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Recycling of Lithium-Ion Electric Vehicle Batteries

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Summary

There are now more than five million electric vehicles in the global fleet [1, 2], and the vast majority of these employ lithium-ion batteries. The number of lithium-ion batteries has skyrocketed, but what will happen to them after they die? This paper builds a case as to why lithium-ion batteries should be recycled and compares recycling processes. The paper also describes the development of a closed-loop battery recycling model that breaks down each process from when a battery leaves the factory to when it is recycled. The U.S. Department of Energy launched its first lithium-ion battery recycling R&D center, called the ReCell Center in February 2019 at Argonne National Laboratory.

Keywords: recycling, battery, lithium battery, materials, sustainability

1 Introduction

Lithium-ion batteries were commercialized in the early 1990s and gained popularity first in consumer electronics, then more recently for electric vehicle (EV) propulsion, because of their high energy and power density and long cycle life. Their rapid adoption brings with it the challenge of end-of life waste management. There are strong arguments for Lithium-ion battery recycling from environmental sustainability, economic, and political perspectives. Recycling reduces material going into landfills and avoids the impacts of virgin material production. Lithium-ion batteries contain high-value materials like cobalt and nickel, so recycling can reduce material and disposal costs, leading to reduced EV costs. Battery recycling can also reduce material demand and dependence on foreign resources. Several companies are finding ways to commercialize recycling of the increasingly diverse lithium-ion battery waste stream. Although Pb-acid battery recycling has been successfully implemented, there are many reasons why recycling of lithium-ion batteries is not yet a universally well-established practice. Some of these are technical constraints, and others involve economic barriers, logistic issues, and regulatory gaps. This paper describes why lithium-ion batteries should be recycled, compares recycling processes, and addresses the different factors affecting lithium-ion battery recycling in order to recommend future work towards overcoming the barriers so that recycling can become standard practice. [3, 4, 5]

The use of lithium-ion batteries has surged in recent years, starting with electronics and expanding into many applications, including the growing electric and hybrid vehicle industry. But the technologies to optimize recycling of these batteries has not kept pace. By 2020, more than 575,000 electric drive vehicles are projected be sold annually in the United States, and this number is expected to climb to more than 1,375,000 by 2025. As recycling of lithium-ion vehicle batteries is not currently a revenue-positive business and relies on fees for profitability, the economic, environmental, and safety issues with this wave of batteries for recycling will only escalate. Industry has not yet invested heavily in developing recycling processes because the risk-to-reward ratio is too high. A coherent R&D effort is needed so that an economic and environmentally sound recycling process will be available to industry and consumers.

2 Battery Recycling Model

Argonne National Laboratory has also developed a model that allows the EV and battery industry, and policymakers and other stakeholders, to gauge the impact of recycling batteries in electric vehicles. The model, named “ReCell”, examines how much money and energy could be saved if we recycle these batteries. From cathodes to anodes and electrolytes, the ReCell model provides a closed-loop battery recycling tool, offers preliminary estimates of total costs as well as environmental impacts such as carbon dioxide emissions. The model breaks down each process from when a battery leaves the factory to when it is recycled.

The ReCell model can provide information to manufacturers up front, so those manufacturers can determine life cycle costs with precision and provide batteries to consumers with minimal environmental and economic impacts. Argonne’s researchers have designed ReCell to be versatile and adapt to the challenges that recycling of lithium ion batteries present, such as differing battery chemistries and formats.

The model includes three basic recycling technologies:

- Extracting metals with heat (pyrometallurgical)
- Extracting metals with liquids (hydrometallurgical)
- Direct recycling

Preliminary findings estimate that a cell with a recycled cathode could cost 5 percent, 20 percent and 30 percent less than a new cell using pyrometallurgy, hydrometallurgy and direct recycling routes, respectively, according to estimates from Argonne’s Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model recycling parameters. That same cell could consume 10 percent, 20 percent and 30 percent less energy, respectively.

Additionally, the model considers transportation-related cost and environmental factors, which can help steer the development of a recycling infrastructure. For instance, is it more effective to have one large central recycling center or several smaller centers located throughout the country? Preliminary results from the ReCell model show how a simple change in shipping classification for end-of-life batteries could potentially change a recycled cathode’s cost from 30 percent less than a new cathode to one that only breaks even.

3 Lithium-Ion Battery Recycling R&D Center

3.1 Launch of the Battery Recycling R&D Center

In February 2019, the U.S. Department of Energy launched its first lithium-ion battery recycling R&D center, called the ReCell Center, at Argonne National Laboratory. The ReCell Center is a collaboration between Argonne National Laboratory; the National Renewable Energy Laboratory (NREL); Oak Ridge National Laboratory (ORNL) and several universities including Worcester Polytechnic Institute, University of California at San Diego and Michigan Technological University. Collaborators from across the battery supply chain, including battery manufacturers, automotive original equipment manufacturers (OEMs), recycling centers, battery lifecycle management services and material suppliers, are working with the center. The ReCell Center is supported by DOE’s Vehicle Technologies Office with $15 million over three years. Its work will include development of test beds and a process scale up facility at Argonne. The facilities and expertise are open to everyone that would like to collaborate on battery recycling.

The mission of the ReCell Center is (1) to decrease the cost of recycling lithium ion batteries to ensure future supply availability of critical materials and decrease energy usage compared to raw material production, (2) to develop new battery designs that enable more efficient recycling at end-of-life to make recycling profitable, and (3) to develop processing technologies that make recycling profitable, providing lower cost battery materials resulting in lower cost batteries.

University and national laboratory collaborators will use state-of-the-art R&D tools at their home institutions to develop new methods for separating and reclaiming valuable materials from spent EV batteries. Researchers will then scale up the most promising technologies at the ReCell Center facilities located at Argonne, where industrial collaborators can explore the technologies and develop them further.

The center will be a collaboration space for researchers from industry, academia and other government laboratories to use R&D tools not found at their own laboratories and to grow pre-commercial technologies.

3.2 Technical challenges

Lithium-ion batteries with advanced chemistries are challenging to recycle. Unlike lead-acid batteries, which contain only a few materials that require a few simple operations to recycle, lithium-ion batteries have several materials with complex designs. The methods to separate them are either expensive, energy intensive, or create a lot of waste. The chemistries and morphologies of these compound materials are complex and customized by individual manufactures, making a standard recycling method nearly impossible. The process inputs and outputs for various pathways for lithium-ion battery recycling are shown in Fig. 1.

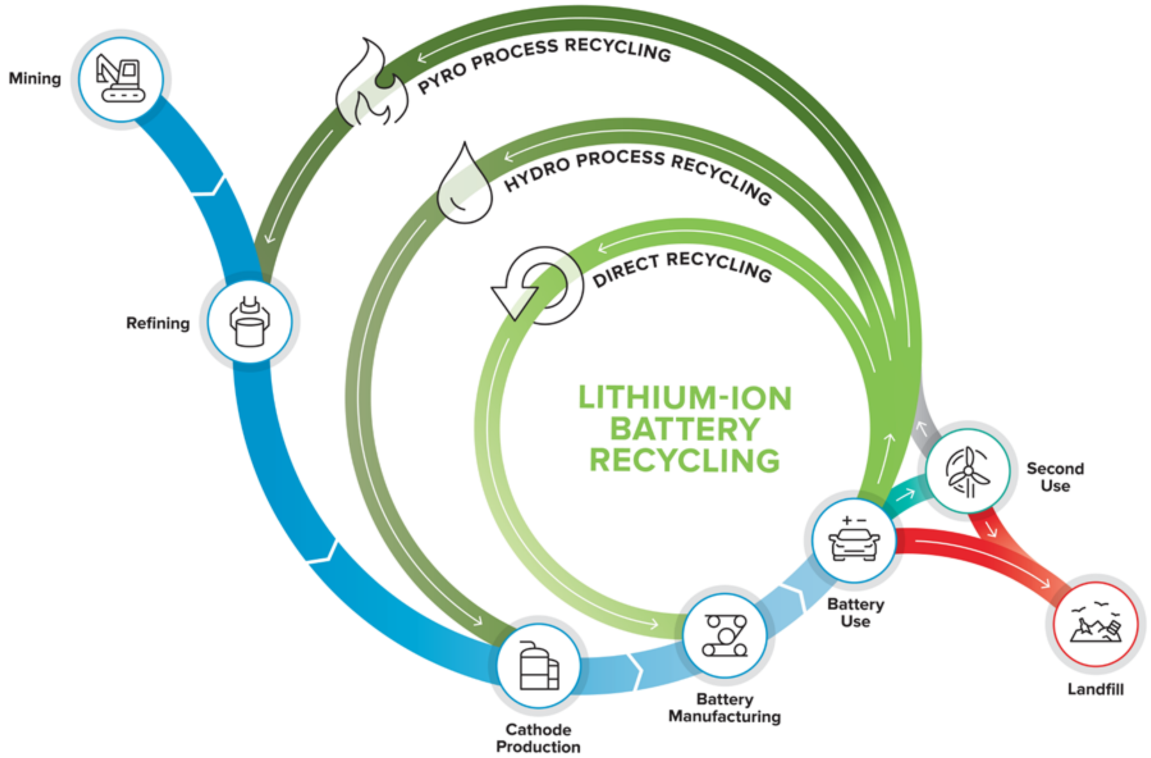

Fig. 1. Process input and output pathways for lithium-ion battery recycling.

Developing a cost-effective and environmentally sound recycling process for advanced battery chemistries, requires advances in separation techniques, a deep understanding of evolving battery chemistries, and the development of novel electrochemical techniques for relithiation.

Developing a recycling process for lithium ion batteries is challenging for several reasons. First, each cell has a complex design and contains a number of different materials. This is unlike lead-acid batteries, which contain three basic materials, requiring only a few simple separation operations. Second, active materials are complex compounds with customized morphologies that differ by manufacturer and even vary within a company's product slate. Third, battery chemistries continue to evolve, causing the target specifications for a recycled product to constantly change.

Today, the process of recovery may cost more than the product material is worth. Battery owners often pay $1 per pound to cover the cost of recycling and that will only increase as cobalt-rich battery systems are phased out, leaving one less recycled component for sale.

There are currently two methods of recycling lithium ion batteries: pyrometallurgical and hydrometallurgical. Both processes have major impediments to wide-scale adoption. Pyrometallurgical recycling (smelting) uses high-temperature furnaces to create an alloy of valuable metals and can handle mixed battery chemistries. Cobalt and nickel are the most valuable elements, but these must be leached and separated from the alloy prior to reuse. Other elements, such as lithium and aluminum, are lost to the slag. Pyrometallurgical recycling is energy intensive, costly and cannot cost effectively recover lithium or aluminum. It only recovers several of the metal constituents while the plastics and organics are burned up in the furnace. To operate this process at an industrial-scale a large investment is required.

Hydrometallurgical recycling is cheaper but requires significant after-processing to make material usable in batteries. Hydrometallurgical recycling involves dissolving the active materials into solution and then separating them into transition metal compounds and lithium salts. It is potentially economical at smaller scale due to lower operating temperatures, lower capital investment, and recovery of more products than smelting.

As battery chemistries move away from cobalt-rich systems, the impetus for recycling using current methods will decline. For industry acceptance, a better recycling process is necessary to recover more materials, more specialized material morphologies, minimize energy use and emissions, and provide economic value.

Direct recycling has the potential to recover materials that can be used in batteries with minimal treatment, thus reducing recycling costs and impacts.

3.3 Technical focus areas

As shown in Fig. 2, the ReCell Center is focusing on solving four of the largest R&D challenges that impede wide-spread adoption of lithium-ion recycling. Solving these four challenges will develop an efficient recycling process that recovers material in high value form for sale back to manufacturers to encourage lithium-ion battery recycling.

Design for Recycling: Designing new batteries with end-of-life in mind can improve recyclability. But to keep the batteries marketable, the center team must develop new designs that trade minimal loss in energy density and cost for the ability to use cheaper, new recycling processes at end of life.

Direct Cathode Recycling: Direct recycling enables recovery of cathodes and other materials from spent lithium-ion cells in a condition suitable for direct re-entry into the lithium-ion battery market, providing a lower cost reconstituted alterative for battery manufactures. There are several technical issues associated with direct recycling that must be overcome. This is because of the large variety of materials used in lithium-ion batteries and the on-going development of new battery chemistries.

Recycling of Other Materials: A low-energy and low-cost separation system that selectively recovers electrode materials, such as graphite, has not yet been established. The team will develop new methods to recover graphite found in battery anodes and the fluorine found in electrolyte salts. This will increase the viability of lithium-ion recycling by giving manufacturers additional recycled materials to sell for use in batteries and other products. Additionally, the more materials recovered for recycling, the less material that needs to be landfilled or treated as waste.

Modeling and Analysis: To determine the best materials and chemistries for current and future batteries requires detailed testing. The center team will analyze materials under various conditions to understand the process effects of various recycling processes and cell design formats, including material damage and impurity levels. To determine the optimal use of a battery.

Fig. 2. The four research focus areas for the Lithium-Ion Battery Recycling R&D Center

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