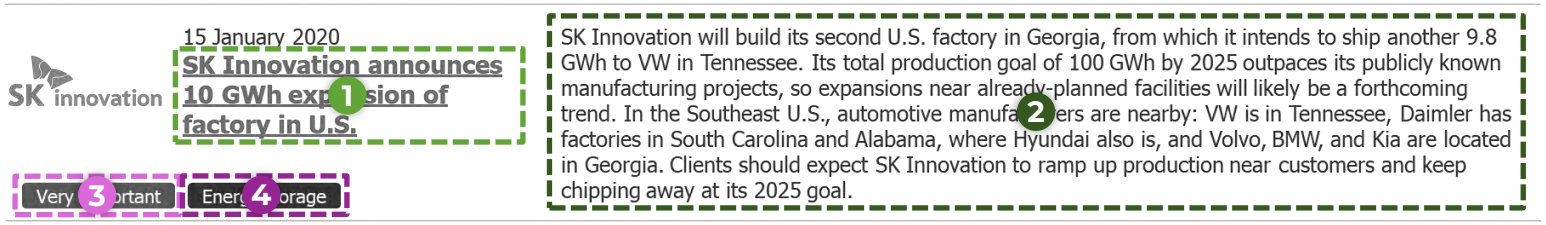
Singapore Battery Consortium Q4 2023 Newsletter

December 2023

SINGAPORE BATTERY CONSORTIUM

Understanding curation of recent industry developments and technology news

Recent industry and technology news are specifically curated based on the relevance to the progression and impact on the battery industry. Each news event is categorized based on importance as rated by Lux's subject matter experts and area of focus (see below for description for both).



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
Strategy and regulations	Strategic developments as well as policies with transformational impact on new battery technology developments
Battery developments	Technology developments in electrochemical energy storage, such as Li-ion and solid-state batteries
Electric mobility	Battery deployments for powering road, rail, aviation, and shipping – includes movement of goods and people
Residential energy storage	Hardware and software technologies for commercial and residential battery applications
Stationary storage	Utility-scale and long-duration battery storage for grid services and renewables integration

Tapping into novel and non-critical materials for cathode and anode developments remains a growing area of interest for the industry

Lawrence Berkeley National Laboratory set to commercialize cathode material made of rock salt

Low Importance | Battery developments

Lawrence Berkeley National Laboratory researchers have proposed using rock salt as cathode material to eliminate the need for nickel and cobalt. The researchers suggest that rock salt structure has a specific pattern, and it can be used with any transition metal to form a disordered structure, enhancing materials' electrochemical properties, especially energy density. It already has funding from the the U.S. Department of Energy and claims the product can be commercialized within five years. Despite its funding and a consortium of 50 scientists, the proposal still lacks research maturity, and looking at the timeline of technology development in the battery industry to date, such claims seem far-fetched.

NOVONIX

Study backs improved sustainability of Novonix's dry-cathode production process

Average Importance | Battery developments

An engineering study has found that Novonix's dry particle microgranulation process to manufacture cathode eliminates the need to wash, filter, and dry materials before producing cathodes. According to a report from Hatch Ltd., Novonix's patent-pending technology produces no sodium sulfate as a byproduct, eliminates water need for core material production, and reduces power consumption by 25%, processing cost by 50%, and facility cooling water by 65%. Other cathode manufacturers, such as 6K and Sylvatex, have made similar claims, but Novonix is first to get a third-party review.

X-BATT®

X-BATT and Consol Innovations collaborate on coal-based anode materials

Ignore | Battery developments

X-BATT develops composite anode materials using polymer-derived ceramics (PDC), while Consol operates coal mines in the U.S. X-BATT's coal-based anode uses heat-treated waste coal and PDC, and the resulting material can be blended with silicon for higher capacity. The company has demonstrated 1,000 cycles to 80% capacity retention in 18650 cells. This activity is being stood up by the government and a mining company as both are looking to support domestic coal production, but the technology is unlikely to be disruptive enough to displace graphite. Clients should steadfastly ignore this joint venture unless it can offer a significant performance benefit over graphite.

Next-generation battery chemistries are on the cusp of commercialization as first-of-kind facilities are set for production

SQM Lithium Ventures taps emerging startups via new accelerator program

Average Importance | Strategy and regulations

Chilean lithium miner SQM launched a USD 40 million venture arm in 2022 to invest in early-stage startups and support emerging technologies across the lithium value chain through its accelerator program. SQM focuses on three areas: lithium assets, water efficiency, and mobility. It announced the first program cohort in June and a second cohort in September 2023. Given the growing demand for batteries and other lithium products in the next decade, companies like SQM are going to be responsible for not only expanding mineral operations but also doing so sustainably.

Separator coating of Li-metal batteries gets a commercial-size facility from Sepion Technologies

Very Important | Battery developments

Argonne-related company Sepion is moving forward into converting its pilot-scale separator coating facility to commercialize production. The company announced a 25,000 ft.^{2} production facility that will run 100% on renewable energy and increase Sepion's pilot separator coating capacity by 1,000-fold and its polymer synthesis scale by 100-fold. These materials will be used to manufacture Li-metal batteries, and the facility has the capability to produce 10-Ah pouch cells. Sepion will be one of the first to commercialize Li-metal batteries if successful, but higher production prices will still affect commercialization growth.

eVTOL manufacturer brings in Amprius' silicon anode cells as an electric aviation solution

Very Important | Electric mobility

Amprius has secured an order for silicon-based Li-ion batteries from an electric vertical take-off and landing (eVTOL) aircraft manufacturer contingent upon the successful testing and demonstration of the sample cells, which will be delivered by the end of 2023. In August 2023, Amprius unveiled a Li-ion battery with 400-Wh/kg specific energy at a 10C discharge rate and high-power output. These high-power cells provide the propulsion and power required for takeoff, cruise, and landing and are claimed to increase flight range by 50%. Amprius has one of the highest specific energies among its counterparts, but cycle life remains a significant barrier.

Recent surge in extreme weather events is renewing focus on leveraging stationary storage for energy resiliency and reliability

Volta Trucks files for bankruptcy as it struggles to raise funds

Average Importance | Electric mobility

Volta Trucks has begun bankruptcy proceedings in Sweden after failing to raise capital. The company attributes this to the bankruptcy of parts supplier Proterra and uncertainty over its unnamed battery supplier. The company also plans to file for bankruptcy in the U.K., where it had operations. The difficult funding environment has seen several electric vehicle startups go under, including Proterra, Lordstown Motors, and Embark, with others like Arrival struggling. Given that Volta had made progress up to the point of achieving EU certification for its 16-tonne vehicle, interested clients should explore possibilities of acquiring its core technology.

China's new graphite export controls send a warning signal to an unprepared battery industry

Very Important | Strategy and regulations

Starting December 1, 2023, the Chinese government will require special permits for exporters of three key grades of graphite essential for electric vehicle batteries. China has dominated global battery materials supply chains over the past two decades, including 90% of graphite supply. The new restrictions could disrupt battery production in other countries, forcing them to invest in local supply chains — which can take a decade or more to solidify. Expect innovation activity to pick up in graphite processing and for synthetic graphite production to gain traction.

U.S. to invest up to USD 3.46 billion in grid resilience and reliability

Very Important | Stationary storage

As part of the Grid Resilience and Innovation Partnerships Program, and funded by the Bipartisan Infrastructure Law, the U.S. will spread a USD 3.46 billion investment across 58 projects with a goal of 35 GW of newly installed renewable energy and 400 microgrids. The U.S. has struggled to incorporate the large amount of renewables into its aging grid infrastructure, and resiliency is becoming an increasing concern with more extreme weather events straining the grid. Clients should note the focus on both local energy systems and interregional transmission, which will not only ease deployments of future projects but also open up opportunities for developments in previously inaccessible places.

Critical minerals are quickly becoming a national security concern as nations aim to de-couple itself from current supply chains

Australia pumps AUD 2 billion into fund to de-risk critical mineral processing

Very Important | Strategy and regulations

The Australian government is adding AUD 2 billion to its funding of the Critical Minerals Facility, a mechanism to finance projects lacking private capital. Australia is a global leader in lithium extraction, with over 50% market share, but it lacks processing infrastructure, sending 98% of its lithium concentrate to China. Australia is investing hundreds of millions of dollars to stand up a refining industry to own 20% of refining market share by 2027. Australia is taking inspiration from the U.S. to de-risk mineral supply chains by funding early-stage technologies, mining, and refining projects. However, governments also need to implement policy measures to expedite permitting, alongside the essential financial support.

Nuvve could go bankrupt despite recent momentum in V2G

Average Importance | Electric mobility

Nuvve raised over USD 18 million in early 2021 but has since seen a stock price drop of over 90%. Now, the company seeks to raise USD 2 million by selling 13.7 million shares to a single institutional investor. Although this may seem strange, Nuvve had announced partnerships with Swell Energy and Cajon Valley School District to provide vehicle-to-grid (V2G) services using school buses in 2022. Utilities clients should not be discouraged by this announcement; more automakers are enabling V2G capabilities, and regulatory barriers to enable market participation are changing, making V2G commercialization more realistic.

Sodium-iron battery developer Inlyte Energy raises USD 8 million in funding

Average Importance | Battery developments

Inlyte's battery is based on a sodium-metal-hallide battery that also utilizes nickel, making the technology inadequate for low-cost energy storage. One year earlier, the company acquired Beta Research Ltd., which owned significant IP and processing equipment to make sodium-metal-hallide batteries. As part of an Advanced Research Projects Agency-Energy program, Inlyte is working to increase the cycle life of its sodium- and iron-based battery chemistry for commercial viability. When companies recycle old energy storage technologies, similar to what EnerVenue is doing, they tend to make a big splash early on, and Inlyte is no exception with its considerably large seed round; however, the technology will compete directly with Li-ion batteries and has significant ground to cover in terms of cost parity and systems integration.

Upstream mining companies and downstream automakers are becoming actively involved in the battery value chain

Volvo offering bidirectional vehicles, energy storage, and EV chargers

Very Important | Electric mobility

Volvo will offer energy storage and electric vehicle (EV) charging technologies and services through its newly launched Volvo Cars Energy Solutions. Volvo is also launching a new model of its EX90 electric SUV, which supports bidirectional charging through AC. Volvo's technology differentiates by enabling vehicle-to-grid (V2G) through AC, significantly reducing charger costs (one of the main barriers to commercialization). Volvo will test V2G in Sweden's residential market with distribution system operator Göteborg Energi. Utility clients should monitor the project, specifically looking at the type of grid services provided and the total number of participants.

Ionic is bringing a nanosilicon anode material production facility to Utah, U.S.

Very Important | Battery developments

Ionic Mineral Technologies, a partner company of Applied Minerals, announced plans to open a nanosilicon anode material production facility with a capacity of 2,000 tonne/y by the second half of 2024. This will be Phase I of a three-phase project with an aim to reach 20,000-tonne/y capacity in the last phase. The production process will include 15% silicon-to-graphite loading but is capable of 100% silicon loading if needed. Ionic's patent-pending process uses the nanotubular structure of the halloysite to produce nanosilicon using a metallothermic reduction method to reduce production time and improve anode capacity.

Altilium raises USD 2.5 million Series A to scale up recycling capacity and produce CAMs

Average Importance | Battery developments

SQM Lithium Ventures (SQM) invested USD 2.5 million in Altilium's Series A to scale up its demonstration plant and retrofit an 8,000-tonne/y solvent extraction-electrowining facility in Bulgaria to process black mass. Altilium plans to build its battery recycling and cathode active material (CAM) facility by 2027. The company plans to partner with corporates across the battery value chain, such as SQM and Marubeni Corporation, with which Altilium is exploring a potential joint development. Qualifying CAMs from recycled feedstock is a challenging and time-consuming process but can lead to a greater upside than simply recycling materials.

Novel critical minerals extraction technologies will be critical to meet the supply gap from incumbent mining capacity

Li-Cycle's struggles continue as battery recycler cites mounting cost of its hub project

Very Important | Battery developments

Li-Cycle announced it paused construction pending review of its long-anticipated hub. It cited increasing costs as the key factor. Li-Cycle disclosed that completing the hub would cost nearly twice the capital (up to USD 1 billion). While Li-Cycle has built several "spokes" — battery preprocessing plants — the hydrometallurgical hubs are central to its success. The company has stopped all its Canadian and European projects and cut staff. Set to lose USD 250 million in 2023, Li-Cycle has a massive battle for survival ahead. While it might be premature, in the event of bankruptcy, Li-Cycle's assets and IP are bound to be valuable to established chemicals and industrial players with recycling business.

Latrobe extracts magnesium from industrial fly ash; production facility set for 2024

Average Importance | Battery developments

Latrobe plans to use fly ash from coal-fired power plants in Australia as feedstock to extract magnesium through a novel leaching and pyrohydrolysis process. The company has collaborated with Tenova, a major player in minerals processing technologies, on development and plans to commence operations at a 1,000-tonne-capacity plant in 2024. While the availability of magnesium doesn't pose an immediate risk to existing applications, sustainable sourcing of materials and diversification of supply chains are two underlying forces behind localization and novel approaches developed by Latrobe.

ReElement Technologies plans critical minerals refinery for the U.S. market

Average Importance | Battery developments

ReElement Technologies completed a USD 44.9 million bond purchase from the City of Marion, Indiana. This incentive is tied to ReElement's agreement to develop a 42-acre campus in Marion — another example of U.S. states looking to attract battery recycling developers to boost the local economy. As part of the campus, ReElement will construct a rare earth magnet and lithium iron phosphate battery recycling facility. The facility will produce 5,000 tonne/y of lithium hydroxide/carbonate and 750 tonne/y of rare earth oxides. ReElement says its ligand-assisted displacement chromatography separates metal ions and a dilute acid washes out the critical metals for recovery for less than solvent extraction.

Sodium-ion continues to gain commercial traction as major battery manufacturers pursue it as the next option beyond Li-ion

Volvo to acquire Proterra's battery unit for USD 210 million

Average Importance | Electric mobility

Volvo won Proterra's bankruptcy auction and will take over the latter's assembly factory in South Carolina and development center for battery packs and modules in California. The acquisition still needs clearance from regulators and a bankruptcy court and is expected to wrap up early in 2024. Volvo plans to use the acquired assets to speed up its battery electric roadmap. Several electric vehicle (EV) startups like Proterra, Volta, and Arrival have been facing difficulties recently. This acquisition is a confirmation that Proterra's demise was not due to shortcomings in its technology.

Blink unveils bidirectional AC charger for the U.K. and Irish markets

Average Importance | Electric mobility

The EQ 200 delivers up to 22 kW of charging power and complies with ISO 15118 certification. Additional features include Wi-Fi, Ethernet, Bluetooth, and 2G and 4G connectivity, enabling interaction with home energy management systems. Blink primarily focuses on offering public charging hardware; with this product, the company is expanding its offering to residential customers. Unlike most companies offering bidirectional charging equipment, Blink differentiates by enabling discharging through AC instead of DC. Utilities should note that implementing AC reduces costs and could increase commercial adoption.

Northvolt predictably pursues Na-ion batteries in collaboration with Altris

Very Important | Battery developments

The cells have a specific energy of 160 Wh/kg and use Prussian white cathode material with a hard carbon anode. Altris previously disclosed its Prussian white material has a specific capacity of 170 mAh/g, which is identical to that of lithium-iron-phosphate, and cells operate at similar voltages. Northvolt's energy density claims align with Altris' developments, but clients shouldn't get overly excited until cycle life data prove the company has addressed the major hurdle for Prussian white materials.

Battery swapping looks to make a mark outside of China as an alternative to EV fast charging

U.S. Treasury releases guidance on IRA electric vehicle tax credits

Very Important | Strategy and regulations

Treasury has released more concrete guidelines about compliance to receive the full credit. EV batteries with components or critical minerals from foreign entities of concern (FEOC) are ineligible for the tax credit. In addition, half of the tax credit is only eligible if 50% of battery components are from North America, with requirements increasing every year. The other half of the credit concerns critical materials, noting that these can come from free trade partners. Although there have been concerns about automakers being able to achieve the ambitious requirements set forth, this announcement remains firm on banning batteries and materials from FEOC while prioritizing manufacturing in North America.

Ample's partnership with Stellantis could pave the way for EV battery swapping's commercial adoption

Very Important | Electric mobility

In 2024, a pilot program in Spain will integrate Ample's battery-swapping modules into a fleet of 100 Fiat 500e electric vehicles (EVs) used for car sharing. Ample mentions its technology can provide a fully charged battery in less than five minutes. Stellantis, one of the world's largest automakers, mentioned it can deploy the swapping stations in public areas within three days. This announcement is significant for the commercialization of the technology and while deployment times are aggressive, short installation times can be achieved as Ample's technology swaps modules instead of packs, allowing it to develop smaller portable stations.

Carrar ready to deliver immersion-cooled battery modules to Volvo for proof-of-concept project

Low Importance | Battery developments

After securing several manufacturing partnerships earlier this year, Carrar attracted attention from global automakers. It joined Volvo's CampX accelerator program and has just completed its first major project with the automotive OEM, suggesting Volvo is evaluating immersion cooling technology for use in either passenger or commercial vehicles. Although there is no update from Volvo about the project, it is a sign that Carrar is scaling production quickly to become competitive with Xing Mobility, Wattalps, and Exoès. While it is unlikely many automakers will adopt immersion cooling for passenger vehicles, acquisition or exclusive licensure are likely to be the main paths forward.

Second-Life EV Batteries

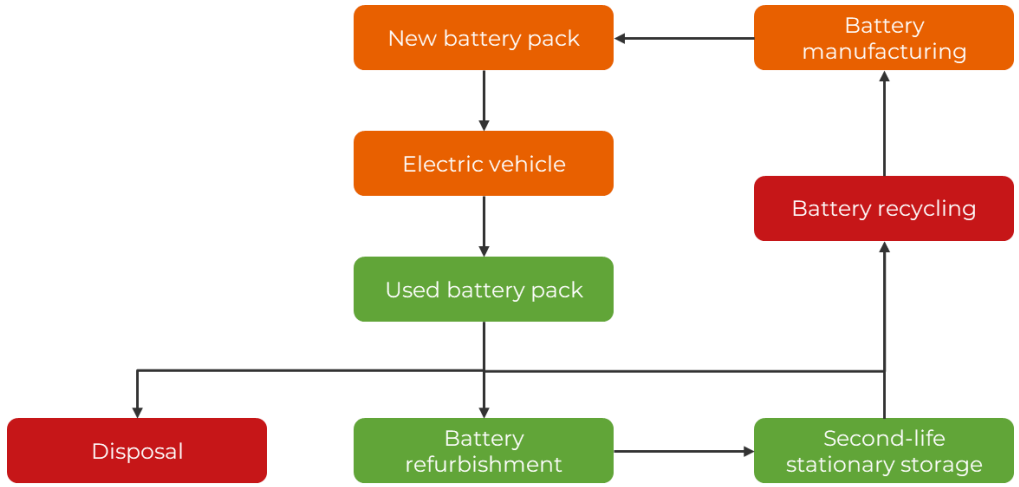
Image Source: Renault Group

Used battery collection and refurbishment remain the key bottlenecks in a robust second-life EV battery supply chain

Electric vehicle batteries are considered to have reached its end-of-life for automotive applications once it passes the 80% usable capacity threshold. However, the remaining capacity and performance of the battery depends heavily on the climate conditions, driving habits related to both acceleration and miles travelled, charging habits, and other external factors. Furthermore, there is a high amount of variance in form factor and chemistry between electric vehicle models – making simply grouping batteries together for stationary storage applications complicated.

Due to this variance several key, but costly steps are required between the procurement of “used battery packs” and “second-life application in stationary storage” and fall in two categories:

- **Repurposing:** Battery packs are collected and tested for sufficient remaining capacity and similar batteries are combined for a second-life stationary storage unit.
- **Refurbishing:** Battery packs are collected and disassembled to component modules and cells. Each module and cell are tested and reconditioned, if required. Similar cells are grouped and arranged into modules and repackaged into new battery packs.



Illustrative second-life EV batteries lifecycle from battery manufacturing to end-of-life.

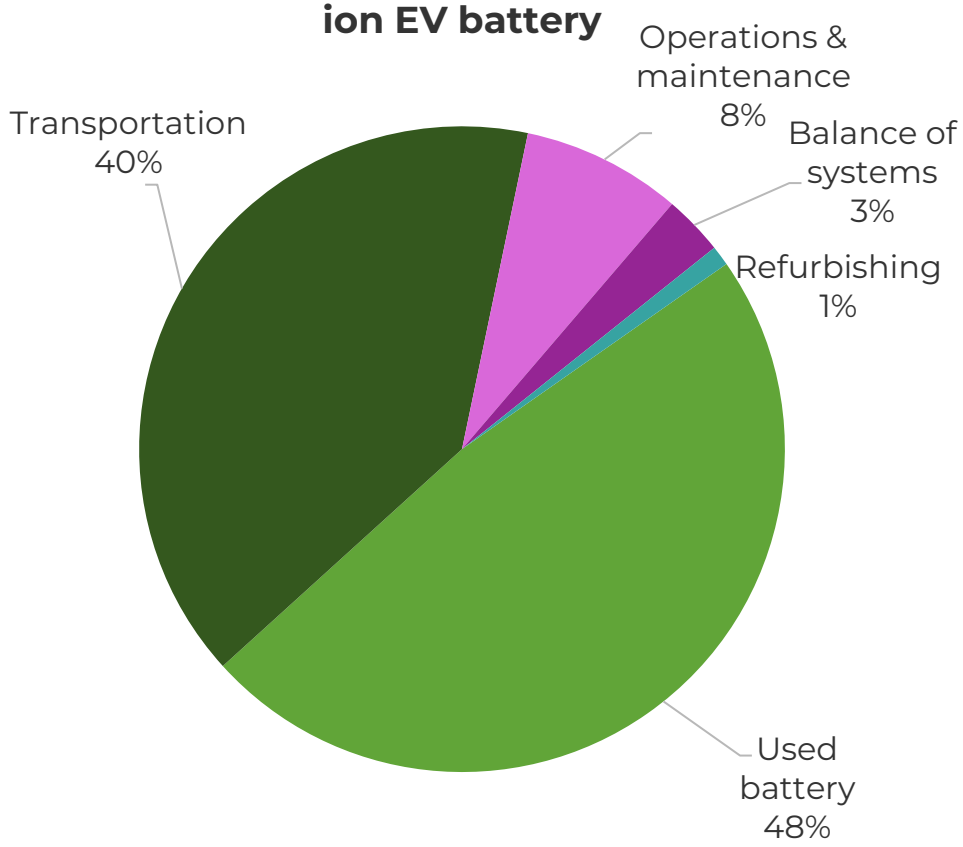
Transportation cost for second-life batteries have varied widely in studies conducted over the past decade

Li-ion batteries are typically regulated as hazardous materials and classified as "dangerous goods" in the U.S. under the Department of Transportation and in Europe under the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR), requiring specific containers, labeling, and stipulations for transporting new and collected batteries.

In addition, collection and delivery costs vary based on the collection distance from the source of the batteries and the repurposing facility. A 2011 study by Oak Ridge National Laboratory projected transportation costs to account for upwards to 40% of total second-life battery cost (right figure), recent analysis from Argonne National Laboratory's EverBatt attributes transportation cost to be significantly lower – between 5% to 10% of overall costs. **The wide range of modeled costs over the past decade is largely attributed to the current lack of supply chain for second-life EV batteries.**

The National Renewable Energy Laboratory (NREL) modeled in their battery second use (B2U) analysis three collection scenarios for 1 GWh of total battery capacity – local, regional, national – highlighting both the impact on cost for varying distances of transport and the potential economic optimization of a regional (515 km/load) supply chain. See the table on the following slide for scenario details.

2011 cost breakdown of second-life Li-ion EV battery



Source: Oak Ridge National Laboratory (adapted by Lux Research)

Annual transportation costs for handling 1 GWh of second-life Li-ion batteries highlights the potential for a regional supply chain

Scenario	Truck capacity	Truck cost	Roundtrip distance	Operating cost	Annual operating cost
Local	339 kWh	USD 62,000	48 km/load	USD 0.25/km	USD 35,832
Regional	2,613 kWh	USD 141,000	515 km/load	USD 0.31/km	USD 61,440
National	2,613 kWh	USD 141,000	3,862 km/load	USD 0.31/km	USD 460,800

Source: National Renewable Energy Laboratory (NREL); distances converted from miles to kilometers

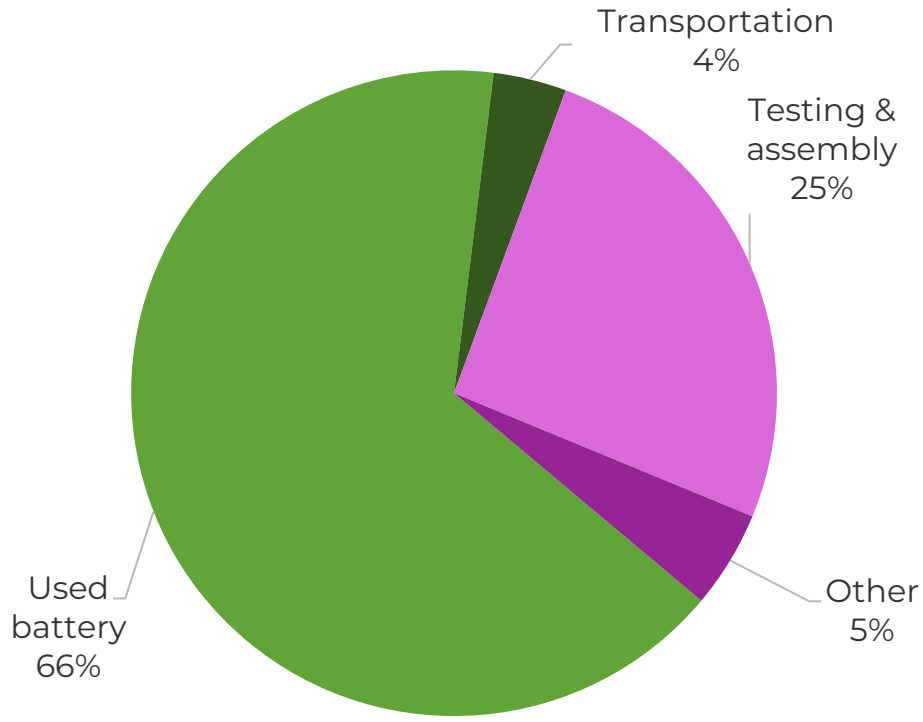
Despite past studies, transportation will likely account for less than 5% of total costs and be a minor cost barrier for second-life batteries

The latest analysis conducted via NREL's B2U model projects transportation costs at only 4% of the total second-life battery cost; approximately USD 3/kWh out of an estimated USD 82/kWh second-life battery price. NREL's estimation is based on an annual capacity of 1 GWh of batteries being transported via Class 8 container trucks with 2,613 kWh of shipping capacity per load in a regional collection scenario. The regional scenario specifies a repurposing facility based in Los Angeles, California with collection occurring in Los Angeles, San Jose, and San Diego. **Lux estimates transportation costs to be less than 5% of second-life battery costs going forward.**

Despite the currently nascent and fragmented supply chain for second-life-batteries where the collection and transport is largely owned and operated by individual repurposing companies, **transportation itself will likely be a minor cost barrier for second-life batteries.**

The emergence of a second-life battery market will be the key driver in a more robust supply chain. As the volume of used battery packs increases, **Lux expects automakers to a take a direct role in establishing the downstream portion of their supply chain – creating regional hubs for second-life Li-ion battery processing**, including both repurposing and recycling.

Cost breakdown of second-life Li-ion battery



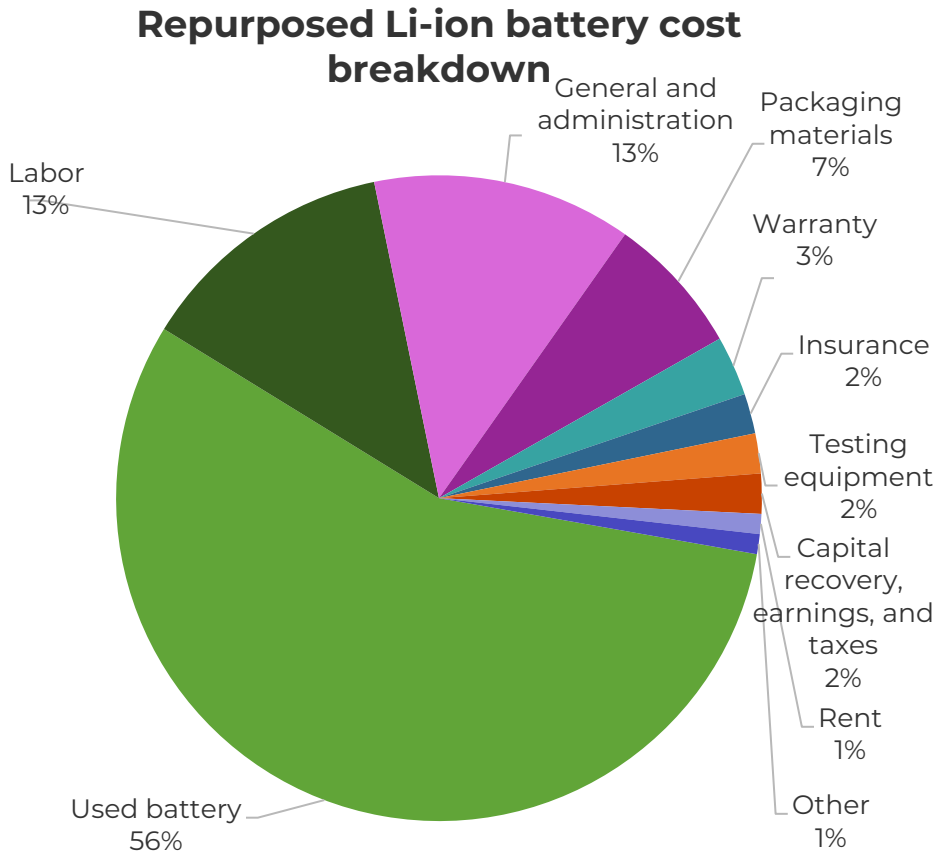
Source: National Renewable Energy Laboratory (adapted by Lux Research)

Falling prices for new Li-ion batteries play the largest role in bringing used battery cost below 50% of second-life battery prices

Based on review of academic literature since 2015, Lux Research found the **cost contribution from the purchase of used batteries accounted for 55% to 66%** of the total cost of second-life Li-ion batteries. While studies have shown the direct reuse of a second-life EV battery without repurposing or refurbishing can reduce overall costs by upwards to 30%, this outcome is very unlikely given the growing safety standards around Li-ion batteries. Martinez-Laserna et al. (2017) modeled a cost breakdown of second-life Li-ion batteries, highlighting the largely unavoidable costs not associated with the used battery itself (right figure).

In addition, NREL's analysis for a second-life battery price ceiling is a direct function of new battery prices, depth of discharge, and battery health – highlighting the correlation of second-life battery cost with the costs new Li-ion batteries. **With falling Li-ion prices, second-life battery costs will continue to decrease proportionally.**

New battery price	Depth of discharge	Second-life battery price
USD 250/kWh	60% 50%	USD 83/kWh USD 180/kWh
USD 150/kWh	60% 50%	USD 50/kWh USD 108/kWh

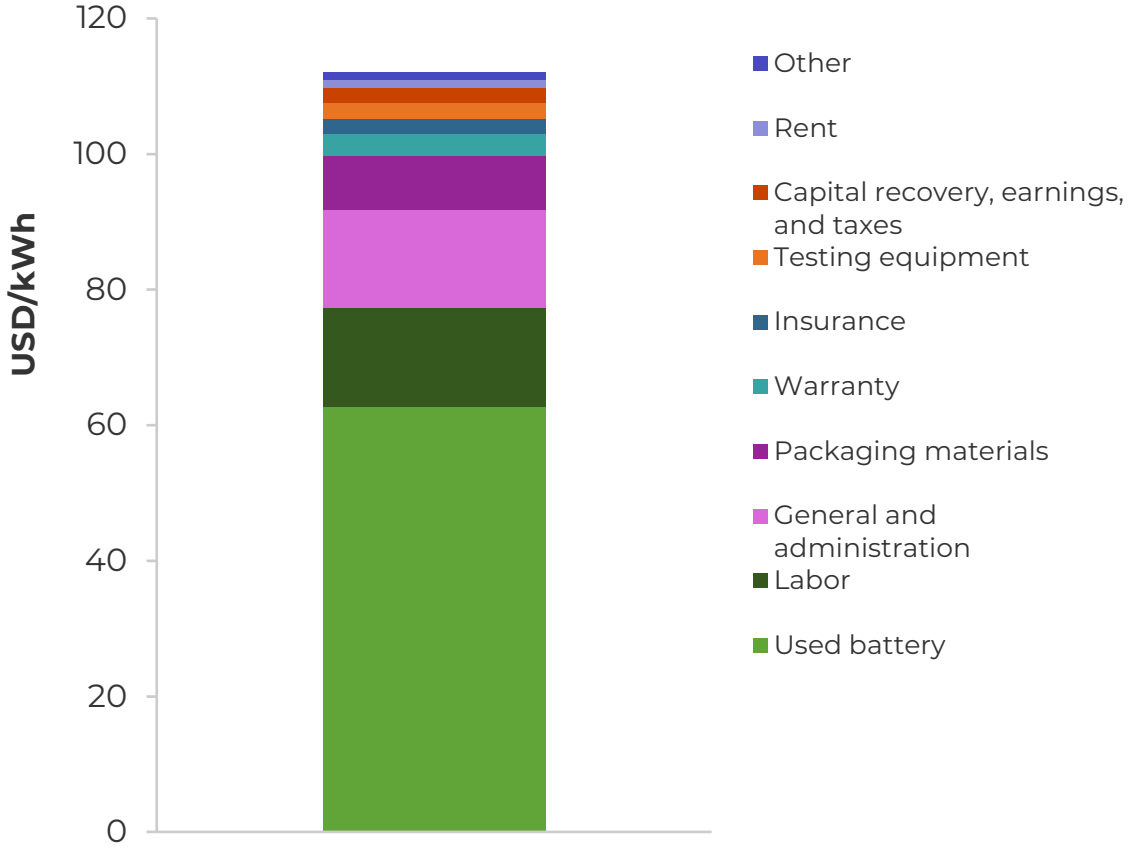


Source: Ikerlan Technology Research Centre (adapted by Lux Research)

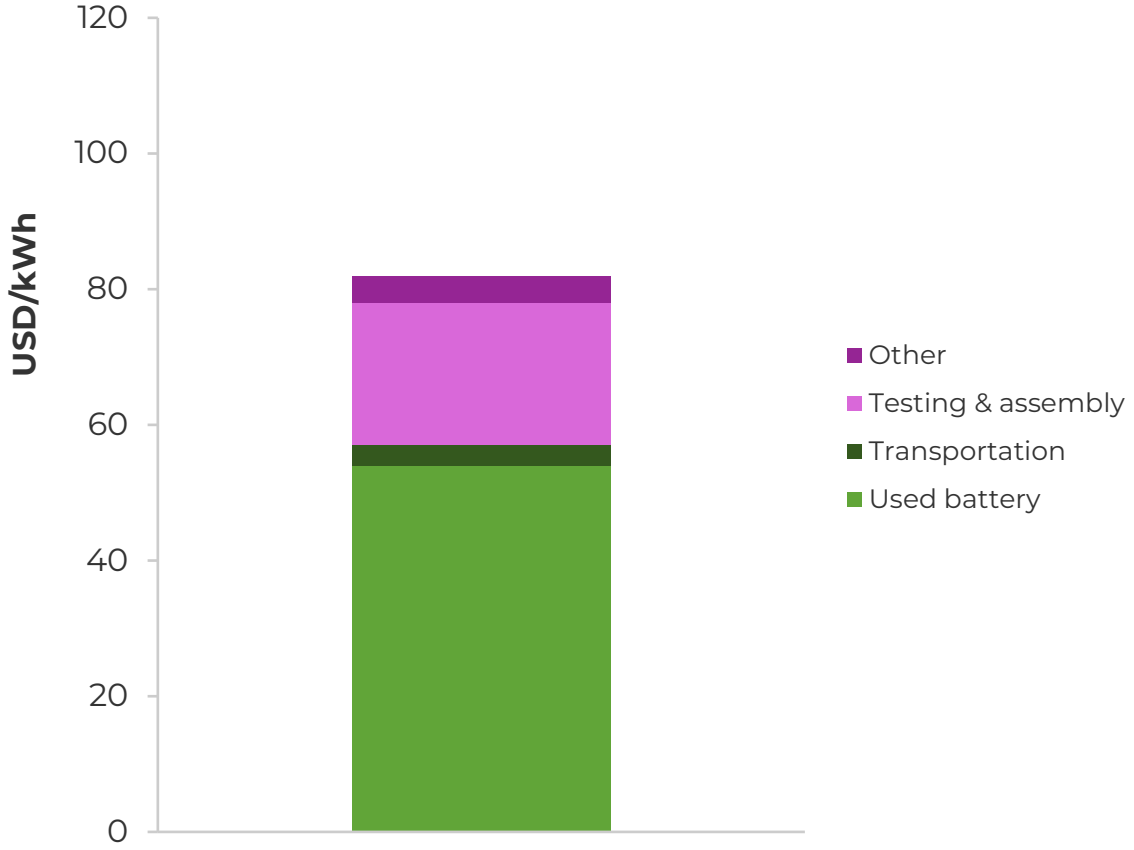
Source: National Renewable Energy Laboratory

Various estimates puts the range of cost for second-life batteries between USD 82/kWh and USD 112/kWh

Repurposed Li-ion battery cost breakdown (Ikerlan Technology Research Centre)



Cost breakdown of second-life Li-ion battery (National Renewable Energy Laboratory)



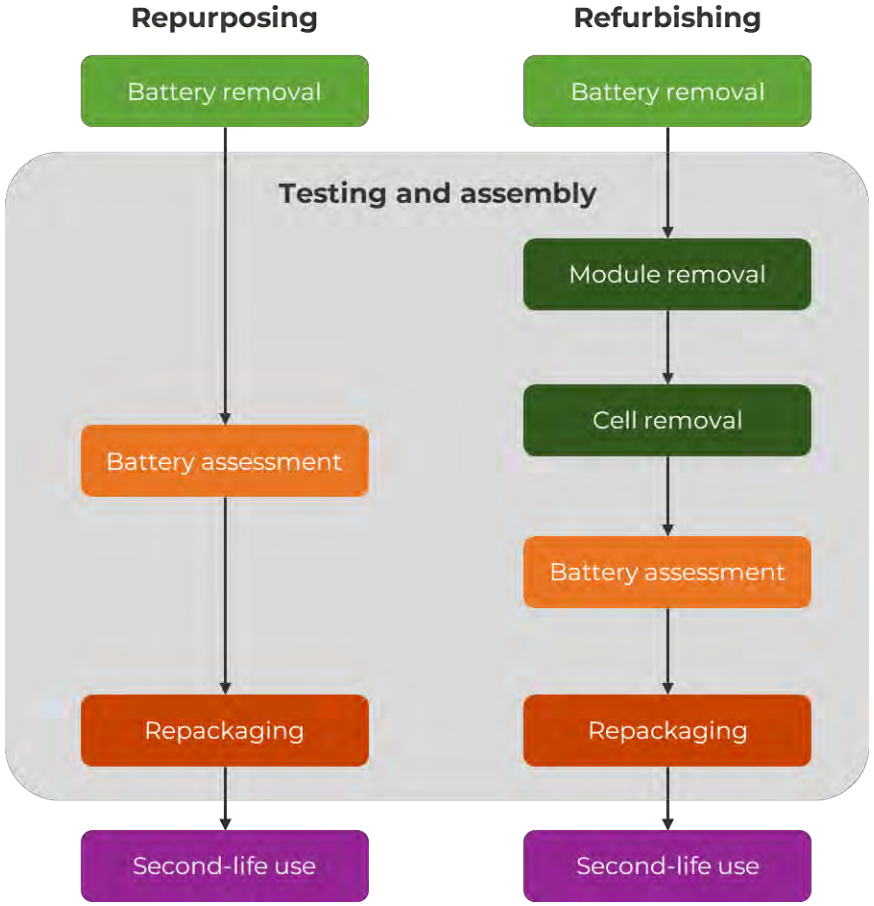
Above cost stacks are derived from the cost breakdown figures based on NREL's B2U analysis and Martinez-Laserna et al. (2017)

Testing and assembly of second-life batteries make up approximately 25% of total second-life battery costs

Regardless if the second-life batteries will be repurposed or broken down into its module and cell components for refurbishment, **the initial step in second-life preparation is the removal of the battery pack from the electric vehicle.** Costs are entirely associated to the labor of opening the vehicle and disconnecting the battery, typically accounting for around USD 6.50/kWh of the total second-life battery cost.

The testing and assembly (25%) of second-life batteries remains the key cost driver outside of the purchase price of the used battery (66%) according to NREL. Within testing and assembly, several steps occur in order to produce a viable second-life battery suitable for second-life use (i.e. stationary storage). The number of steps in the testing and assembly process is dependent on either a repurposing or refurbishing approach, with module and cell removal required for the latter.

Battery assessment is at the core of testing and assembly, with battery characterization requiring extensive labor and costs to determine the state-of-health (SOH) of the battery. Battery packs that fall below the minimum criteria can be further disassembled to select modules and cells that do fit the requirements.



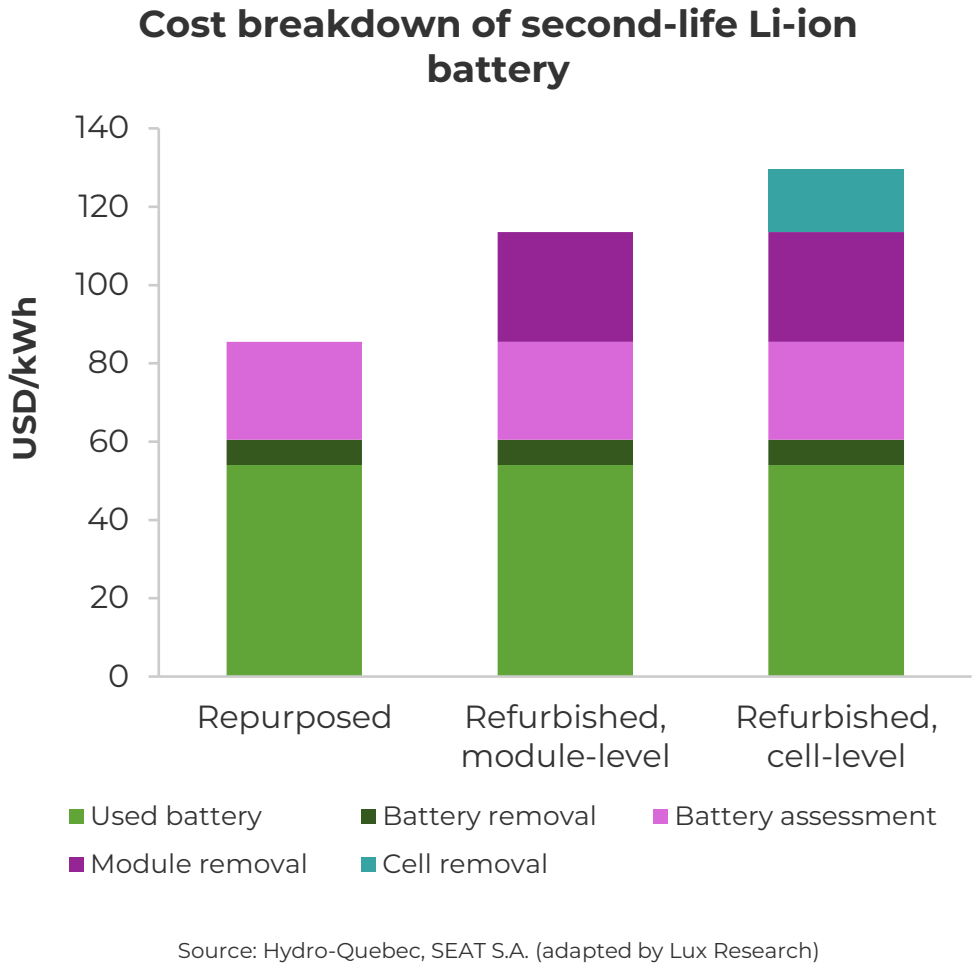
Illustrative process flow comparing testing and assembly steps of repurposing and refurbishing of used Li-ion batteries

Refurbishing second-life batteries is potentially cost competitive, but repurposing faces challenges with growing number of pack designs

Analysis shows that repurposed second-life batteries present an economic case with an approximate USD 85/kWh price. Refurbishing second-life batteries at the module- and cell-level are also cost competitive with an **estimated USD 113/kWh and USD 130/kWh price** – both of which are below new Li-ion batteries that are on average USD 132/kWh.

While the lower cost of repurposed second-life batteries is attributed to less labor-intensive processing, handling, and repacking of modules and cells, repurposing faces challenges as the variation of battery pack designs continues to increase. **Repurposing is only ideal when sourcing identical batteries in terms of pack size, form factors, and chemistry** for stationary storage applications given that multiple batteries will be required to be integrated into a single battery energy storage system.

In order to capitalize on the economic benefits of second-life batteries, the development of a supply chain that takes into consideration the make and models of batteries being collected will be critical. While the current electric vehicles largely use Li-ion NMC and NCA today, **more battery chemistry offerings in the market will exacerbate the complexities of the second-life supply chain.**



Source: Hydro-Quebec, SEAT S.A. (adapted by Lux Research)

CASE STUDY

Nuvve, University of Delaware, and BMW demonstrate second-life battery storage systems in regulated electricity market

Project Background

- The demonstration, led by the University of Delaware, was part of a larger initiative to address policies and regulations for the electricity market to allow electric vehicles (EVs) and second-life batteries to act as distributed energy resources.
- The project was registered with PJM, the largest electricity transmission operator in the U.S., at Nuvve's facilities at the Star Campus, University of Delaware, and deployed Nuvve's V2G GIVe platform.

Technical Specs

- Nuvve repackaged used BMW Mini E batteries for a 200-kW capacity stationary storage system, connected with two EV charging stations, and an aggregator at the University of Delware to participate in the PJM frequency regulation market.
- An open-source protocol aggregator technology is used to communicate with the second-life system, EVs, and charging stations. The technology also tracks energy needs of the EV fleet and monitors the grid-connection status for the charging stations.

Project Location	University of Delaware Newark, Delaware United States
Project Status	Began operations in 2019
Key Players	NUVVE, University of Delaware, TransPower, BMW

CASE STUDY

Nuvve, University of Delaware, and BMW demonstrate second-life battery storage systems in regulated electricity market

Key Differentiators and Commercial Aspects

- This project is the largest demonstration in a regulated electricity market to assess compliance with net metering and interconnection to manage trips.
- PJM participated as the policy-making stakeholder to understand the cost-effectiveness and ease of implementation, University of Delaware as R&D leader, and Nuvve provides their GIVe software platform to control multiple distributed assets.
- The demonstration cost was USD 227/kW, though faced challenges in backfeeding and was limited in its ability to participate in PJM's retail transmission market.
- Despite lower upfront capital costs, sourcing batteries for MW-scale demonstrations and managing regulatory standards of bidirectional interconnections will be a major hurdle.

Lux Take

Nuvve's platform provides access to performance data of the original vehicles, which may be advantageous in acquiring and assessing second-life battery health at the end-of-life of existing vehicles.

Source: University of Delaware

CASE STUDY

EVgo partners with BMW to launch second-life batteries to supplement DC fast charging stations

Project Background

- Following a successful pilot at the University of California San Diego, EVgo integrated second-life BMW i3 batteries into a public DC fast charging station. The batteries store off-peak solar energy from the grid and later use that to supplement EV charging during periods of high demand.
- While BMW provided the recycled battery packs, and technical support for installation, Princeton Power Systems provided inverter hardware and integrated them with the packs. Kisensum, now acquired by ChargePoint, developed and integrated software controls for the site-level demand charge management.

Technical Specs

- The charging station integrates two battery packs into a single housing, with each pack having a capacity of 22 kWh and offering a 30 kW/44 kWh energy storage system.
- To avoid demand spiking when multiple vehicles are charging at the same time, the energy storage system kicks in to reduce the grid load and, subsequently, the cost of charging during peak hours.

Project Location	Union City, California United States
Project Status	Began operations in 2018
Key Players	EVgo BMW Princeton Power Systems Kisensum

CASE STUDY

EVgo partners with BMW to launch second-life batteries to supplement DC fast charging stations

Key Differentiators and Commercial Aspects

- EVgo chargers in the first six months supplied 26 MWh of electricity, which equates to more than 3,300 gallons of gas and a total of 18 tonnes CO_2 of avoided emissions.
- Located in public parking lots, EVgo claims its charging stations have seen an average increase of more than 40% usage month-over-month since installation. EVgo has expanded its offering with four additional DC fast charging stations in Bakersfield, California to enable all-electric road trips between Los Angeles and Las Vegas.
- While EVgo's approach addresses the current fast charging demand, growth of EVs on the road will require additional stationary storage capacity. It also remains to be seen if and how the value from the stationary storage system will translate into economic benefits of the charging station.

Lux Take

While profitability remains challenging for fast charging network operators, EVgo's relationships with automotive OEMs and ride-sharing service providers put the company on a solid path for growth.

Source: EVgo

CASE STUDY

Audi targets MW-scale installations as a potential end-of-life solution for its growing electric vehicle fleet

Project Background

- Audi set the goal that 40% of all newly sold Audi models will be electrified by 2025 – equivalent to about one million EVs per year. This project aims to integrate EVs into the energy industry and create a network fostering wider applications of EVs beyond mobility.
- Audi has brought several partners on board, including The Mobility House, that is already working on V2G and Smart Grid projects on the EUREF campus for quite some time. Belectric has built the 110 m^2 facility that hosts 20 used Li-ion batteries sourced from Audi's test vehicles.

Technical Specs

- The 1.25 MW power, 1.9 MWh storage system uses 20 second-life Audi e-tron Li-ion batteries and tests various interaction scenarios between electric vehicles and energy grids.
- They started selling 1 MWh, sufficient to charge around 200 electric cars, to the Berlin medium-voltage grid, while the remaining 0.9 MWh serve as a safety net and to power the entire 5.5-hectare office and science campus with electricity for almost two hours.

Project Location	Berlin, Germany
Project Status	Began operations in 2019
Key Players	THE MOBILITY HOUSE, Audi, EUREF Campus Berlin, BELECTRIC

CASE STUDY

Audi targets MW-scale installations as a potential end-of-life solution for its growing electric vehicle fleet

Key Differentiators and Commercial Aspects

- This facility is Germany's largest multi-use energy storage unit that compensates for fluctuations in the grid and optimizes energy supply.
- Intelligent technology from The Mobility House controls the battery storage and interfaces with the electricity market, adjusting the charge and discharge of the system based on the requirements of the EUREF campus and grid.
- The project aims to use real-time insights for further diverse integration in grid applications, such as storing surplus electricity from renewable energies Northern Germany's wind farms.
- Location with economical renewable electricity will be vital for commercial viability of similar project. Moreover, regulatory support will be needed to implement electricity storage and supply standards.

Lux Take

Due to strong regulatory support, Germany remains a hotbed for energy storage projects. While The Mobility House highlights a potential 20% reduction in CO_2 emission,

Source: The Mobility House

CASE STUDY

Daimler and The Mobility house target grid balancing application with MW-scale installation with second-life batteries

Project Background

- The project is designed to compensate grid fluctuations by leveraging battery modules currently in "storage" that may be eventually used for electric vehicles.
- Getec Energie led the development of the energy storage system with Daimler and The Mobility House holding equal equity stakes in the project.

Technical Specs

- The 8.93 MW/9.8 MWh system consists of 1,920 battery modules that are bundled to create a "replacement parts store" for Daimler's fleet of third-generation electric Smarts. While in "storage" the batteries are available to the electricity market for grid balancing applications.
- This marks The Mobility House's fourth second-life battery storage project with the first two deployed in Lünen, Germany with a combined installed capacity of 20 MW/21MWh and the third begin operations in the same year with Audi.

Project Location	Elverlingsen, Germany
Project Status	Began operations in 2019
Key Players	THE MOBILITY HOUSE DAIMLER GETEC

CASE STUDY

Daimler and The Mobility house target grid balancing application with MW-scale installation with second-life batteries

Key Differentiators and Commercial Aspects

- Efficient dual usage of the battery systems improves the life cycle costs of e-mobility by adding value at the beginning of the vehicle battery life cycle by deliberate battery-conserving charging and discharging.
- The store hosts batteries by Daimler-subsidiary Mercedes-Benz Energy that are managed and controlled by intelligent software technology from The Mobility House before eventually marketed to the grid via Getec Energie that provides customized power and gas supply solutions.
- The company claims that after long period of use in a vehicle the capacity of a high-voltage battery falls below 80% of the original capacity, it can still be used effectively in second-life battery storage systems the economical value proposition is unknown and raise skepticism for the future.

Lux Take

Daimler's efficient double usage of battery systems claims to improve the life cycle cost of batteries. While a unique application of EV batteries, this remains a niche application centered entirely around Daimler's initiatives that would be challenging to replicate without an automotive partner.

CASE STUDY

Nissan and the University of Warwick explore improved grading and sorting process for end-of-life EV batteries

Project Background

- Partly funded by the United Kingdom's Department for Business, Energy & Industrial Strategy (UK BEIS), the project explores improved ways for grading and sorting used Li-ion batteries from Nissan LEAFs for second-life applications. In total, the project costs GBP 1.4 million with UK BEIS providing GBP 900,000 in funding.
- 50 Nissan LEAF batteries were used in the project at the University of Warick's Warwick Manufacturing Group department along with partners AMETEK and Element Energy, a testing instrumentation manufacturer and energy analytics company, respectively.

Technical Specs

- WMG developed an algorithm to characterize and test batteries at the pack level and improved ways of grading battery pack modules using electrochemical impedance spectroscopy (EIS) in as little as 3 minutes – a process which previously took over 3 hours.
- AMETEK manufactured specialized testing equipment and embedded WMG's technology into grading machinery. The demonstration was managed and coordinated by Element Energy.

Project Location	University of Warwick, Coventry, United Kingdom
Project Status	Began operations in 2019
Key Players	NISSAN, WMG THE UNIVERSITY OF WARWICK, ELEMENT ENERGY, AMETEK

CASE STUDY

Nissan and the University of Warwick explore improved grading and sorting process for end-of-life EV batteries

Key Differentiators and Commercial Aspects

- Rapidly sorting and testing EV battery packs are a critical step in streamlining the second-life battery supply chain and can potentially serve as a steppingstone for the UK's development of an end-of-life strategy for EV batteries.
- The project determined that modules with a SOH of >65% remain suitable for stationary storage applications and is currently expanding its capabilities to test upwards to 50 modules at once, compared to the current two during the pilot phase.
- AMETEK continues to refine its electrochemical impedance spectroscopy process with expectations the rapid grading and testing process can achieve a 30% reduction in costs over incumbent processes.

Lux Take

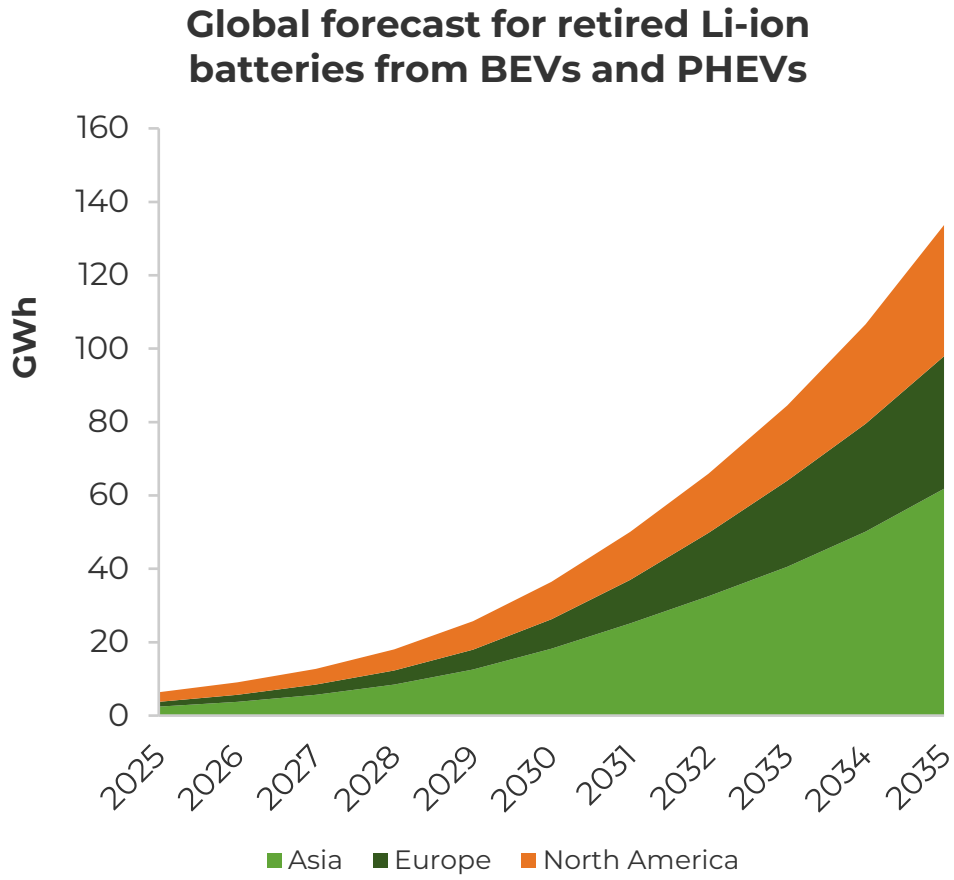
WMG has been able to reduce the grading time from hours to a few minutes per module, with a reported accuracy of ±3.2% for battery SOH. Developments in the grading stage has the potential to continue to lower the barriers of commercial feasibility of second-life batteries.

Source: WMG

Demand for local battery recycling infrastructure and emerging recycling technologies will accelerate battery recycling

Second-life battery use faces stiff competition from battery recycling as the two options compete for the **potential 134 GWh of retired Li-ion battery capacity by 2035** from battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). Battery manufacturers and automakers continue to expand into battery recycling, driven by three key factors:

- **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 and countries are beginning to outline more specific regulations for Li-ion waste disposal and recycling.
- **Economic development** of recycling will benefit all players along the battery value chain, encouraging further battery production network development. Regions without access to raw materials can potentially reinject recycled materials back into the local battery ecosystem.
- **Technologies** for Li-ion battery recycling has improved in recent years, with recyclers claiming recovery rates upwards of 98%. Companies, both large and small, are accelerating development and scaling up capacity with significant funding.



Global forecast for retired Li-ion batteries from battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) reaches 134 GWh by 2035.

Players across the existing Li-ion battery value chain benefit from the emergence of battery recycling, impeding second-life use cases

Chemicals and materials companies producing cathode precursors will provide a source of demand for recycled materials, working directly with recyclers to guide product specifications.

Cell manufacturers will reap the most benefit from the emergence of battery recycling. Directly recycling will allow them to capitalize on their own manufacturing scraps and innovations in more desirable formulations will drive new recycling activity.

Mining companies possess transferrable metallurgical experience, operating pyrometallurgical and hydrometallurgical plants.

Cathode producers work closely with recycling companies to provide specifications on cathode products, qualifying recycled cathodes for re-use.

Automakers face pressure from policy and regulations for handling end-of-life batteries and will benefit from a robust battery recycling industry.

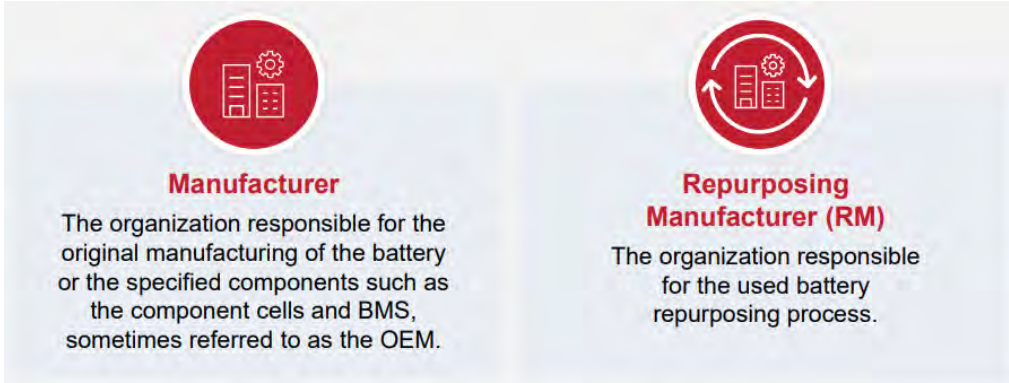
Second-life battery safety standards and evaluation protocol remains arduous for battery repurposing and refurbishing companies

In 2018, Underwriters' Laboratories (UL) released the first edition of "UL 1974: Creating a Safe Second Life for Electric Vehicle Batteries" specific to covering the sorting and grading process of battery packs, modules, and cells originating from EVs. While UL 1974 provides standards for the methods of grading and sorting, additional standards for second-life use, such as stationary storage require additional certification under UL 1973. In the process, the repurposing manufacturer are required to conduct the following:

- **Removal of all original manufacturer labeling and markings** – the repurposing manufacturer is responsible for the inherently "new" battery.
- **Documentation on the state of health of the battery** – this includes the battery, modules, and cells, which can be corroborated by BMS data, if available.
- **Visual inspection** – looking for visible damage, electrolyte leakage, traces of burning, damaged wires, and damaged casings and enclosures
- **Testing and validation** – batteries that pass the initial two tests are then required to be monitored for storage capability, grading, and general process testing for voltage, BMS controls, and discharge/charge cycling
- **Long-term data collection** – repurposing manufacturers are also responsible for long-term data gathering of repurposed cells to further improve battery characterization

Interest Category	Number of STP members
Producer	11 – 4R Energy Corp, Panasonic Corporation, Gogoro, Enel-X, Energy Moana Technology, Enersys, etc, from US, Canada, Japan and Taiwan
Regulator/AHJ	5 – Including New York City Department of Buildings, International Association of Electrical Inspectors
Government	3 – US Army, Pacific Northwest National Laboratory & National Research Council of Canada
Testing & Stds Org	7 – Including Laurie Florence from UL LLC, CSA Group, Intertek, etc, from US, China and Taiwan
Supply Chain	2 – BMW Group (Germany) & Rejoule Inc (US)
General	11 – Including University of California San Diego, Canadian Battery Association, Institutions, Associations and Consulting firms from US, Canada, China and Taiwan
Commercial & Ind'l Users	2 – from US and China

Technical panel consisting of stakeholders across the value chain for UL 1974. Source: UL



Second-life battery certification and responsibility fall on repurposing manufacturer. Source: UL

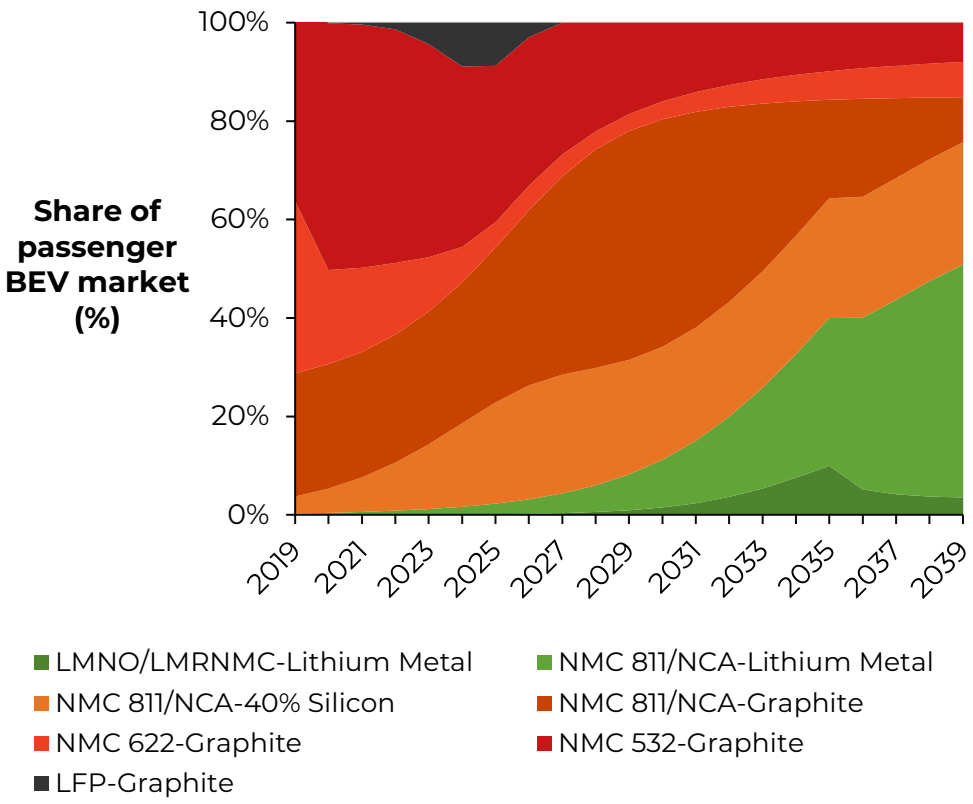
Continued innovations in Li-ion battery anode, cathode, and electrolyte materials leads to diversity in battery pack chemistries

Electrode innovation continue to offer the largest benefit to Li-ion batteries in terms of improving energy density and specific capacity. Further battery chemistry developments will also enable reduce pack costs and increase the number of applications for electrification. However, at the same time, **the introduction of various chemistries will make second-life battery applications more challenging** – with second-life manufacturers needed to source identical chemistries for repurposing and repackaging – **tipping the scales in favor of battery recycling.**

With lithium spot prices at an all-time high and production capacity expansion lagging projected demand from EVs, the Li-ion battery industry will seek lower lithium intensity chemistries. In result, **the Li-ion battery industry is expected to see a shift in battery chemistries in the share of the EV market post-2025.**

While current end-of-life operations continue to emerge, the diversity poses a challenge to large-scale adoption. Li-ion batteries continue to lack standardization and the variability in composition, as well as design, will make **downstream processes, such as disassembly, module removal, and cell separation costly as manual labor will likely to be required.**

Li-ion Battery Roadmap: Lithium Price Spike



Lithium price spike will drive technology adoption to less lithium-intense chemistries and suppress silicon adoption, leading to a diverse battery chemistry mix in the market

Numerous factors hinder the potential of second-life EV batteries for stationary storage system applications

Fragmented collection and refurbishment remains bottleneck in supply chain

Second-life batteries suffer from an immature supply chain and compounded by limited supply. A major bottleneck in second-life batteries is the efficient handling and testing prior to deployment as stationary storage system. Growing diversity in battery chemistries will further exacerbate existing challenges as third-party end-of-life handlers will need to adopt flexible technology platforms for handling, testing, and packaging second-life stationary storage systems.

Comprehensive regulations remains the key to unlock potential of second-life batteries

The volume of end-of-life batteries from BEVs and PHEVs are still limited, which has resulted in a lack of a second-life market and accompanying supply chain. One indicator of an emerging market will be policy and regulations, first from individual municipalities and then rolling up into federal-level mandates. Supportive regulations will also lead to a maturation of the supply chain, potentially streamlining collection, transport, testing, and deployments.

Recycling is poised to dominate end-of-life processing due to materials supply concerns

While Lux does not expect recycled battery materials to contribute significantly to overall battery materials demand, it provides an incentive to develop battery materials processing capacity. With growing battery material supply concerns and initiatives to increase local battery manufacturing, battery recycling will be one method to encourage a local battery value chain for the recovery of high-value materials.

Document prepared by Lux Research

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