



Renaissance superStorage™

recycling & second-life strategy

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summary

Everyday consumer electronics batteries are small in size and low energy, making it relatively easy for recyclers to treat them utilising well developed techniques. Conversely, large energy storage systems (ESS) batteries such as our superStorage™ platform can contain several hundred cells grouped in packs. Further, as an outcome of the standard commercial warranty, most of these systems will have between 60-80% initial energy capacity at end-of-life. Most ESS require significant disassembly to recycle, which is often complicated by non-standard design and disassembly procedures between differing battery manufacturers. Consequently, recycling of large lithium-ion batteries ('LIBs') has to date been much more complicated than smaller consumer electronic LIBs.

Our strategy is to address the recycling challenge up-front – in the design stage before the beginning of the batteries life – and to embrace existing fully and emerging battery stewardship guidance and legislation.

Specifically, the superStorage™ platform employs a deliberately standardised pack, rack and multi-rack design, regardless of the chemistry of power/energy performance. Each element in the platform (e.g. BMS, busbar, racking) has been designed to simplify disassembly and repurposing.

By employing standardised prismatic cell formats, we avoid manual dismantling and sorting (removal of plastics and casings) by standardising cell casing and assisting in the crushing, milling and selective separation of aluminium and copper.



Reducing sorting complexity

Mixed batteries need to be separated into pure waste streams and segregated by chemistry type before recycling. Given the potential hazards, time is typically required to sort spent LIBs in identifying cell chemistry types due to a lack of proper labelling or signage on the cells and related components. This means that the use of automated separation techniques such as AI and robotics is somewhat challenging. We address this by using uniform cell chemistry across our product range, and informing our battery recycling service providers of our cell chemistry prior to collection, which is then used to presort direct to recycling.

Our LIBs will have a unique QR code identification number to simplify record-keeping for battery waste management and the battery second-life community.

Simplifying the discharge process

Batteries in landfill or recycling plants can easily be damaged or short-circuited, which leads to the potential for fire or explosions. One way to mitigate this risk is to discharge the LIBs to a safe operating voltage before entering the waste stream for recycling. At present, this is not performed by the last person to use the battery before end-of-life. As a result, many LIBs in the waste stream contain significant energy quantities and potentially substantial fire risk. This fire risk is exacerbated when further disassembly is required.

Our proprietary battery management system will automatically trigger discharge recommendations toward the end of life or as degradation nears the limit to ensure safety during recycling and resource recovery operations.

Because of their high residual energy and physical size and weight, our batteries will be electrically discharged (rather than wet discharge). Today, the main difficulty is the wide range of different battery sizes and designs and a non-standardised electrical connection point on batteries. As battery stewards, we will ensure spent batteries are collected by appropriate battery recycling service providers, where energy will be discharged at their licensed processing facilities as per their internal processes.

We will also work closely with our research collaboration partner CSIRO, who has recently developed an electrical discharge system that can deal with batteries and readily fit into industry process handling. To offset the cost of deployment of such a system and improve the business energy sustainability, this battery discharge device is also designed to capture the electrons from the discharge process and feed them into the recycling plants' daily electrical loads. This function reduces the plant's overall electricity use, reducing the electricity costs whilst simultaneously improving safety and sustainability.

We address this issue by designing a plug-and-play industry standard prismatic cell format. This standardisation and industry-standard communications protocols dramatically simplify and reduce the cost of discharging technology.



Simplifying the disassembly process

For larger battery racks, the recycling process will be assisted by the ability to disassemble the batteries down to the pack, module or cell level. This allows the separation of the different battery components such as cells/modules from other hardware such as battery management systems, inverters, packaging, plastics etc.

We address this by investing in a design that standardises the rack, pack, Battery Management system and cell format (prismatic). This design may enable automation and robotics to follow pre-programmed repetitive actions to exactly known objects in fixed positions.

Simplifying the adoption of second-life batteries

After they have reached the end of their first designed helpful life, a battery's future use is termed its second life. SLBs can be profitably employed in a wide range of applications profitable including distributed node telecom backup power, decentralised mini and microgrid, residential and light commercial load following, power backup for generation asset outages, residential demand management including energy time shift and peak shaving plus PV, intelligent grid load dispatch, UPS, voltage support, wind generation grid integration for a short duration as well as T&D upgrade deferral. There are applications that research indicates will not be SLBs-viable, including load levelling/energy load levelling, energy power reliability plus peak shaving and wind generation grid integration for a long duration.

Battery performance assessment is critical to predicting how long and how well-retired batteries perform in second-life applications. Due to ER's Renaissance BMS system design, ER will have data on all superStorage products in the field. This gives us direct insight into the use case of modules and racks in their first life to determine whether they will be amenable to a second life. The SLBs present larger cell-to-cell variability than the new batteries. Further, by enabling the ability to disassemble each module and testing individual cells, we can ensure that we "match" second-life cells closely to optimise

performance in their second life. The closer the match, the better the restored battery will perform and the longer the life will be. Packs designed for heavy loads and wide adverse temperature ranges will typically be matched to ± 2.5 per cent. Such a tight tolerance may not be possible with refurbished cells and mono-blocks.

We will support second-life batteries by designing with heterogeneity between cells and packs.

The other major technical challenge is the complex battery degradation phenomena. The LIBs ageing leading to capacity fade is a combination of several ageing mechanisms with reactions specific to the particular materials and LIB chemistry. The two major factors in the degradation of negative electrodes are solid electrolyte interphase (SEI) instability and lithium metal plating. The LIBs degradation mechanism can be broadly separated into three categories: loss of lithium inventory, loss of active anode material, and loss of active cathode mass.



The challenge of truly understanding the battery failure mechanism is that it requires dismantling the cell and intensively inspecting individual components. For a LIB to operate in a reliable, efficient and safe manner, it requires a battery management system. The core function is to accurately estimate the State of Charge (SOC) and State of Health (SOH), challenging due to the lack of sensors for electrochemical phenomena inside the cells.

We will further support second life batteries by ensuring our proprietary battery management system evaluates the battery's second-life potential by measuring and benchmarking its capacity fade, impedance growth and efficiency fade.

Supporting the development of a viable metal recovery process

As per Battery Stewardship regulations, we aim to take back batteries at the defined end of life. At our facility, we will design processes to be able to assess all our modules on the return to the factory, determine the state of health (SoH) of each cell that makes up a pack/rack then undertake one of two things:

- Cells that are assessed as still having useful life or an SoH above the defined end-of-life criteria, will be put aside for "second life applications."
- Cells assessed as at the end of life or an SoH below the defined end-of-life criteria will be sent for recycling via one of ER's partners.

We will be an early and proactive adopter of current and any new regulations or recommendations arising from Battery Stewardship legislation



supporting information

Recycling process

We are not a battery recycler, and this is not the focus of our business. However, we intend to partner with companies in the field that share our passion for energy storage and a circular economy. As we progress towards Renaissance Two (cell manufacturing), we will actively seek to employ recycled content in our cell chemistry. These may be materials recovered by direct recycling processes used in cathodes, anodes and electrolytes. These materials will need to be qualified against ER's exacting standards for materials and cell quality. Still, our goal is to provide support to those companies recycling cells and the materials thereof to reach these thresholds.

Direct recycling process

Direct recycling is also called cathode to cathode recycling, particularly attractive for batteries with high value elements in the cathode. The main difference between hydrometallurgy and the direct recycling process is that hydrometallurgy uses a strong acid to dissolve the cathode into the aqueous solution. In contrast, direct recycling retains the cathode crystal morphology. However, as the feed waste stream will mix different types of battery chemistry, direct recycling will lead to a mixture of cathode materials. Unless the retention of the structure of the cathode mixture is found valid, there is no clear advantage of the direct recycling approach under current battery manufacturing processes.

Anode(graphite)recovery

Research into Graphite recovery is ongoing, with several viable alternative methods under investigation. It is clear while hydrometallurgical processing for metal recovery makes Graphite possible, pyrometallurgy-based recovery does not. Recovery of Graphite before hydrometallurgy requires electrolyte removal, and these processes are usually undertaken in sequence before metal dissolution.

Our ultimate is the re-use of the recovered Graphite. Initial research indicates that this secondary anode material's best performance is achieved when the extraction of excess electrolyte is done with subcritical CO₂. However, this adversely affected the crystallinity of the recovered Graphite. This has implications when considering the re-use of recovered Graphite for making new anode materials. While the literature has shown that the change in crystal structure doesn't change secondary anodes' capacity, it is not clear what impact the change in structure has on the recharge and charging cycles, the lifespan or the quality of LIBs that can be manufactured from these recovered materials.



Metal recovery

Pyrometallurgy Recovery Process

The pyrometallurgical process extracts metals by heating electrode parts to form alloys. Lithium can be recovered by leaching, but the cost and energy requirements are not economically favourable (at current lithium prices). The pyrometallurgy method requires less pre-treatment of battery scrap, therefore, has the advantage of having the lowest cost. However, burning plastics will release dioxins classified as a highly hazardous material and lead to secondary pollution issues. Except for the waste gas, the pyrometallurgy process also suffers from waste slag, high energy costs due to mechanical treatment and some metal loss.

Hydrometallurgy

Hydrometallurgy provides a more specialised method for the recovery of metals from complex metal-containing wastes. Metals are recovered through leaching and extraction at low temperatures. The advantage of hydrometallurgy is its high recovery rate, lower energy consumption than pyrometallurgy, and ability to cope with low metal ion concentrations. The downside of hydrometallurgy is it has many more process steps than pyrometallurgy. Currently, most recycling companies are adopting the pyrometallurgical process, mainly due to the lower cost and scalability. It's becoming more favourable to use the hydrometallurgical process as the higher value derived from metals recovered can cover the processing cost and create an economically viable business model. Pyrometallurgical and hydrometallurgical processes can be mixed to deal with waste recycling. Umicore and BATREC are significant companies adopting the pyrometallurgical process. More than 70% of the recycling processes are primarily hydrometallurgical in China, with the rest of the 30% accounting for pyrometallurgical combined with mechanical processes.

Following the solubilisation of metals from waste LIBs by hydrometallurgy-based processes, complex and mixed metal solutions are generated that require further processing to separate and purify constituent metals. Regardless of the metal solubilisation method employed, the recovery of metals from the complex metal-containing leachate solutions can be challenging due to complex chemistries and co-digested compounds associated

with binder and other materials if they are not appropriately removed. To separate pure metal fractions, various separation and extraction methods or sequential separation and extraction are required. Here, techniques such as solvent extraction and electrodeposition are used in combination to produce pure metals or alloys or precipitation of metal species using hydroxides, sulphides and other complexing agents, which can then be further purified or refined.

In chemical precipitation, sources of hydroxide or sulphide ions or complexing agents are added to the solution. The pH, if necessary, is adjusted using caustic soda or lime to promote the precipitation of metals at increasing pH set points. In most instances, though, metal species' co-precipitation often occurs when adjusting pH because of the similar chemical properties of these metal ions in solution, resulting in only semi selective or non-selective separation of metal species. Since lithium-ion does not precipitate under these conditions and remains in solution, it is separated with relative ease from all other metals. It can be recovered conveniently by precipitation as lithium carbonate or hydroxide. Recovered metal ion precipitates then require further processing to produce pure metal salts, metals or mixed metal alloys.

Efficiencies of extraction are determined by the solution's initial composition, the combination of the extractants used and the extraction conditions, particularly pH. Using various types and varieties of chemical extractants, solvent extraction has been demonstrated to separate and purify metal species from waste LIBs. However, challenges exist in separating the valuable metal ions cobalt, nickel and manganese from the solution due to their similar chemical properties. In some studies, the purification of these metals has been improved using the combination of solvent extraction and membrane separation. Driven by electrochemical reduction reactions, metals can be separated and purified from solutions generated by leaching waste LIBs. Electrodeposition, including electroplating for the production of pure metals and alloys, has also been attempted to recover metals from waste LIB leaching solutions. Still, in most cases, electrochemical recovery studies were limited to single metal electrode materials. To date, the separation of these three essential metal ions solely by electrochemical means has not been achieved.



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