into either commodity markets or to cathode producers. **Technology improvements can push recovery rates past 90%** and output higher-quality materials, which increases the revenue for recyclers. Technology is also focusing on increasing the **sustainability** of the process, leading to less wastewater and lower energy consumption.

BATTERY RECYCLING: KEY DRIVERS

East Asia's dominance in battery manufacturing gives it a head start in recycling

Compared to North America and Europe, the APAC region recycles 10 times more Li-ion batteries, and that rate will grow with manufacturing expansion.

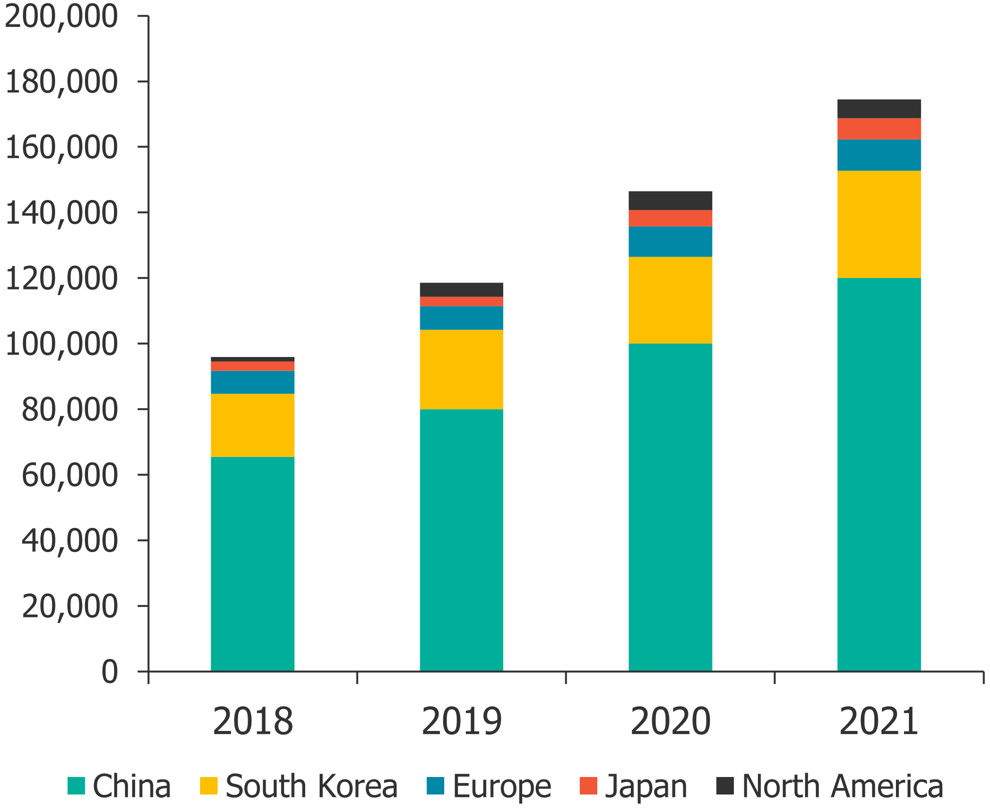
China. Top recyclers in China include Shenzhen Green Eco-manufacture (GEM), Quzhou Huayou Cobalt New Material, Ganzhou Highpower Technology, Hunan Brunp Recycling Technology, and Guangdong Guanghua Sci-Tech. In 2018, China banned the import of hazardous material, making it impossible to process other countries' batteries.

South Korea. EcoPro, the cathode material supplier for LG Energy Solution, is setting up a recycling in partnership with GEM. Similarly, POSCO is cooperating with Huayou Cobalt to process black mass in South Jeolla.

Japan. Although recycling capacity is smaller in Japan, the country participates in the development of recycling technology. Sumitomo Metal Mining is the largest Li-ion battery recycler in the country; Dowa is also currently operating recycling facilities. Toyota has been actively filing patents for improved recovery technology.

Li-ion Battery Recycling Rate

Tonnes of waste batteries



Source: Circular Energy Storage

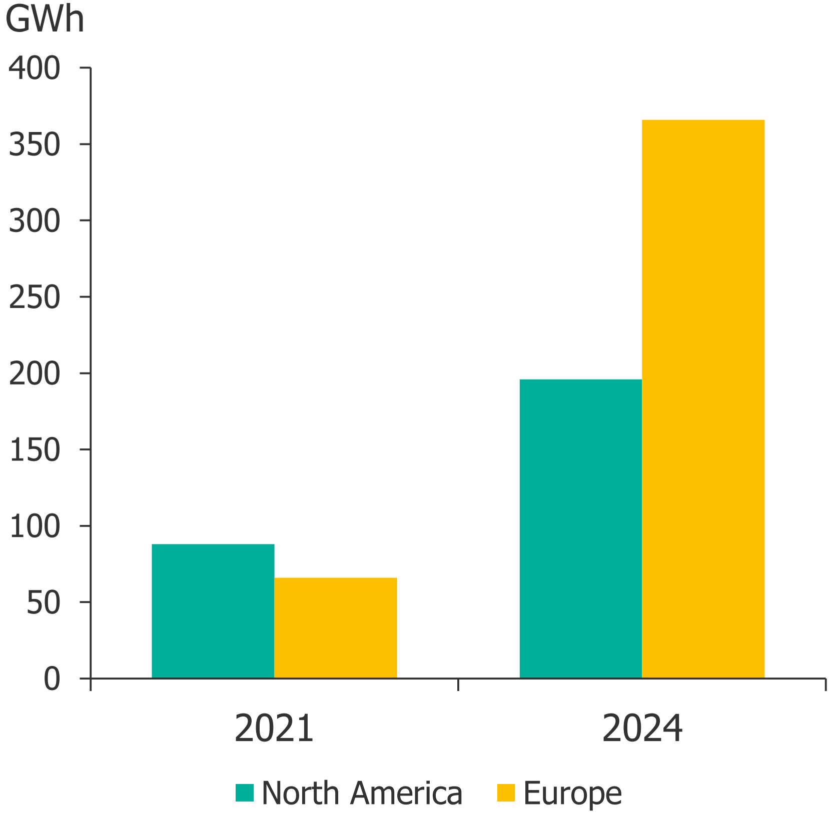
North America and Europe are building out recycling in anticipation of a developing battery industry

Historically, Asia has been the largest market for black mass processing, but battery recycling creates opportunities for regions with a less mature battery industry. As both North American and European battery industries look to decrease their dependence on Asia, recycling engages local players for materials processing and cathode production.

Europe is the second leading market for Li-ion battery recycling. The EU has proposed a comprehensive policy to manage battery end of life, requiring high recycling rates and recycled content quotas for new batteries. Europe is currently the second-largest region for battery manufacturing and will see a CAGR of 77% through 2024. In anticipation of a corresponding explosion in demand for battery recycling, Europe's interest in recycling reflects its limited involvement in upstream materials supply; instead, recycling would allow for the region to capture imported materials and retain them.

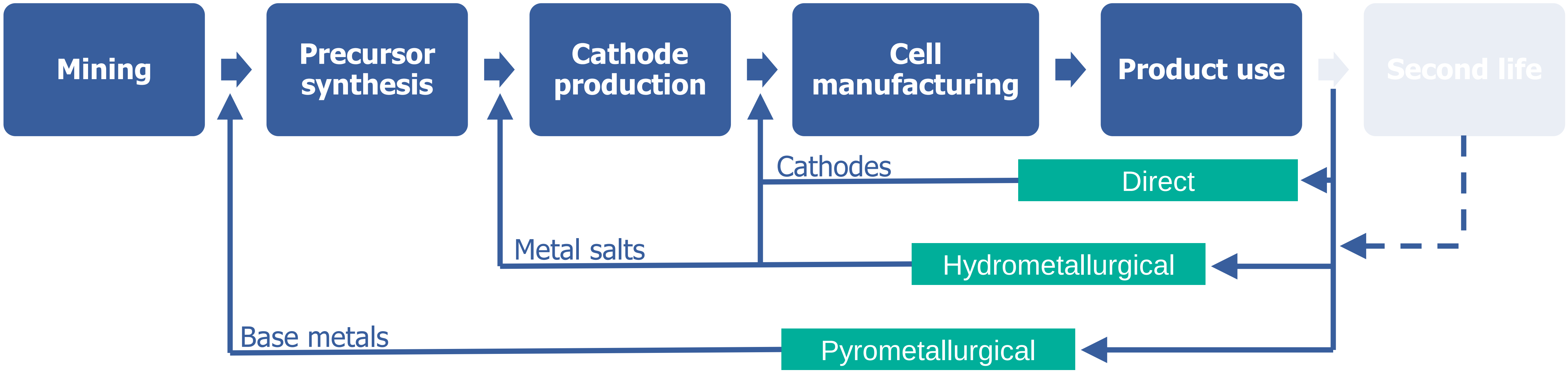
North America is building up recycling capabilities alongside its major manufacturing hubs. The region lags in battery deployment compared to Europe and Asia, so much of the market for recycling depends on consumer electronics and manufacturing waste. While the U.S. has more involvement in raw materials extraction, both domestically and abroad, recycling would encourage local cathode manufacturing.

Current and Planned Li-ion Manufacturing Capacities



Battery recycling technologies bypass steps in the value chain

For each recycling technology, the value of recovered material is directly correlated with how many steps of the Li-ion battery value chain it can replace. **Direct recycling** will recover the most valuable cathode material, which can directly be used for further cell manufacturing. **Hydrometallurgical processes** can produce metal salts for use in cathode production, given that the product is battery-grade purity, and other parts of the battery like anode material. **Pyrometallurgical processes** output base metals, which will often require further refinement in order to be reinjected into the battery supply chain. In all recycling processes, recovered materials that are not battery-grade are sold off to other materials companies for use in other industries.

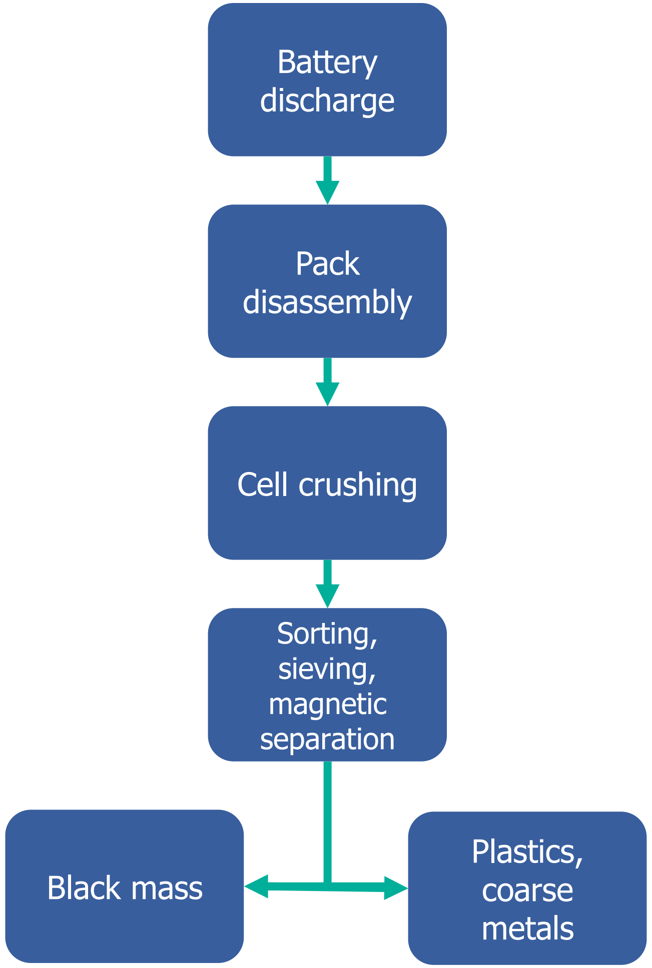


Innovation in mechanical processing is driven by the need to safely and economically deactivate the battery

Mechanical processing involves the dismantling of the battery and subsequent crushing of individual cells. Battery pack designs have yet to be standardized, so cells must be discharged and extracted from the packs by hand, with external housing and circuitry discarded. The cells then undergo removal of the electrolyte and separation of components, typically via shredding the cell and sorting. The resultant materials are plastics, coarse metals, and black mass – a composite metal powder that contains cathode and anode material, plus small amounts of aluminum and copper from current collectors.

Battery recycling companies differentiate themselves in mechanical recycling by utilizing different methods for cell deactivation and shredding. The two general methods are shredding under an inert atmosphere and shredding in an aqueous solution. The benefits of shredding under an inert gaseous atmosphere are that the cell materials remain dry and there is no wastewater treatment, though its specific atmospheric conditions make the process more expensive. Shredding in an aqueous solution is a more widely adopted process, mainly due to its lower cost.

The plastics and coarse metal products are sold off to other materials companies, while black mass is either further processed by the company that produced it or traded to another black mass processor. Black mass value is determined by the quality of the powder; the level of impurities and the content of valuable metals influence the market price of black mass.

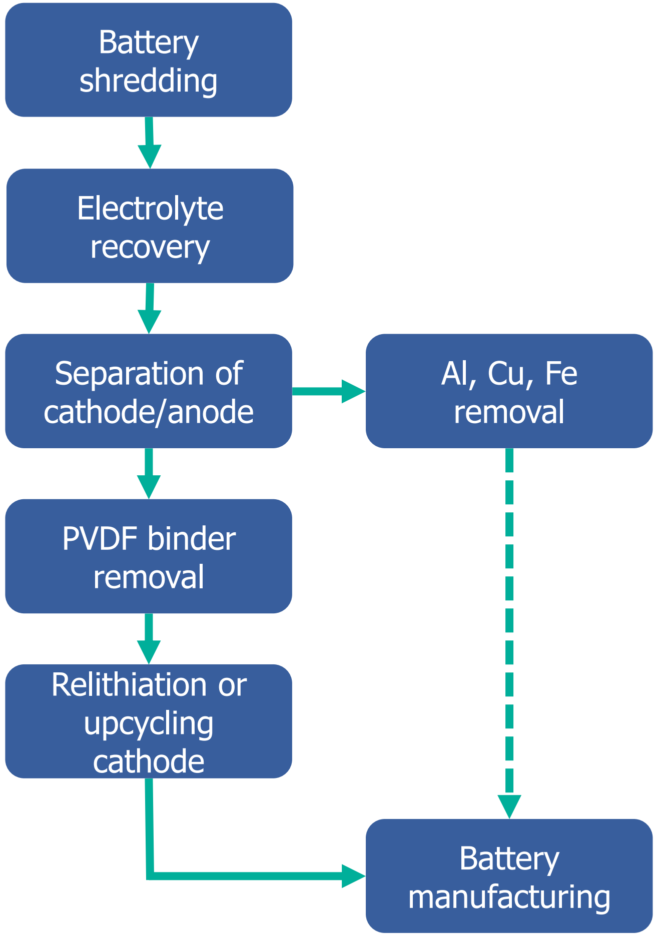


Innovations in direct recycling create opportunities to restore and upgrade spent cathodes

Direct recycling is the recovery, regeneration, and reuse of battery components directly without breaking down the chemical structure. The process can recover cathode materials directly by sorting batteries upstream to keep the electrode chemistry uniform.

After discharging the cells, the electrolyte is recovered by exposure to supercritical CO_2 under low temperature and pressure. The cells are shredded, separating the less valuable components, such as plastics and cell casing. The current collectors—copper and aluminum—are separated from the cathode and anode either using either gravity separation, leaching, or froth flotation. Farasis Energy, for instance, uses a selective leaching step during which the shredded cathode is cleaned off residual copper and aluminum in an alkaline solution.

Finally, the recovered cathode material undergoes a relithiation process, where a fresh source of lithium, typically in the form of lithium hydroxide, is thermally sintered with the recovered cathode to restore the cathode chemistry. While direct recycling can restore spent cathodes, another opportunity being explored in research is upcycling cathodes to more desirable cathode formulations. The ReCell Center, established by the U.S. DOE in 2019, is exploring relithiation steps to convert NMC 111 to NMC 622 by sintering nickel hydroxide and lithium hydroxide

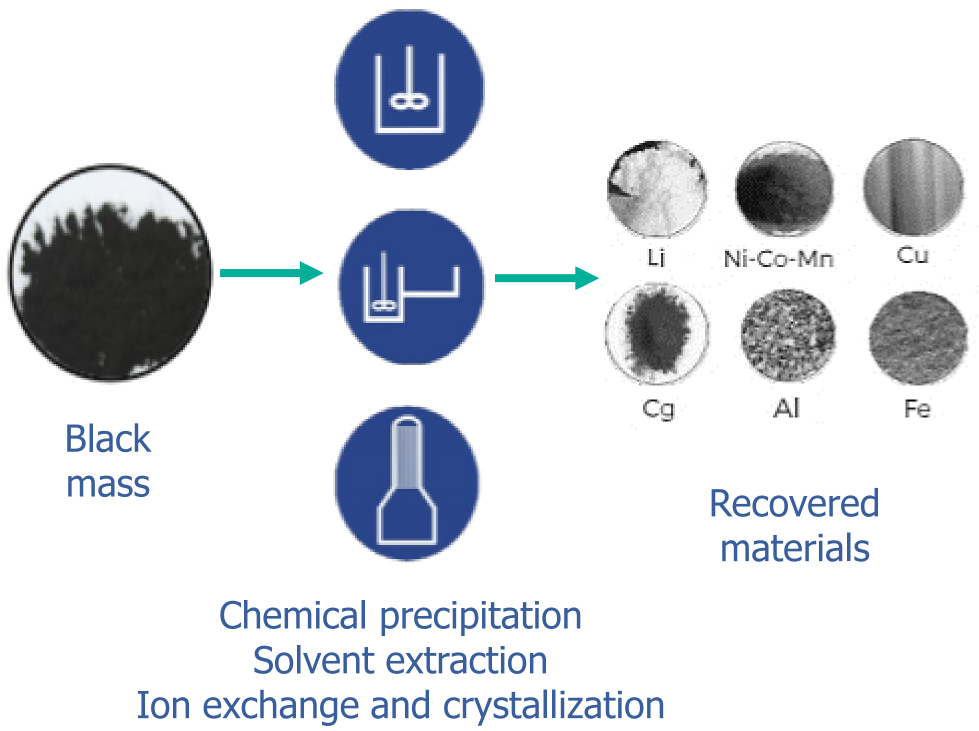


Companies are patenting hydrometallurgical processes, but trade secrets and process expertise are key success factors

Once the battery is shredded to a black mass, hydrometallurgical recyclers use acidic reagents to dissolve the black mass of battery materials into different constituents. The process recovers key metals as metallic salts (metal sulfates or hydroxides) through chemical precipitation, solvent extraction, or crystallization. Hydrometallurgy has a lower energy footprint than pyrometallurgy and can offer higher cathode material recovery rates as well as higher purity. Recyclers today boast recovery rates as high as 98%.

However, the technology has its challenges, including process complexity, selectively separating some elements (Co, Ni, Mn, Fe, Cu, and Al) in the solution due to their similar properties, and the amount of wastewater generated, all of which can add to the cost of recycling.

Hydrometallurgical processes have seen significant patent activity over the past decade. While recyclers have relied on trade secrets and process engineering expertise, **many companies today are patenting the entire process as well as the chemical compositions of the black mass**. For instance, Li-Cycle has patented the chemical composition of the black mass it produces as well as the subsequent chemical leaching/solvent extraction process.

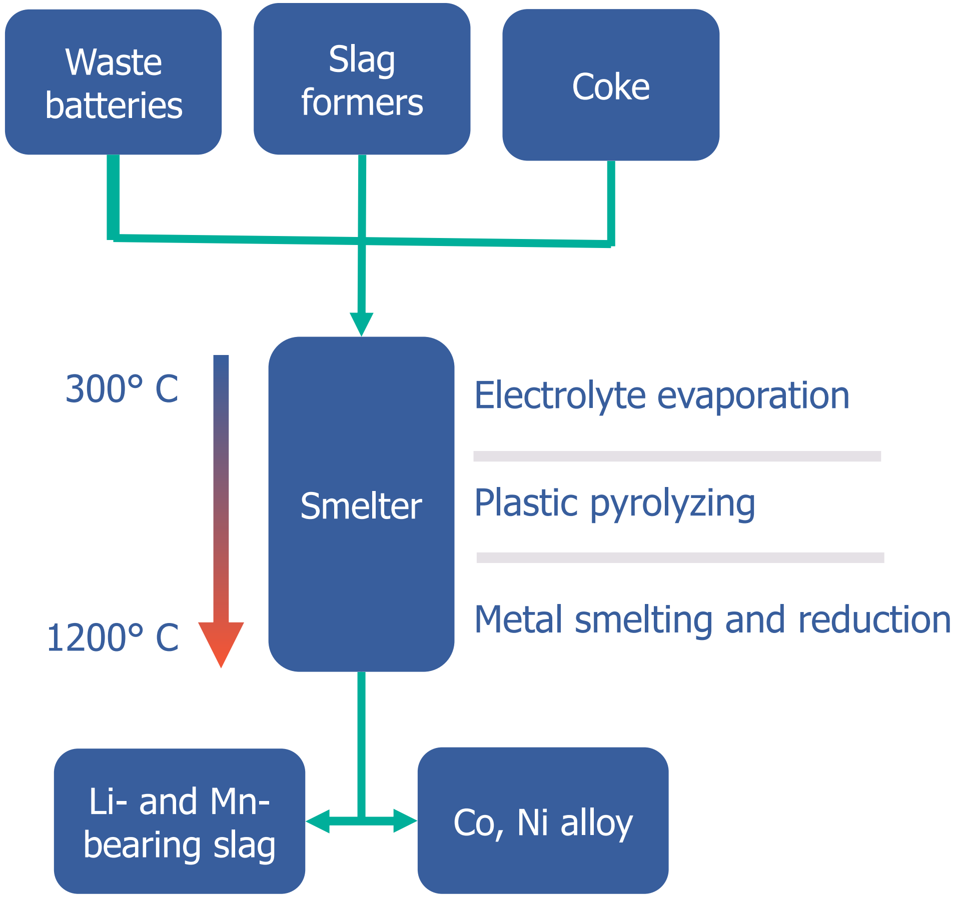


Innovation activity in pyrometallurgy remains low, but companies are experimenting with hybrid processes

Pyrometallurgy has been widely used for recycling nearly all types of batteries. It involves thermal treatment or smelting to decompose the components of spent Li-ion batteries. The process often includes two steps. First, spent batteries enter a furnace or smelter at a low temperature to avoid hazardous explosions and to evaporate the electrolyte at around 300 °C.

The battery then enters a pyrolysis zone at around 700 °C to burn off the plastics, while the remaining battery materials are reduced to an alloy of Cu, Co, Ni, and Fe and a slag containing Li, Mn, Al, Si, and some Fe. Pyrometallurgy is optimized to recover Co, while **Li and Mn recovery remains a key challenge in most pyrometallurgical processes**. Li and Mn are trapped in the slag of complex materials, making the recovery process uneconomical for most battery chemistries in the future.

As cathodes move toward lower cobalt content, the value of recycled batteries deteriorates. To make up for lower-value battery materials, recyclers are coupling pyrometallurgy with hydrometallurgy in a hybrid step to recover lithium as lithium carbonate and cobalt as an oxalate via an acid leaching step.



Waste collection and pack disassembly presents a logistical risk for many recyclers

Although recycling policy for Li-ion batteries is disparate and immature in most regions, near-universal restrictions on the transport of hazardous materials apply to spent Li-ion packs. Companies focused on hydrometallurgy or direct recycling have adopted a hub-and-spoke model: Pack collection and disassembly occurs within a network of smaller processing facilities, and the subsequently recovered materials, including black mass, are handled at a central facility.

Transportation costs add significantly to the cost of recycling, particularly when transporting spent batteries over large distances or between countries. Shipping hazardous goods adds to expenses, and each country may add further fees for import and export of spent batteries.

Manual disassembly adds to both labor and safety costs. With the numerous pack designs available for large-format Li-ion batteries, most recycling processes rely on an initial stage that requires people to sort through the packs and remove external components and circuitry.

Battery crushing or deactivation outgasses toxic chemicals, mainly due to fluorinated solvents in the electrolyte. One solution is to shred under an inert atmosphere, which can add cost, or in an aqueous solution, which requires further wastewater treatment.


Source: Oak Ridge National Lab

BATTERY RECYCLING: CASE STUDIES

Exploring technology opportunities in battery recycling

By 2030, the battery recycling supply will be rapidly accelerating but will require innovative recycling processes to obtain as many materials from the battery pack as possible. On the following slides, we explore three different technology examples of how companies are bringing these recycling technologies to market:

- While mechanical recycling is standard across most battery recycling steps, we will take a closer look at OnTo Technology's direct recycling process that can refurbish spent battery cathodes and maximize the use of manufacturing waste.
- Hydrometallurgical recycling is still at an early stage, but companies like Battery Resourcers and Li-Cycle are entering commercial-scale production. With improving rates of recovery and lower opex, hydrometallurgy is the second technology scenario clients should consider.
- Although pyrometallurgy has a lower innovation momentum than other processes, we explore Umicore's hybrid technology that improves recovery rates and extracts valuable materials using a traditional technology.

OnTo Technology LLC

BATTERY RESOURCERS

umicore

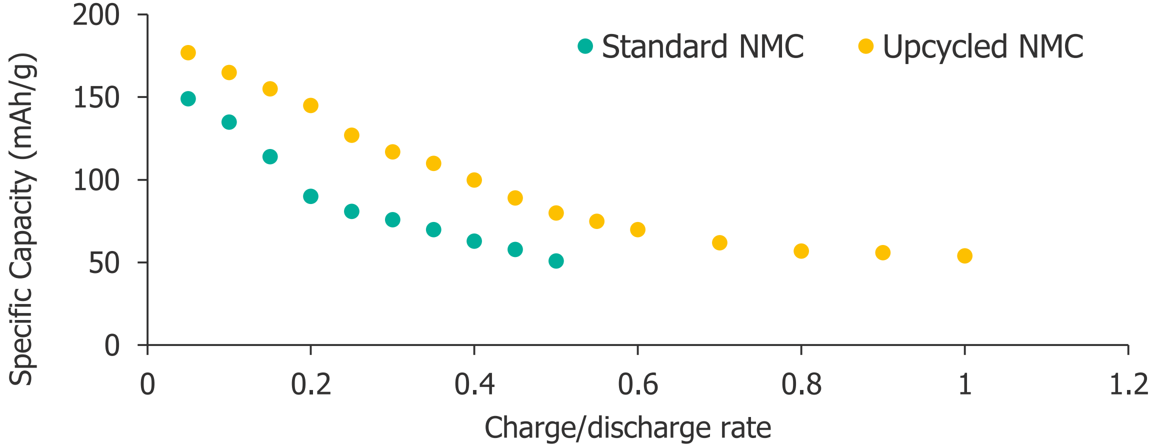
OnTo Technology leads innovation efforts in direct battery recycling

OnTo Technology was the first battery recycler to file IP on direct recycling, which is agnostic to cathode material type. The company recovers cathode materials by either disassembling the cell and scraping it off the current collector or shredding the battery and then sieving and separating the battery materials to isolate cathode materials.

OnTo Technology's newer innovations focus on refurbishing cathode materials or completely recycling the materials hydrothermally to relithiate and sinter cathode powders as electrode material for new cells. OnTo claims that its process costs about 60% less than pyrometallurgical or hydrometallurgical processes. The graph shows that the capacity and charge rate of the upcycled nickel-manganese-cobalt (NMC) cathodes match or exceed those produced via standard NMC cathode manufacturing.

OnTo Technology has been focusing on partnerships to license out its recycling and cell deactivation technology, including relationships with LG Chem and Nissan.

Discharge rate and capacity retention
Standard vs. upcycled NMC



Data source: [OnTo Technology battery rejuvenation]

LUX TAKE

Direct recycling reutilizes parts taken from used batteries, thereby conserving energy and materials that have already invested in manufacturing. Lux anticipates the greatest opportunity for direct recycling from manufacturing waste, where cell manufacturers can control the input waste stream in order to recycle the same cathode chemistry.

Battery Resourcers recycles cathode active materials into new battery cathodes

Battery Resourcers is focusing on a hydrometallurgical recycling process to produce battery-grade cathodes. The process begins with mechanical shredding and separation. The company then adjusts the chemical composition of the resultant black mass to match the desired proportions for the output cathode material. For NMC, this would involve adding specific amounts of nickel, cobalt, or manganese. Then the cathode material is coprecipitated out of the black mass slurry. Further precipitation is possible to recover other battery materials.

The technology is agnostic to input battery chemistry, and Battery Resourcers claims an improved recovery rate of 90%. The materials recovered by its process that don't meet battery-grade purity are sold to other companies for nonbattery applications. Battery Resources raised $20 million in April 2021 and plans to ramp up processing to 10,000 tons of waste batteries, from which 28% of recovered materials can go directly to new batteries, and 68% can be recycled into other products.

LUX TAKE

While most battery recycling companies will generate revenue only from sales of recovered materials, Battery Resources' differentiator is recovering materials to produce NMC cathodes as a product. Its recovery process can adjust different ratios of nickel, manganese, and cobalt, which allows a diverse stream of Li-ion batteries to be recycled, including LFPs.

Umicore improves on traditional pyrometallurgy with a hybrid process to improve metals recovery

Umicore employs a hybrid pyro-hydrometallurgical recycling process for spent Li-ion batteries. Starting with pyrometallurgy allows the company to be less restrictive about what battery chemistries can be combined in a waste stream compared to only hydrometallurgy processes. Umicore utilizes process design and furnace technology and recovers cobalt, manganese, and nickel salts after a subsequent hydrometallurgical leaching process.

The combined pyro-hydro process produces two outputs from the furnace: an alloy and a slag. The alloy contains Cu, Co, Ni, Li, and part of the Fe, and the slag consists of Al, Si, Ca, Fe, Mn, Li, and REEs. Slag from Li-ion batteries can be integrated into standard lithium recovery processes.

Umicore's 7,000 ton per year plant in Belgium can improve recovery rates over smelting to around 80%. In 2018 and 2019, the company signed partnerships with Audi, BMW, LG Chem, and Northvolt to expand its business across Europe. It plans to expand its capacity to 100,000 tons by 2022.

LUX TAKE

A pyro-hydrometallurgical approach to Li-ion battery recycling has potential to reduce energy consumption and improve recovery rates compared to traditional pyrometallurgy. If Umicore can achieve battery-grade recovery of lithium, the company would have a competitive advantage over others pursuing the same technology.

BATTERY RECYCLING: CASE STUDIES

Exploring technology opportunities in battery recycling

For years, Li-ion battery recycling has been dominated by larger companies with access to legacy metallurgical recycling technologies. As recycling establishes itself as an important piece of the Li-ion battery value chain, newer entrants with less experience in the field are forming partnerships to establish a presence. On the following three slides, we examine different approaches to forming networks that companies have used to build up Li-ion battery recycling capabilities:

- Waste management companies have experience with the logistics needed for collection and handling of hazardous materials but may not have the in-house expertise on recycling technology. By acquiring startups with the technology, TES made a swift entry into battery recycling.
- Large companies form consortia to benefit from the strengths of each member, and battery recycling can engage with players across industries simultaneously. We examine a consortium that includes Fortum, Nornickel, and BASF.
- Even with the best recycling rates, a battery recycling company won’t be successful unless it can prove out its technology at scale. Redwood Materials started strong by engaging with customers early and then building up scale processing.

TES

fortum

REDWOOD MATERIALS

E-waste recycler TES expands footprint into battery recycling with acquisition of Recupyl's IP and assets

TES is a global player in electronic waste recycling. Founded in 2005 in Singapore it offers services to technology companies, IT equipment providers, and electronics OEMs. Since its inception, TES' services have included takeback and transport of electronics and batteries to its processing centers in Asia. More recently, the company entered battery recycling to close the loop for its OEM customers, helping them acquire carbon credits and achieve sustainability goals.

In 2018, TES acquired French battery recycler Recupyl's assets and IP after it went bankrupt. The technology recovers Li, Co, Ni, Mn, Cu, and Al from Li-ion batteries (including LFP), alkaline, and zinc-carbon batteries. Recupyl developed one of the few processes today at scale that recovers Li from the electrodes as well as Li from spent electrolyte.

TES' second move into battery recycling was an investment in Singapore-based Green Li-ion, which the company claims can recover 90% of cathode metal salts with a 99% purity to be directly used in cathode production.

LUX TAKE

While automotive OEMs and cell manufacturers announce plans to move into Li-ion battery recycling, logistics remain a challenge for the industry. Clients shouldn't ignore traditional waste management companies like TES that are well-connected across the waste collection and recycling value chain.

Fortum, Nornickel, and BASF form consortium to develop closed-loop materials system

Fortum, Nornickel, and BASF announced a partnership in 2020 to develop a closed-loop materials system for Li-ion batteries in Europe. The cooperation will utilize recycling technology owned by energy company Fortum, BASF will use recycled materials for cathode precursor production, and Nornickel will install the recycling unit next to its nickel refinery.

Fortum acts as the technology supplier; the energy company acquired hydrometallurgical recycling company Crisolteq before the announcement. Crisolteq had a commercial-scale hydrometallurgy plant in operation, and in 2021, Fortum announced a $28 million investment to scale up its capacity.

Further engagement with BASF will guarantee that the products output by facilities operated by Nornickel will achieve battery-grade purity and will find use in cathode precursor materials. Nornickel will benefit by engaging with Fortum's energy expertise and developing more efficient nickel processing technology.

LUX TAKE

While automotive OEMs and cell manufacturers announce plans to move into Li-ion battery recycling, logistics remain a challenge for the industry. Clients shouldn't ignore traditional waste management companies like TES that are well-connected across the waste collection and recycling value chain.

Redwood Materials scales recycling capacity rapidly with reliable customer base

Redwood Materials is primarily targeting recycling of battery manufacturing waste. It counts Panasonic as a major customer, and its recycling facility is located near the Tesla/Panasonic Gigafactory in Nevada. Envision AESC is Redwood Materials’ second Li-ion manufacturing customer, also recycling scrap from its production facility in the U.S. Amazon uses Redwood Materials as an e-waste and consumer electronics battery recycler.

Starting in 2019, Panasonic started a pilot program with Redwood Materials to recycle its manufacturing waste, and it now processes all waste from the Gigafactory. As of 2021, Redwood Materials had a recycling capacity of 45,000 tons per year, or in battery terms, 3 GWh per year. The company is expanding its capacity by expanding its current facility and building a second plant next to the Panasonic factory in Nevada.

LUX TAKE

Redwood Materials’ early access to customers and proximity to battery manufacturing have given the company a competitive advantage. The management team’s extensive industry knowledge was key to its rapid growth, proving that battery recycling requires a strong network across the battery value chain.

Widespread battery recycling adoption is hindered by technology limitations and uncertain profitability

Despite a flurry of activity in the past few years, battery recycling remains limited by both technological and economic factors. The industry has historically been buoyed by high-cobalt-content consumer electronics batteries; as BEV batteries begin dominating Li-ion waste streams, recyclers will have to process diverse cathode chemistries at higher volumes. The main barriers to battery recycling in the near term are:

There's an immediate need for technology and process innovation. Current battery collection infrastructure and recycling technology are not optimized for cost-effective reuse of valuable materials. Improvements in recycling rate, efficiency, and cost savings drive current R&D efforts, but integration into large-scale recycling will take time. As battery waste volumes increase over the next few years, the recyclers with the best technology will be the most competitive.

Diversity in EV batteries poses a challenge to large-scale adoption. While the current battery recycling infrastructure has focused on consumer electronics, whose batteries are nearly the same in size and material composition, the Li-ion batteries used in EVs lack standardization. The variability in design and composition poses a challenge for waste collection and sorting. It also makes it difficult to automate disassembly and recycling processes, requiring costly manual pack removal, pack disassembly, module removal, and cell separation.

The path to profitability is not guaranteed. The value of waste batteries lies in the recovered cathode materials. Recovered battery-grade metals fetch a higher price but require careful refining processes. Furthermore, less valuable cathode chemistries like LFP drag down the economic outlook. Regulations across the globe will force recyclers to accept high volumes of batteries, but it's up to them to make this profitable.

Every player across the Li-ion battery value chain will be affected by recycling

Mining → Precursor synthesis → Cathode production → Cell manufacturing → Product use → Second life

Mining companies have transferable metallurgical experience. Even by 2035, recycled materials will represent less than 5% of battery demand, so raw materials from mining will continue to be central to battery production. Miners have long operated pyro-and-hydrometallurgical plants and are well-versed in their technical challenges.

Chemicals and materials companies that produce cathode precursors will provide a source of demand for recycled materials. They will be able to work with recyclers directly to guide product specifications.

Cathode producers have a similar role to precursor materials companies; they work closely with recycling companies to provide specifications on cathode products. These companies will need to qualify recycled cathodes so that they perform like cathodes made from new materials.

Cell manufacturers will likely see the most benefit as battery recycling capacity grows globally. Less complex processes like direct recycling will help them capitalize on their own manufacturing scrap. Research and innovation in upcycling cathodes for more desirable formulations will also drive new recycling activity. Companies should look to startups that refurbish battery electrodes through minimal use of new materials and energy.

Automotive OEMs face pressure from policy and regulations that assign waste collection responsibilities to them. However, just as automotive companies are involving themselves in battery manufacturing, automotive companies stand to benefit from a robust recycling industry.

BATTERY RECYCLING: OUTLOOK

What are the markers of success in Li-ion battery recycling?

Recycling Li-ion batteries is a higher-stakes business than previous battery recycling efforts. Policy will promote high collection rates and assign responsibility for recycling to product integrators. Li-ion batteries will remain valuable throughout their entire lifetime, so recyclers are tasked with optimizing recovery. The following factors outline what is needed for success in battery recycling:

- **Strengthen partnerships** across the battery industry value chain. Recycling has been dominated by traditional e-waste recyclers. Automotive OEMs, cell manufacturers, and chemicals and materials companies, along with waste management companies, are announcing new recycling capacities in response to policy and the need to create a local recycling infrastructure to reduce their reliance on Asia's dominance in the market. Clients should expect to see more recycling activity in North America and Europe, as well as South Korea and Singapore, which are emerging as potential hubs in Asia.
- **Quality of recovered materials** will be a key area of innovation for recyclers as they seek to produce battery-grade metals. Technology will play a critical role in improving the purity and overall recovery rates of batteries approaching their end of life. Look to innovators like Battery Resourcers and Green Li-ion that promise purities over 99% for recovered cathode active materials to be used directly in cathode manufacturing.
- **Economical material recovery** is necessary to build a business case, but profiting from recycling isn't guaranteed. Recyclers should focus on high recovery rates for battery-grade nickel, cobalt, and lithium to maximize revenue. Because recycling is a critical part of the battery materials value chain, clients should focus on technologies that extract the most from end-of-life batteries. Both direct recycling and hydrometallurgy can produce cathodes, but hydrometallurgy currently offers a battery chemistry-agnostic recycling process, supplying high-value materials back in cathode production.

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Lux Research is a leading provider of tech-enabled research and advisory solutions, helping clients drive growth through technology innovation. A pioneer in the research industry, Lux uniquely combines technical expertise and business insights with a proprietary intelligence platform, using advanced analytics and data science to surface true leading indicators. With quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, Lux clients are empowered to make more informed decisions today to ensure future success.

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