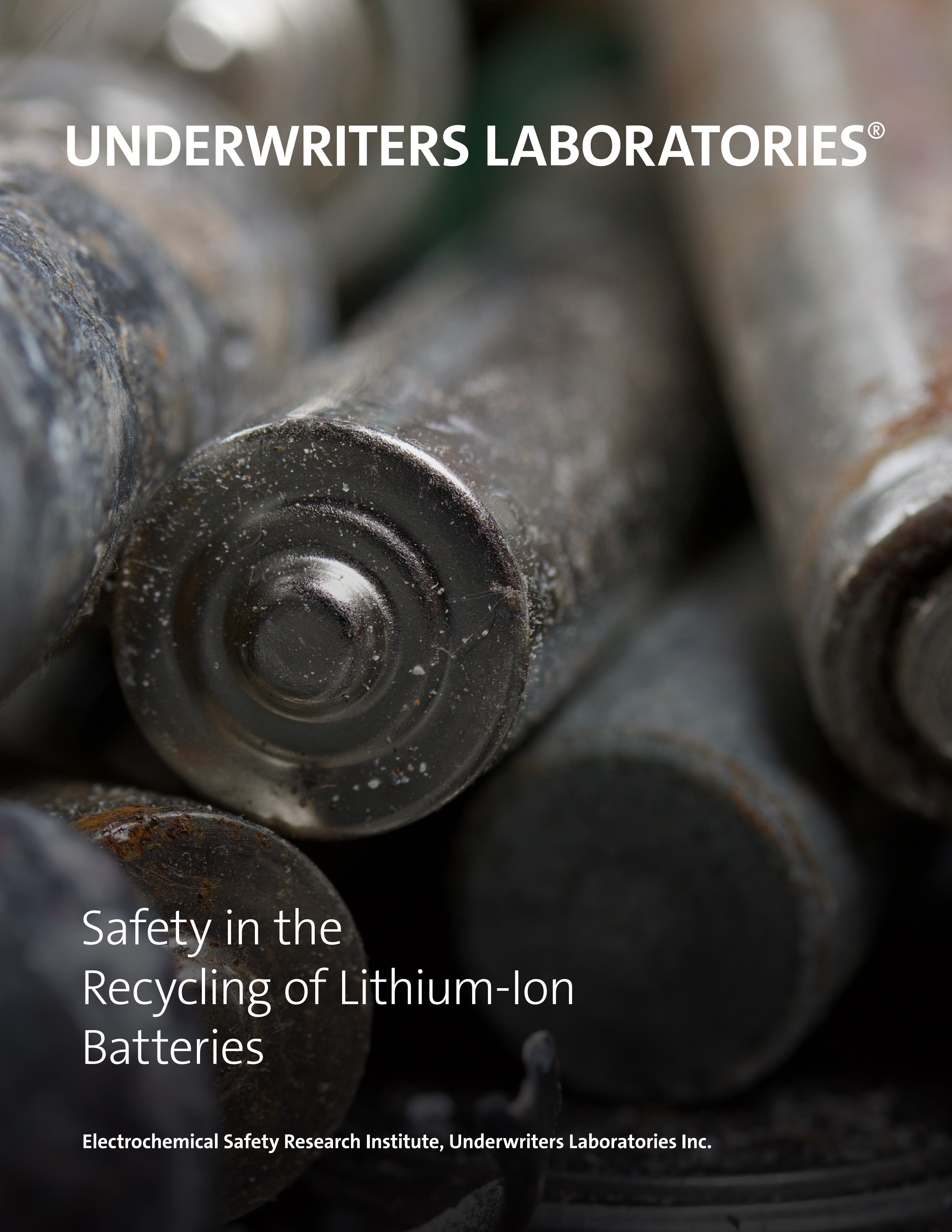

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Safety in the Recycling of Lithium-Ion Batteries

Electrochemical Safety Research Institute, Underwriters Laboratories Inc.

Executive summary

Lithium-ion batteries make advances in consumer electronics and electric mobility possible. High energy and power density — in addition to improved cycle and calendar life — make lithium-ion the battery chemistry of choice for applications from portable consumer devices to electric vehicles (EVs) and grid energy storage.

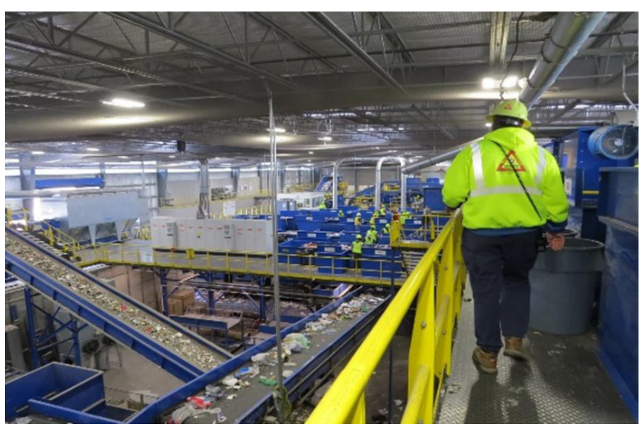
With the increased use of lithium-ion batteries in myriad products, the question of what should be done with the batteries at the end of their lives is fueling one of the most significant emerging problems in the world of waste management. Recycling batteries plays an important role in addressing rising demand for such devices and applications. Efficient and safe recycling processes can recover the constituent materials and enable a circular economy by driving the optimization of resources, reduce the consumption of raw materials, and recover waste by recycling or giving it a second life as a new product. Such processes, however, come with their own risks and challenges, as described in this white paper.

The mission of the Electrochemical Safety Research Institute (ESRI) is to advance safer energy storage through science. As ESRI conducts more in-depth research on recycling lithium-ion batteries, the data the institute collects will help advance Underwriters Laboratories' mission of making the world a safer place by introducing new standards in this area and disseminating the knowledge gained through research using various channels — including journal publications, conferences, and webinar presentations.

Why are we concerned about the safety of recycling lithium-ion batteries?

The proliferation of lithium-ion batteries has led to an increasing number of batteries ending up in municipal waste.[1] Improper battery sorting is causing an increase in the frequency of fires in recycling facilities.[2, 3] The following incidents are just a few reported in the news media:[4]

- A garbage truck caught fire in 2019 after a lithium-ion battery was thrown into the regular trash. The battery was damaged when the truck compressed the trash it had picked up, leading to a fire.
- A recycling truck in Washougal, Washington, caught fire and had to dump out its fiery contents in another 2019 incident involving lithium-ion batteries. It took firefighters four hours to extinguish the flames.
- Lithium-ion batteries were also implicated in a large New York City fire in 2018 that required the efforts of 200 firefighters and a full day of work to put out. This event caused significant damage to a recycling plant and halted commuter train travel.
- A 2018 study by the California Product Stewardship Council (CPSC) linked batteries to 65% of the fires that occur in California's waste management facilities.[5]



Recycling facility showing the processing and sorting of materials.[3]

Lithium-ion batteries are highly reactive and can undergo thermal runaway because of various hazards. These include mechanical hazards (crushing, penetration, deformation), electrical hazards (shorts, overcharge, over-discharge), and thermal hazards (external heat).[6] In recycling facilities, a single thermal runaway event can act as an ignition source and increase the likelihood of fires when lithium-ion batteries are mixed and processed with municipal waste.

Today, lead-acid and lithium-ion are the two primary battery chemistries that can be recycled, followed by, to a lesser extent, nickel-based batteries. Lead-acid batteries must be recycled per regulation 40 CFR Part 273 and its subsections. The U.S. Environmental Protection Agency (EPA) has detailed information regarding the regulations and requirements for lead-acid batteries on its website.[7] Few states in the country have established regulations for recycling lithium-ion batteries.[8]

Lithium-ion cells are available in various formats, ranging from small coin or button cells and metal can cylindrical to prismatic metal can and pouch types. Typically, lithium-ion cells contain a transition metal oxide cathode and a carbon-based anode. A polymeric material referred to as a separator physically keeps them apart. The electrolyte used in lithium-ion cells contains lithium salts dissolved in flammable, organic carbonate-based solvents. In designs for larger batteries, a significantly large number of cells may be connected in series and parallel configurations to obtain the required voltage and capacity for the battery. For example, an EV battery pack is composed of hundreds to thousands of lithium-ion cells connected electrically to provide the high voltage and capacity required for the vehicle to run.

The wide variety of battery pack sizes and designs — as well as cell sizes and formats — makes it difficult to standardize or automate processes for disassembly in a recycling facility. The design complexity and safe handling of these high-voltage systems require highly trained staff to disassemble the battery packs.

Lead-acid batteries have a 99% recycling rate in the United States.[9] Robert Rapier reported that, compared to the high rate of recycling for lead-acid batteries, the recycling rate of lithium-ion batteries is approximately 5%.[10] His report states that this significant difference in the recycling rate is because the environmental impacts of lead-acid batteries are more fully understood as compared to lithium-ion batteries. Furthermore, regulations prohibiting the disposal of lead-acid batteries and monetary incentives tied to the collection and return of spent batteries help increase the recycling rate.

Lead-acid batteries undergo a simple process of crushing followed by sorting. Crushing lithium-ion batteries leads to the creation of internal short circuits (see Figure 1), after which the separator is breached, resulting in a fire and thermal runaway.[11, 12] Disassembling lithium-ion batteries safely is challenging and time-consuming because of the variety of internal and external design configurations used as well as the materials with which they are constructed. Uncontrollable heat generation from the batteries — along with combustible gas generation resulting from the fire and thermal runaway — can cause explosions. Discharging or neutralizing any stored charge in batteries before opening or shredding them for recycling can improve the safety of subsequent steps but presents its own set of challenges. Discharging batteries individually, as well as the recovery of useful chemical components, can add significant costs to the process.

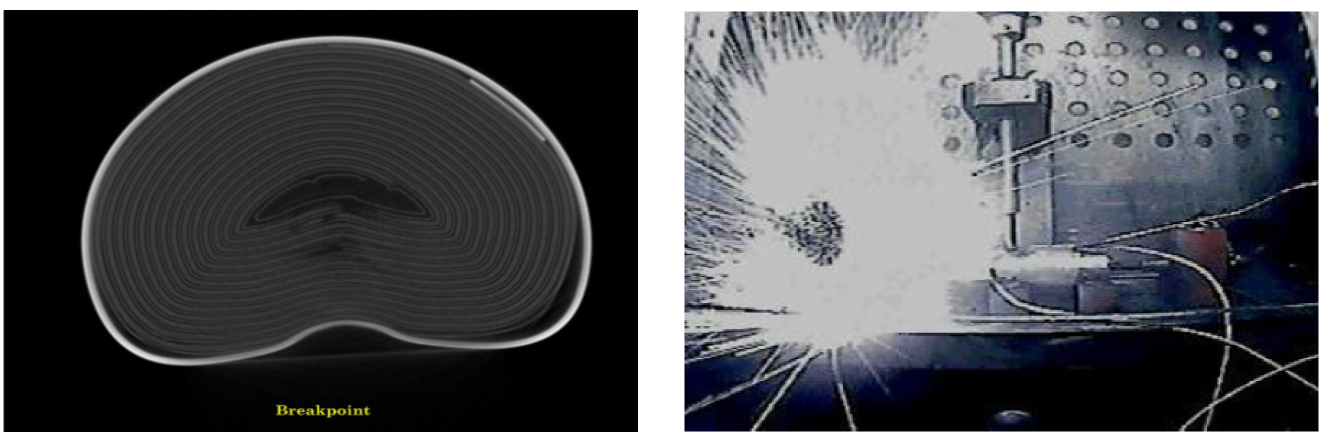


Figure 1. Computerized tomography (CT) scan of a cylindrical 18650 lithium-ion cell showing breakage in the separator when crushed (left) that leads to fire and thermal runaway (right).

The increasing trend in incidents like those described above — along with concerns regarding improper lithium-ion battery disposal — indicates an urgent need to address the risks and challenges associated with recycling. Lithium-ion battery fires can represent a significant business risk, as they impact the health and safety of those employed at waste and recycling facilities.

Conclusion

The need for more reliable lithium-ion battery recycling solutions has increased. Consumer awareness to encourage the safe disposal of lithium-ion batteries at designated collection sites represents an important step. Using public education to inform consumers about the proper use and disposal of batteries via the appropriate recycling containers, training waste facility employees in spotting and handling risky batteries during the recycling process, and knowledge of general battery safety will significantly help in the safe recycling of lithium-ion batteries. Additional training for recycling and collection center staff to properly identify and sort lithium-ion batteries is also needed. Similarly, recycling centers need improved detection and fire-extinguishing methods to address the fire risks associated with lithium-ion batteries. Although the EPA does not have specific regulations for recycling lithium-based batteries, it recommends that the 40 CFR Part 273 regulation be used for large batteries or for a large collection of smaller batteries.[7] Regulations and incentives specific to lithium-ion batteries would encourage manufacturers and consumers to improve proper disposal, collection, and recycling.

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