



Recycling Sector

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30 Second Snapshot:

- Argonne National Laboratory envisions U.S. self-sufficiency in lithium-ion battery technology by 2050, but challenges include waste stream standardization, labeling inconsistencies, and existing regulatory patchworks.
- Industry and government stakeholders are investing in research, exploring alternative battery chemistries, and are striving for a shared vision of a sustainable battery recycling future.
- To achieve sustainability, the industry is focused on safety enhancements, capacity expansion, education, collaboration, and engagement with

Introduction

As the world advances toward a lithium-ion powered future, the recycling sector in the United States finds itself at the forefront of the effort to accomplish circularity through reduced consumption and environmental impact. The U.S. Department of Energy (DOE)'s [National Blueprint for Lithium Batteries 2021-2030](#) has emphasized that the United States needs to bolster its domestic lithium-battery manufacturing in response to the [projected five to ten-fold growth](#) in the global lithium battery market over the next decade. Argonne National Laboratory's [Li-Bridge report](#) projects a vision of the United States being self-sufficient in lithium-battery technology by 2050, predominantly sourcing energy materials from recycled batteries within the nation's recycling sector.

Recyclers already face numerous challenges related to lithium-ion battery recycling for consumer products, let alone the explosive growth in the adoption of electric vehicles (EVs)—which includes cars, trucks, buses, scooters, bicycles, and more.

These challenges include:

- receiving battery-powered products not designed for efficient removal of batteries;
- identifying and sorting lithium-ion batteries;
- maintaining safety standards despite a lack of standardization in battery chemistry or form factor;

- increased safety hazards caused by improper disposal of batteries by consumers; and
- the practical limitations of storage and transport to specialized facilities that can properly recycle lithium-ion battery materials.

This fact sheet outlines the current landscape for lithium battery recycling, what lies ahead, how recyclers are adapting and preparing, and the key areas of focus to ensure a smooth and safe lithium-ion battery recycling industry.

Current Landscape: Lithium-Ion Battery Recycling

While lithium-ion batteries can range in size from smaller than a penny to over three feet in length, most lithium-ion batteries making their way to recyclers come from household or handheld consumer products, according to insights from industry experts. Like battery size, the way batteries are manufactured and integrated into consumer products varies greatly. In consumer electronics—which are becoming [more common](#) and increasingly more likely to be improperly disposed of—batteries could be removable but are often designed to be embedded in devices, making removal difficult and expensive for recyclers. Exacerbating this difficulty is the challenge of successfully identifying products with lithium-ion batteries, especially in facilities not designed to handle their recycling. Below is a deeper look at the key challenges to effective and safe lithium-ion battery recycling.

Consumer Sector: Lithium-ion batteries in consumer goods can be removeable or embedded in devices to varying degrees and can be found in consumer electronics or mobility solutions such as e-bikes or e-scooters. Due to a [lack of standardization](#) in how these diverse streams are processed, various kinds of recyclers—from residential MRFs to paper mills and metal recyclers—receive these batteries without the ability to handle them properly or cost effectively.

Safety and Labeling: Lithium-ion batteries introduce significant safety concerns in the recycling process, particularly in facilities not designed to handle them. Identifying and separating these batteries from other materials during the recycling process is essential to maintain safety at recycling facilities. Most notably, a lack of universal labeling standards both on batteries themselves and on product packaging makes spotting batteries [difficult](#) during the separation process.

Lithium-Ion Battery-Induced Fires: Batteries face a heightened risk of damage during the extraction and sorting process, which can lead to [fires](#), predominantly from devices like laptops, cell phones, and tablets—but also from EVs. Fires can result in personal injury, disruptions, damage to facilities and adjacent properties, and serious [insurance liability](#) concerns for facilities.

The U.S. Environmental Protection Agency (EPA) has noted an increasing number of fires caused by lithium-ion batteries in the recycling and waste management process. Although it is challenging to capture data on all such fires, an [EPA report](#) documented 254 fires across 64 waste and recycling facilities caused by lithium-ion batteries from 2013-2020. Impacts ranged from minor incidents to severe ones that resulted in facility destruction and injuries. Materials Recovery Facilities (MRFs) were notably adversely affected by fire incidents caused by lithium-ion batteries:

- 78 percent of MRFs had to involve emergency services.
- 22 percent of MRFs reported injuries.
- Approximately 43 percent of these MRFs faced financial losses.

If damaged or agitated, lithium-ion batteries can undergo “[thermal runaway](#),” leading to fires that can be dangerous in places filled with flammable materials. Such fires can be devastating, as evidenced by a MRF fire in California requiring over [\\$8.5 million](#) in repairs. Annually, battery fires cost the recycling sector more than [\\$12 billion](#), significantly impacting operations across the entire industry.

EV Recycling Sector: Consumer lithium-ion batteries are not the only battery problem the recycling sector is grappling with. As more EVs reach the end of their lifecycle, recycling or reusing their batteries will pose considerable challenges. The sheer difference in mass between consumer electronics, e-mobility products, and EVs illustrates the problem clearly. A single 80 kilowatt-hour EV battery holds the power equivalent of approximately 6,100 iPhone 15 batteries. Potential electrical discharge from these batteries can present safety issues. Additionally, when EV batteries are [damaged](#) upon arrival at a recycling facility or during recycling processes, they pose even more intense fire and safety hazards than their smaller consumer product counterparts.

Aside from the safety risks, extracting batteries from the vehicle due to their [integrated designs](#) and the [lack of standardization](#) will complicate EV battery recycling and reuse efforts.

The structure and makeup of EV batteries add to the complexity of recycling and make uniform recycling practices elusive. Some automakers use a series of [cylindrical cells](#) to power an EV, while others use a [pouch-type cell](#) design; automakers can also use proprietary battery chemistries. Compounding this, automakers’ designs are more integrated, often incorporating a battery into an EV’s chassis, making removal and recycling daunting tasks.

Beyond removal, transporting heavy EV batteries presents logistical challenges, exacerbated by a [relatively small number](#) of dedicated recycling facilities for EV batteries. Batteries [crisscrossing state lines](#) to reach these facilities, if improperly stored and prepared, can lead to bottlenecks, increased costs, and greater safety risks on the road.

[Regulatory inconsistencies](#) across the United States, however, add layers of complexity to the recycling landscape. The EPA, for instance, has [only recently](#) begun to provide some clarity on lithium-ion battery regulations, but many specifics remain undefined. This ambiguity makes it challenging to establish consistent recycling practices, especially in states like [California](#), [New York](#), and [Minnesota](#), which have their own unique regulatory landscapes regarding recycling.

Recyclers Prepare for a Battery-Driven Future

Despite the challenges, recyclers are readying themselves for a more sustainable future in battery recycling. The current landscape of battery recycling showcases [three dominant methodologies](#): hydrometallurgy, pyrometallurgy, and direct recycling. Hydrometallurgy uses chemical solutions to recover metals; pyrometallurgy applies high temperatures to transform metal oxides; and direct recycling extracts and refurbishes cathode materials for reuse.

Direct recycling holds promise with the potential for lower energy, reagent, and fixed costs at facilities if the cathode material can be reconditioned. This method faces steep challenges, however, because the battery must be disassembled, and a lack of standardization adds considerable complexity to this approach. Fortunately, the DOE's [ReCell Center](#) is aiming to advance direct recycling methods for lithium-ion batteries. The Center researches methods of direct recycling that will improve cost effectiveness, and applies their research to various battery cell types including wound, prismatic, and pouch cells to enhance recyclability regardless of battery composition.

Recyclers are also looking ahead at how emerging alternatives to lithium-ion battery chemistries could impact both the existing methodologies to recycling and add new functional and logistical challenges when it comes to differentiating between batteries of different makeups. For instance, manufacturers are researching alternative chemistries like solid-state batteries, which forego the critical minerals found in lithium-ion batteries. However, as solid-state batteries are still largely in research and development, there are [very few](#) studies or real world examples on proper recycling methods or life-cycle assessments. A similar issue exists for [sodium-ion](#) batteries as well.

Other more established—and more readily available—alternatives like [Lithium Iron Phosphate \(LFP\) batteries](#) are beginning to replace highly valuable Nickel Manganese Cobalt (NMC) batteries, which will affect the value proposition for recyclers. Reuse and repurposing may be more appropriate pathways for LFP batteries that have reached the end of their useful life in an EV.

The expected surge in [EV batteries](#) highlights the growing need to establish efficient recycling strategies to mitigate potential mismanagement of retired batteries. The international stage offers a glimpse into potential avenues for successful battery recycling

practices. For instance, the European Union's (EU) [Battery Pass](#) consortium details multinational collaborative efforts to standardize labeling, lifecycle tracking, and sustainability standards across EU borders. This effort aligns with other global initiatives like [the Global Battery Alliance](#) (GBA) and [Catena-X](#). The GBA is a public-private collaboration platform founded in 2017 at the World Economic Forum to help establish a sustainable battery value chain by 2030, while Catena-X is an EU-funded initiative implementing data-driven efficiencies to the automotive value chain, including a battery passport system to enhance sustainability and circularity.

Understanding the unique risks associated with the increase in EV battery recycling, organizations like ISRI have taken proactive steps. The [High Voltage Electric Vehicle Technology Training for Recycling Professionals](#) online course is tailored to equip recycling facilities with the knowledge to tackle new challenges emerging in the EV battery recycling domain.

Due to [projected supply shortages](#) and sustainability pledges, EV battery manufacturers and automakers have begun to shift their focus towards circularity. As manufacturers increasingly aim to consolidate and improve the sustainability of their supply chains, recyclers have the opportunity to develop partnerships that benefit all parties.

For instance, Redwood Materials has announced direct partnerships with major battery manufacturers and automakers, such as [Panasonic](#), [Ford](#), [Volvo](#), and [Toyota](#). These partnerships will help manufacturers source recycled cathode materials for EV batteries and improve circularity. Direct partnerships also help recyclers because manufacturers can better communicate their chemistries and form factors to recyclers—improving efficiency and safety at recycling facilities.

Recyclers can also work with policymakers and regulators to enhance workplace safety regarding lithium-ion batteries, such as with [OSHA's recent bulletins](#) on safety and training surrounding the recycling, storage, inspection, and emergency action plans that recyclers can incorporate to further promote safety and sustainability.

The state governments of California, New York, and Minnesota are also taking proactive measures to establish recycling guidelines and mandates by directly referencing lithium-ion batteries in existing battery disposal laws, in addition to providing [guidance](#) and [responsibilities](#) for consumers on these new regulations. Washington is also researching the [management](#) of EV batteries and will use their findings to better inform future laws. Additionally, laws such as [Extended Producer Responsibility](#) (EPR) in [California](#) and [Washington](#) are changing the recycling landscape in their states by shifting the onus of responsibility from consumers to manufacturers. As policymakers and regulators continue to turn their attention to lithium-ion batteries, recyclers will have more opportunities to inform policy in a way that can better address challenges affecting the sector.

The Road Ahead: Key Focus Areas

Amid the evolving lithium-ion battery recycling landscape, recyclers are committing to embracing their increasingly important role in the circular economy. **Safety enhancements** are a primary goal, with efforts by recyclers to [bolster safety protocols](#), [advance detection and sorting mechanisms](#), and [amplify training](#) to effectively lessen risks associated with lithium-ion battery recycling.

Recyclers are focusing their **Policymaker Engagement** on supporting the [implementation](#) of universal lithium-ion battery labeling—both on products and on battery cells themselves—and improving regulations that encompass both consumer electronics and EV batteries.

Capacity Expansion is another area of progress, as recyclers are actively seeking ways to [bolster](#) the national infrastructure for lithium-ion battery recycling. This includes initiatives to work [closely](#) with automobile manufacturers to alleviate logistical concerns and [streamline](#) the recycling process for large battery volumes.

Recyclers are also invested in **Education and Collaboration**, where they are stepping up to enhance [public awareness](#) and [education](#) about the importance of battery recycling within a greener economy. They are exploring the [development](#) of more accessible lithium-ion collection points, which could simplify the recycling process industry-wide.

Combined, these initiatives demonstrate the recycling sector's commitment to keep pace with the increasing demand for lithium-ion batteries and to foster a sustainable battery lifecycle.