An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling

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Acronyms and Initialisms List

CFR	Code of Federal Regulations
CPSC	Consumer Product Safety Commission
EPA	Environmental Protection Agency
EPR	Extended producer responsibility
FAA	Federal Aviation Administration
FDA	Food and Drug Administration
HHW	Household hazardous waste
HW	Hazardous waste
LIB	Lithium-ion battery
MRF	Materials recovery facility
MSW	Municipal solid waste
PED	Portable electronic devices
RCRA	Resource Conservation and Recovery Act
WTE	Waste-to-energy

Executive Summary

This report was written to explore the growing number of fires caused by lithium-ion batteries (LIBs) in the waste management process. Anecdotal information has shown that materials recovery facilities (i.e., recycling centers or "MRFs") and other waste facilities have seen an increased number of fires due to LIBs, but there has been limited data on fire incidents at a national level. This report will help fill in this research gap.

Data was collected by searching publicly available information on LIB fires in the waste management process, usually from local news reports. A limited number of industry experts were also interviewed for this report to collect relevant first-person accounts of LIB issues. Background information on LIB chemistry and the waste process is provided for context. Incidents of non-waste LIB damage cases and existing waste incident surveys were included to shed more light on this issue.

This report does not capture all fires caused by improperly discarded LIBs, because not all incidents are made public, and not all incidents are covered by the news. Due to these limitations, we believe that the incidents we have identified and described in this report represent the cases that were relatively easy to find, and that there are likely to be a significant number of additional relevant cases that we did not identify.

This report found 64 waste facilities that experienced 245 fires that were caused by, or likely caused by, lithium metal or lithium-ion batteries. Among the facilities were MRFs, transportation vehicles (garbage trucks, etc.), landfills, and other waste management industry locations (electronics recyclers, transfer stations, etc.). The included fires occurred between 2013 and 2020 in 28 states and in all 10 EPA Regions.

These 245 fires affected the facilities and surrounding communities in a variety of ways, which were consolidated into four main impacts: injuries, external emergency response, service disruptions, and monetary losses. Some fires caused little to no impacts, such as a number of small fires at a Pacific Northwest landfill that were easily extinguished by staff members without issue.[1] Unfortunately, some fires were large and destructive, such as those that destroyed entire facilities and caused millions in damages, injured firefighters, and led facilities to stop collecting LIBs.[2]

Our findings indicate that LIB fires are happening across the full spectrum of the waste management process, but MRFs appear to have faced the brunt of the negative impacts. Of the facilities we found to have experienced an LIB fire in the past seven years, 78% of MRFs have had to call emergency responders at least once, as opposed to 40% of landfills. Five MRFs (or 22%) in our dataset have experienced injury impacts from LIB fires, compared to only two other facilities (a transport truck and a battery recycler). Close to half (43%) of the MRFs that experienced fires have faced monetary impacts. Among the cases we compiled, MRFs also had the highest incidence of service disruption (39%).

Such impacts are not surprising when the waste management process is examined. The highly mechanized waste management process often includes machines that crush and consolidate waste and

[1] See Industry Experience 2 and facility 45: Pacific Northwest Landfill

[2] See facility 20: Republic Services Recycling Center, Plano, TX; facility 15: Royal Waste Services, Queens, NY; and facility 52: Westonka Library Battery Drop-off Bin, Mound, MN

is inhospitable to LIBs, which can be damaged easily. When damaged, LIBs can start fires by igniting the surrounding trash and recyclables.

Due to increased consumer adoption of portable electronics, LIBs will only continue to become more prevalent in the waste management process and incidents such as these could also increase. However, through increased collaboration between and action by consumers, industry, and regulators, approaches to safely managing these batteries could be evaluated and implemented.

1) Introduction

This section presents background information about LIBs and the environmental regulations that currently apply to them. It describes waste management processes in the United States and why LIBs are so incompatible with them, as well as examples of non-waste LIB fires and existing waste incident surveys.

1.1) Lithium-ion Batteries: Useful and Ubiquitous

LIBs are powerful, relatively inexpensive, and lightweight energy sources that power a wide array of electronics and portable tools and are therefore nearly ubiquitous in today's world. LIB applications in consumer electronics include wireless headphones, cell phones, laptops, tablets, handheld gaming devices, hearing aids, calculators, hoverboards, e-cigarettes, portable tools, cameras, and other devices. They are also found in larger applications such as electric vehicles and energy storage systems.

Given their usefulness, it is not surprising that the number of LIBs in circulation has increased rapidly in recent years and is projected to continue rising at a near-exponential rate (Argus, 2017). In fact, a report commissioned by Call2Recycle in 2016 projected that 42 million kilograms (92 million pounds) of LIBs would be sold in 2020, with 26.5 million kilograms (58 million pounds) reaching end of life that same year (Kelleher Environmental, 2016). Beyond being used in consumer electronics and appliances, the transition we are seeing from internal combustion engines to electric vehicles will require a major increase in LIB production (Ding et al., 2019). Likewise, demand for LIBs and other types of rechargeable batteries[3] will increase as the world transitions to relying on renewable energy sources that require large-scale energy storage systems to address their intermittent nature (Department of Energy [DOE], 2019).

1.2) Lithium-ion Battery Design and Fire Potential

An LIB is composed of the same fundamental components as other batteries: one or more cells made up of an anode, a cathode, and a separator. The anode, or negative end of the battery cell, is usually composed of a graphite matrix embedded with a lithium compound. The anode also contains a current collector, which is often comprised of copper. On the opposite end of the cell, the cathode (or positive end) is often cobalt oxide, though other compounds (e.g., iron phosphate, sulfur, manganese oxide, etc.) can be used, depending on the chemistry of the LIB. A liquid electrolyte is located between the anode and cathode, and a thin layer of polyethylene or polypropylene acts as the 'separator' in the middle that selectively allows the lithium ion to pass from one side to another, creating the useful voltage that powers a device. Batteries are composed of one or more of these power-generating cells. Please see figure 1 for a diagram of an LIB.

[3] Other rechargeable battery types include currently available chemistries like nickel-cadmium, nickel-metal hydride, and lead-acid (PRBA: The Rechargeable Battery Association, n.d.), as well as more experimental chemistries like lithium-air, sodium-ion, lithium-sulfur (Battery University, 2020), and vanadium flow batteries (Rapier, 2020). However, this report focuses on lithium metal batteries and LIBs because they are the most common types in use and primary cause of battery-related fires in the waste management process.

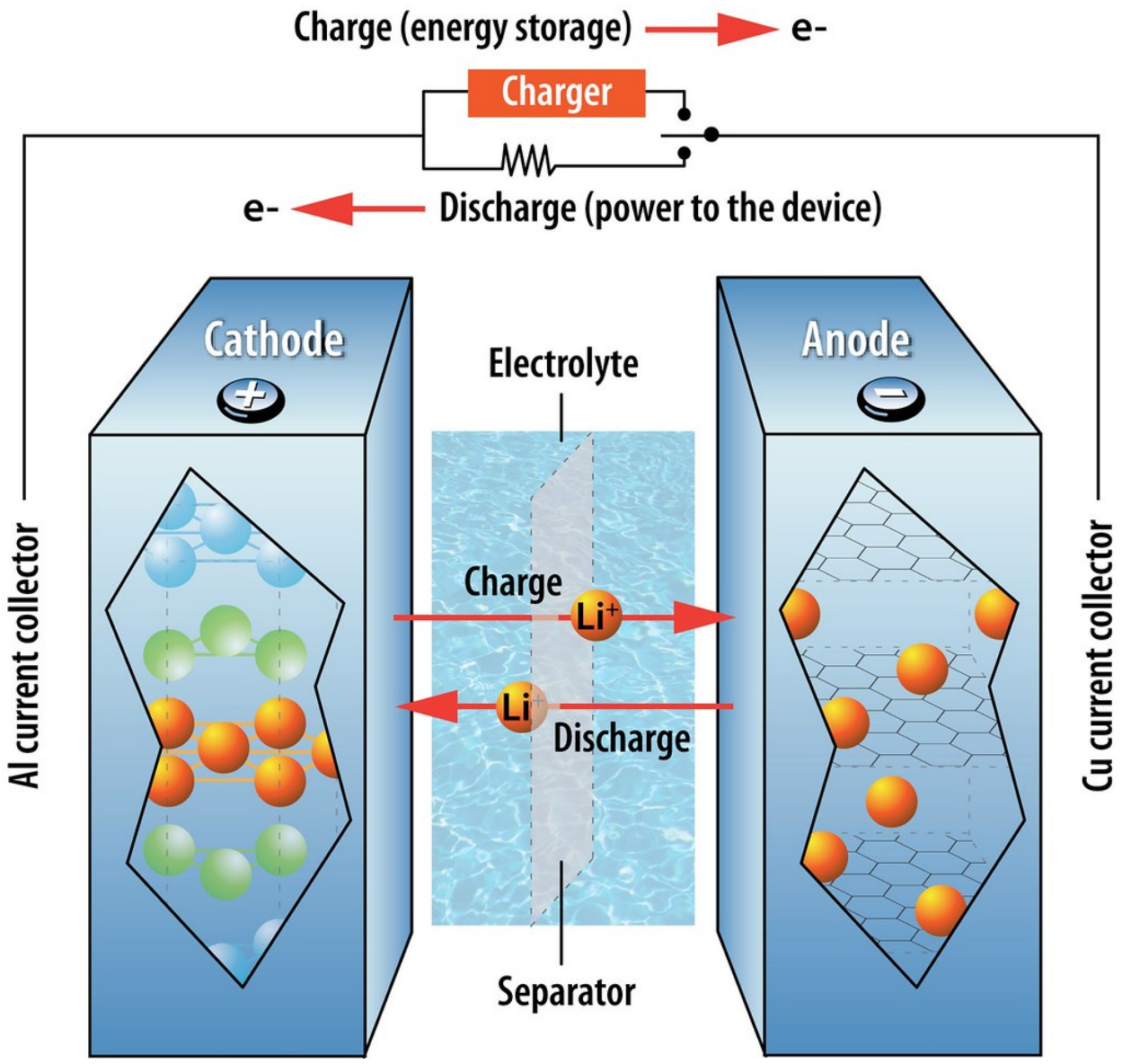

Figure 1: Diagram of an LIB.
"How a lithium-ion battery works" by Argonne National Laboratory licensed with CC BY-NC-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-sa/2.0/

During discharge, positively charged lithium atoms (called lithium ions) in the anode move through the electrolyte, across the separator, and into the cathode. In so doing, they leave behind electrons that cannot cross the separator. With nowhere else to go, these electrons move into the current collector and through a circuit that powers the device. This process can be reversed by running a current in the opposite direction—i.e., by recharging the device (University of Washington Clean Energy Institute [UW CEI], n.d.). Lithium metal batteries, sometimes called lithium primary batteries or simply lithium batteries, use this same mechanism but cannot be recharged. This report focuses primarily on LIBs, though lithium metal batteries share many characteristics with LIBs and thus pose similar threats in the waste management process.

LIBs exhibit several desirable characteristics that make them the preferred choice for many rechargeable devices. From an environmental health perspective, LIBs are preferable to other rechargeable chemistries like nickel-cadmium (NiCad) batteries because LIBs are not known to contain certain toxic chemicals like lead or cadmium. Self-discharge rates, or how quickly the battery will lose a charge while not in use, are also low for LIBs. But perhaps most importantly, LIBs have high energy density, meaning they store a large amount of energy relative to their size and weight (UW CEI, n.d.).

However, this high energy density and the materials needed to achieve it make LIBs prone to combustion or explosion when they are damaged. A damaged or defective LIB may experience thermal runaway, a reaction in which the battery unexpectedly releases its energy and begins self-heating in a runaway reaction. This reaction can quickly produce enough heat to ignite materials near the battery, even if the battery itself does not ignite. Though other types of batteries can experience thermal runaway, LIBs are particularly prone to combustion because they store such large amounts of energy. An LIB's electrolyte is also combustible, providing fuel to the fire, though there is on-going research to find non-ignitable electrolyte substitutes. If the heat is not dissipated sufficiently, thermal runaway will spread to other cells of a multi-cell battery, or even to other LIBs located nearby.[4] In practice, this chain of events means that LIB fires that are suppressed often reignite as more cells or batteries enter thermal runaway (Mikolajczak et al., 2011).

One of the most common causes of thermal runaway in LIBs is physical damage to the battery. When a battery casing is punctured, crushed, or otherwise mechanically damaged,[5] the separator may be pierced. If the separator is breached, a short circuit can develop as the anode and cathode come into contact, allowing the LIB's stored energy to be rapidly released. This short circuit creates heat buildup, which can then trigger thermal runaway in other cells. Notably, physical damage to the battery may not immediately trigger a fire, creating the possibility of a fire later in the battery's life. This threat is significant enough that some LIB manufacturers will discard any batteries that have been dropped or otherwise damaged during manufacturing, even if no physical damage or fire is immediately evident (Mikolajczak et al., 2011).

Other conditions can also increase the likelihood of or even trigger thermal runaway in an otherwise-undamaged battery. LIBs are designed to operate within safe minimum and maximum potential charge levels. However, when internal controls fail, LIBs may overcharge or overdischarge beyond safe levels, increasing the likelihood of thermal runaway. High temperatures and conditions that prevent heat dissipation (e.g., cells packed too closely together) can also increase the risk of thermal runaway. Additionally, if the liquid electrolyte within an LIB evaporates, flammable gases can be generated which could cause the battery case to swell or the LIB to ignite (Mikolajczak et al., 2011). Other authors have noted the generation of toxic fluorine gases from these fires (Larsson et al., 2018).

[4] See facility 33: Union Pacific Train, Houston, TX

[5] Physical damage can even occur within the battery without any external shock; dendrites, or small rigid projections that are formed by the LIB's chemical reactions, can develop inside an LIB and puncture its separator, triggering thermal runaway. Researchers are working to decrease the likelihood of dendrite formation (James, 2020).

1.3) Regulations

When discarded, LIBs are regulated under federal and state waste rules. Under the Resource Conservation and Recovery Act (RCRA), anyone generating solid wastes must determine if they are hazardous waste (HW). When determined to be hazardous waste, waste must be managed from cradle to grave to prevent releases into the environment. A solid waste can be determined to be hazardous either because it is specifically listed as hazardous in the regulations, or because it exhibits a hazardous waste characteristic (ignitability, corrosivity, reactivity, or toxicity). LIBs are not a listed waste, but commonly exhibit the characteristic of ignitability due to the flammable electrolyte. Some LIBs also exhibit the reactivity characteristic. Since some LIBs possess characteristics of HW, this means that some LIBs are HW.

LIBs can be managed as universal waste under the special RCRA HW provisions at 40 CFR Part 273. These provisions are intended to promote safe management of specific HWs (batteries, pesticides, etc.) using simplified management standards, while still ensuring they are safely disposed of as hazardous waste or recycled. EPA has historically encouraged waste handlers to manage LIBs under the universal waste battery classification, but these regulations were written before LIBs became commonplace. Therefore, they are not specifically tailored to the management of LIBs with their high energy density and unique chemistry.

In addition, EPA does not regulate wastes generated at a residence that are composed of common household waste as HW (see 40 CFR 261.4(b)(1)). This means that household LIB waste is not federally regulated as HW. The household hazardous waste (HHW) exemption follows the waste throughout the waste management process, so LIBs disposed of by households are not regulated as HW at any point in the disposal process. **Regardless of their classification as HHW, as a best practice, consumers should *not* dispose of LIBs in their household trash or recycling;** rather, consumers should look for HHW drop-off locations or battery or electronics collection programs that will allow them to properly dispose of their LIBs.

Please note that other standards may also apply to lithium batteries, for example U.S. DOT's shipping regulations and voluntary product safety standards. Additionally, although LIBs disposed in household trash are exempt from federal HW regulations, states can be more stringent and have the authority to regulate solid waste. Therefore, there may be additional state and/or local rules for discarded batteries. Voluntary standards, state regulations, and other safety regulations are not discussed in depth in this document but are critical for safety throughout a battery's lifecycle.

1.4) Lithium-ion Batteries in the Municipal Waste Management Process

Municipal waste usually travels through numerous waste management facilities from the point of generation to the end facility. Originating at homes or businesses, municipal waste then goes to landfills, recycling facilities, or incinerators, with optional stops between. Unfortunately, LIBs can be incompatible with this complex waste management ecosystem in numerous ways. LIBs can be damaged at many different steps of the waste management system, such as when waste is dumped onto tipping floors, loaded or unloaded from transportation vehicles, manipulated with heavy machinery, or processed on conveyor belts and through screens (Timpane et al., 2017). In particular, the highly mechanized processes at MRFs can damage LIBs and trigger thermal runaway, potentially leading to injuries, monetary losses, emergency response, and service disruptions, among other impacts. The number of

LIBs entering municipal waste is also growing rapidly, raising the likelihood of fires caused by LIBs. One MRF tracked the LIBs it pulled out of its incoming recyclables and collected over 1,000 LIBs in less than five weeks—that means that over five LIBs, each of which poses the potential to start a fire, entered the facility *every hour* (Timpane et al., 2017). Reports from operators of MRFs and landfills also indicate that the number of LIBs in the waste management process has risen precipitously in recent years, forcing workers in these facilities to become *de facto* experts at spotting the batteries and extinguishing the fires that they inevitably ignite.[6]

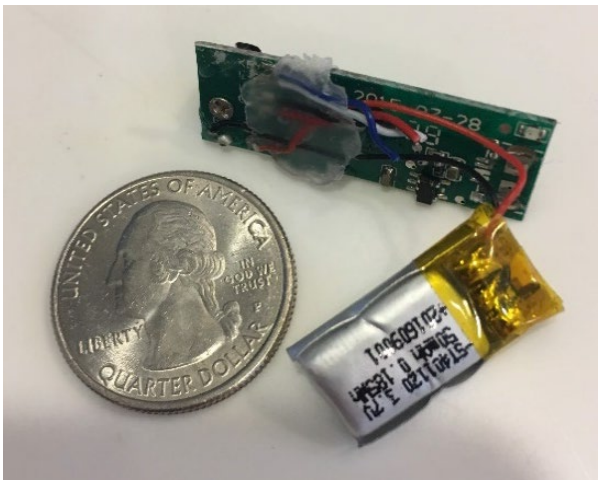

Figure 2: Photo of a small LIB. LIBs can be smaller than a quarter and integrated into a device with other electronics

Dedicated LIB recycling programs could alleviate these problems by diverting batteries that would otherwise enter municipal solid waste (MSW), and could also help meet increasing market demand for LIBs driven by growing demand for electric vehicles, energy storage systems, and portable consumer electronics (Argus, 2017; Ding et al., 2019; Timpane et al., 2017). Recycling could halve the amount of raw natural resources needed for LIB production, decreasing both the amount of ore that must be extracted from the earth and the amount of greenhouse gases emitted in the process (Dewulf et al., 2010). Since raw materials account for over half of the production costs of LIBs (Jacoby, 2019), increasing recycling rates could also drive down battery costs.

Reliable data on LIB recycling is not yet available. A common assumption is that the recycling rate is low,[7] due to technical constraints, economic barriers, logistical issues, and regulatory gaps. This assumption is not universally held, at least internationally and particularly in regard to electric vehicle battery recycling, where it is thought to be higher (Melin, 2019). Most battery recycling occurs outside the United States, although a number of LIB recyclers are in the process of starting operations in the United States in the coming years (Kumagai, 2021). A 2019 report by a London consulting firm estimated that as many as 85,000 metric tons of LIBs were recycled in China and South Korea in 2018, while at most 12,000 metric tons were recycled in the United States, Canada, Europe, and Japan combined (Melin, 2018, 2019). Whatever the true recycling rate is, industry reports that it is growing. On the collection side, Call2Recycle, an organization that supports the collection of LIBs and other batteries for recycling, saw a 36% year-over-year increase in their LIB collection volume in 2019 (Call2Recycle, 2020). Consumers may be becoming more aware of the importance of recycling LIBs due to advocacy campaigns[8] and fires widely reported in the media,[9] but recycling rates for these materials most likely

[6] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and Industry Experience 2 and facility 45: Pacific Northwest Landfill

[7] The literature often refers to a battery recycling statistic that originated in Europe and is close to a decade old; namely, that only about 5% of global LIBs are recycled (European Battery Recycling Association, 2011; Friends of the Earth Europe, 2013; Melin, 2019).

[8] See Industry Experience 3 and facility 6: Larimer County Landfill's Recycling Center, Fort Collins, CO

[9] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA

still lag far behind other recyclable materials and higher levels may be needed to sustainably meet future demand.

1.4.1) Waste Containers and Storage

LIB waste is created when batteries that are no longer functional or desired are disposed, often in trash cans or other storage containers. LIBs are often found discarded in the general trash and recycling bins, rather than specialty battery drop off bins, which can be found in some public facilities or large stores.

Regular waste or recycling bins are not designed for LIBs. Many consumers are not aware of LIB best practices for disposal, which include taping the terminals and/or bagging batteries individually. When discarded in recycling bins or garbage cans without using these best practices, batteries can be jostled together, which could lead to damage. Batteries may also encounter liquids in the bin, including chemically reactive materials. Battery terminals may touch other metallic objects, which could cause the battery to short-circuit and start a fire (Pipeline and Hazardous Materials Safety Agency, 2019).

Some varieties of LIBs may pose additional risk when disposed improperly in garbage cans. For example, LIB-powered vape pens can turn on accidentally in trash cans and start fires by igniting trash. Such an event occurred in Mound, Minnesota: a battery collection bin at the Westonka Library experienced a small fire when a discarded vape pen flipped on and ignited the contents of the collection bin.[10] The fire was extinguished by staff before any damage was done, but the incident shows a danger of disposing of LIBs, even when they are still in devices. Had this fire occurred outside of business hours without staff present, it could have caused a larger fire, potentially injuring first responders or damaging the building.

1.4.2) Transportation

Municipal waste is then collected from containers and transported to facilities. Transportation is usually done by a municipal or commercial waste management vehicle, or less commonly, the waste generator transports their own waste directly to a facility. Waste may also be transported on general transportation trucks or trains, which may not be as prepared to deal with garbage fires as waste management trucks are.

Waste is usually collected by separate recycling and MSW trucks. Some areas may also have specialty vehicles, such as scrap metal trucks. Vehicles are designed to transport certain types of waste, but most are not designed to safely handle LIBs.

Garbage trucks crush waste with on-board compactors. These compactors may damage LIBs, which sometimes leads to the batteries undergoing thermal runaway and igniting the surrounding trash. When this occurs, the standard protocol for haulers is to find a safe location to dump the burning trash and wait for the fire department to arrive and extinguish the fire. However, if the fire gets large enough, trucks and surrounding areas may be in danger of igniting as well.

LIBs may encounter materials they are not designed to touch in transit. This includes other batteries, liquids, acids, alkalis, or other reactive compounds (including bleach, ammonia, or battery acid) (Timpane et al., 2017). Reactions may occur due to this contact, which is another potential way a fire could start.

[10] See facility 52: Westonka Library Battery Drop-off Bin, Mound, MN

LIB fires may also remain unnoticed for longer when they occur in transit. LIBs could be packed below other material and fires may not be immediately visible. An incident may only be noticed after combustion occurs, due to drivers being unable to see the smoke while driving. Such an incident occurred in Livingston County, Michigan, when an LIB fire started in a transport truck.[11] The semi-tractor driver managed to detach his truck cab before the fire spread, but his trailer was damaged by the time he noticed the fire.

The US Department of Transportation (DOT) regulates the movement of hazardous materials, like lithium batteries, when transported in commerce as in the case of contract waste haulers or commercial recyclers. Lithium batteries must be packaged per the regulations found in 49 CFR 173.185, which include requirements for inner packaging, strong rigid outer packaging and protection against short circuits. Marking to indicate the presence of lithium batteries must be placed on each outer packaging. Any commercial entity, such as a battery collection program, is subject to these requirements. Private individuals disposing of household lithium batteries are not subject to these requirements unless they are preparing the battery for shipment using a shipping/mail-in program. Shipments made using carriers other than the United States Postal Service (USPS) are subject to the DOT requirements. Any shipments made using USPS, if authorized, are subject to USPS requirements and restrictions.

More information on DOT requirements can be found on their webpage.

1.4.3) Intermediate Sites

Waste may stop at intermediate sites before arriving at the end-of-life facility. Intermediate sites include transfer stations and drop-off locations like convenience centers.

Transfer stations consolidate waste from different collection routes. These facilities may be located in rural areas too small to support their own landfills or MRFs, and they play an important role in the hub-and-spoke system of waste management. In this system, waste is collected and consolidated at transfer stations and brought to a centralized “hub” location for processing. At the transfer station, typically trucks dump waste onto a tipping floor and it is then loaded onto vehicles, often larger tractor-trailers (Virginia Department of Environmental Quality, 2018). If batteries have been damaged in the transport process, the jostling from unloading and reloading could potentially start fires.

Convenience centers are waste drop-off centers for customers. They are sometimes used for materials that are not accepted at curbside pickup. Waste is stored here and typically transferred to another facility for disposal or processing. Dangers here are similar to those seen at other facilities like MRFs; for example, in Rutherford county, Tennessee, a vacuum cleaner containing an LIB caught on fire when it went through the compactor at the convenience center.[12]

1.4.4) End-of-Life Facilities

Waste LIBs will ultimately end up at a facility designated for recycling, energy recovery, or disposal. These facilities include specialty recyclers (e.g., battery recyclers or electronics recyclers), scrap yards, MRFs, waste-to-energy plants, and landfills.

[11] See facility 26: Sunview Logistics Truck, Livingston County, MI
[12] See facility 58: Rutherford County Solid Waste Convenience Center, Murfreesboro, TN

Battery Recyclers

The ideal end location of an LIB would be a dedicated battery recycler: a facility that is designed to receive LIBs and separate components for recycling into new batteries. In many LIBs, the concentrations of cobalt, nickel, lithium, and manganese exceed the concentrations in natural ores, making spent batteries akin to highly enriched ore (Jacoby, 2019). Thus, waste batteries are a valuable resource, and specialty recyclers provide the opportunity to recover these materials.

Battery facilities mainly recycle LIBs through mechanical or physical separation, pyrometallurgy, or hydrometallurgy. Some facilities use multiple methods to maximize material recovery. The industry is still growing, so new recycling methods are being developed. One method that is being tested at lab scale is direct recycling, in which the engineered cathode structure is maintained throughout the recycling process for use in new batteries (ReCell Center, 2020).

Mechanical or physical separation splits battery components into smaller constituent parts. Larger battery packs (e.g., electric vehicle batteries) may be made of dozens of modules and hundreds of individual cells, which can be split up during the recycling process. After additional processing is done, materials may also be physically separated further with filters, magnets, or sieves (Harper et al., 2019).

Pyrometallurgy (e.g., smelting) is a process that heats material in a high temperature furnace to extract metals. Units run as high as 1,500 °C and the process can recover cobalt, nickel, and copper, but not lithium or aluminum, which end up in a waste residue called slag (Jacoby, 2019). The high heat required causes this process to be energy intensive. An alloy of cobalt, nickel, and copper is the final product, along with residual gases and slag (Harper et al., 2019). The resulting alloy requires more processing to extract individual minerals to be used as components in the battery supply chain.

Hydrometallurgy is a chemical leaching process for extracting and separating cathode metals. It generally has lower capital costs than pyrometallurgy. The process can run below 100 °C, requires less energy than pyrometallurgy, and recovers lithium in addition to the other metals recovered by pyrometallurgy (Jacoby, 2019). The process uses a liquid bath to extract the metal from batteries, which can be composed of caustic reagents such as hydrochloric, nitric, or sulfuric acids (Jacoby, 2019). Different facilities have different processes; for example, one facility crushes batteries under a liquid solution to produce metal solids (known as “black mass”), metal enriched liquid, and plastic fluff (Chen et al., 2019). Materials are then sent to metal refiners for purification and sold back into the market to be made into new batteries and other products.

Even though battery recyclers are designed to process LIBs, fires may still occur. For example, batteries in storage at recycling facilities are at risk of fire prior to recycling. If any of the batteries have been damaged in prior steps of the waste process, a fire could start at any time. Such an incident occurred in Ellwood City, Pennsylvania, when cell phone and radio batteries in storage ignited and burned down a recycler’s warehouse.[13]

Recyclers may also be able to target LIBs for direct reuse. The reuse market is still growing, but one such potential reuse application is giving electric vehicle batteries a second life as energy storage batteries (Harper et al., 2019). Second-life LIBs may also serve as a replacement for lead-acid batteries in various

[13] See facility 57: Inmetco, Ellwood City, PA

applications (e.g., automotive starter batteries, forklifts, and telecommunications backup power systems) (Neubauer et al., 2015).

Electronics Recyclers

Electronics recyclers collect and disassemble various types of electronic products including cell phones, tablets, computers, and printers, and may then shred the scrap or send the scrap out to processors for further treatment. Such processers may be domestic specialty recyclers, or recyclers abroad in South Korea, China, Singapore, Belgium, Germany, or other countries (Chen et al., 2019).

Electronics recyclers are set up to process electronics, not energy storage devices, but now often receive products containing LIBs. For safety reasons, the battery is typically removed from devices prior to processing. However, removing LIBs from some products (e.g., laptops, cell phones or headphones) can be particularly difficult. These devices often contain embedded LIBs that are encased in plastic or glued into devices, making them very difficult or even impossible to remove intact. Electronics recyclers make money per device, and embedded and glued-in batteries slow down the dismantling process dramatically. For example, an iPad with a glued-in LIB may take 40 minutes to disassemble and be worth $1, at most, in scrap (Fowler, 2018). Embedded batteries in electronics jeopardize the economics of the electronics recycling industry. Employees spend time retrieving a low-value product, and, when an LIB starts a fire, even more time is lost and workers' health is threatened. Such an incident occurred at an electronics recycler in Madison, Wisconsin, when a cell phone burst in flames as an employee attempted to remove the battery.[14]

Scrap Yards

Scrap yards collect, sort, and consolidate scrap metal to be resold and recycled into new products. Scrap metal is often bulky (such as from scrap cars and construction scrap) so scrap yards use shredders to shred and consolidate the material. Just like garbage truck compactors, shredders pose a risk: any LIBs that go through the shredder can be punctured and start fires.

The large stockpiles of scrap metal present at most scrap yards also pose a risk if damaged LIBs are present. For instance, a fire started in a 3,000-pound stockpile at Simon Metals in Vancouver, Washington.[15] The battery may have arrived damaged, or may have been damaged in the pile. Sometimes scrap piles are so large that fires deep in the pile can go unnoticed, and when smoke or flames become visible, it can be challenging to put the fire out.

Materials Recovery Facilities

MRFs receive and sort scrap paper, plastics, glass, and metals into separate streams. Different types of recyclables are baled by category and sent to recyclers. Any remaining non-recyclable materials are then sent for disposal. If spotted in the separation process, LIBs will be taken out of the MRF and sent to a specialty recycler or landfill. If LIBs go unnoticed, they may become damaged by the sorting process. Belts, fans, and shakers can jostle batteries against the other materials and can lead to batteries being damaged and starting a fire. Conveyor belts may then send smoldering batteries throughout the facility

[14] See facility 64: Cascade Asset Management, Madison, WI
[15] See Industry Experience 5 and facility 63: Pacific Coast Shredding, Vancouver, WA

unless the belts are stopped. Furthermore, MRFs are full of flammable material. When fires do start, they may spread quickly due to the large amounts of paper and cardboard present.

The overall U.S. recycling rate has grown on average over time, up to 32.% in 2018 (Environmental Protection Agency [EPA], 2020b). Consequently, throughput at MRFs has increased dramatically in recent years, from an average of 129 tons per day in 2001 to 214 tons per day in 2014 (Governmental Advisory Associates, Inc., 2013, as cited in Gershman, Brickner & Bratton, Inc., 2015). Part of this increased material includes contaminants that MRFs are not designed to process, like LIBs. A study done in Florida found an average contamination rate of 25% at MRFs (Townsend & Anshassi, 2020). Mistakes and so-called "wishful recycling" result in many non-recyclable materials showing up in MRFs. As an example, consumers may think plastic earbuds are recyclable without considering the embedded battery within. As there are no standardized labels in the United States for LIBs, and the products are often labeled for international compliance, LIBs are also sometimes labelled with the "chasing arrows" recycling symbol and/or that of a trash can with an 'X' over it (figure 3), which can confuse customers and lead to LIBs being tossed in regular recycling bins rather than being sent to specialty recyclers.

Figure 3: Photo of an LIB labeled with various symbols. LIBs are sometimes marked with symbols both to encourage recycling (bottom left) and to discourage disposal in household waste (bottom right), causing confusion.

Waste-to-Energy Plants

Waste-to-energy (WTE) plants burn waste for energy recovery and volume reduction. Some MSW collection goes straight to WTE plants if landfilling is not available or not desirable in a location. Some waste that is not recyclable and not landfilled also gets sent to WTE plants from MRFs. Material is typically brought into facilities on trucks and dumped onto a tipping floor before incineration. The leftover ash is then disposed in landfills.

Even though waste is supposed to combust at WTE plants, sometimes combustion occurs before waste hits the furnace. Fires can occur on the concrete tipping floor as LIBs are jostled when dumped from garbage trucks, as is thought to have occurred at one WTE plant in Spokane, Washington.[16]

Landfills

MSW landfills are the final destination for most trash generated in the United States (EPA, 2020b). Some landfills sort waste as it arrives, which can lead to LIBs getting pulled out and diverted from the landfill. Without sorting, the batteries will be placed in the landfill with other waste. At this point, the batteries have likely been jostled, crushed, and compressed, so they are very likely to be damaged at this stage. Damaged batteries may then start fires in the landfill, using the surrounding waste as fuel.

Landfills have a few unique characteristics that lead to an increased risk of LIB fires. When trucks or compaction equipment drive through active landfill cells, batteries may be crushed under their wheels

[16] See facility 61: Spokane Waste-to-Energy Plant, Spokane, WA

and ignite the surrounding waste. Walking on the landfill surface is dangerous, so operators take on a certain level of risk when they exit their vehicles to extinguish fires. Batteries may also be exposed to direct sunlight before the landfill cover is applied, which can result in fires being ignited. As garbage decomposes in landfills, temperatures in piles can rise. These higher temperatures can also lead to fires.

Other types of landfills include construction and demolition (C&D) landfills, coal combustion residual (CCR) landfills, and polychlorinated biphenyl (PCB) landfills. C&D landfills could potentially have batteries and flammable construction debris, but CCR and PCB landfills are unlikely to contain LIBs.

Hazardous Waste Disposal Facilities

Some landfills are designated for HW disposal and contain more protections than MSW landfills. Such landfills may also have batteries, as batteries can be designated as universal waste, and therefore managed as HW across the United States. HW landfills are subject to land disposal restrictions and the wastes in them are subject to treatment standards.

However, treatment may not always remove fire hazards for LIBs. Numerous HW facilities experienced severe fires in the early 2000s from waste lithium primary batteries. In one extreme case, the resulting fire burned down the entire facility, which was never rebuilt (D. Case, personal communication, March 17, 2021). More recently, a 2019 fire in a Western HW landfill was likely started by a lithium battery coming into contact with pool chemicals in a landfill cell (EPA, personal communication, 2019).[17]

1.5) Review of Non-Waste Lithium-ion Battery Incidents

LIBs are not just a hazard in waste processing. There have been many documented incidents involving non-waste LIBs. Granted, LIBs are quite safe when not improperly disposed, with a failure rate of less than one in a million (St. John, 2016). Despite this low failure rate, LIBs are so ubiquitous that numerous high-profile incidents have occurred, prompting various U.S. government agencies to place limits and warnings on consumer LIBs. Although some of the following battery fires are due to overcharging, which is largely irrelevant to the waste process, the incidents illustrate the fire risk posed by LIBs—a risk that does not go away once the batteries enter the waste system.

1.5.1) E-cigarettes

E-cigarettes constitute one particularly noteworthy source of improperly disposed LIBs. According to the US Centers for Disease Control and Prevention (CDC, 2020), e-cigarettes, also known as vapes or mods, simulate smoking a cigarette by delivering a cloud of aerosol, flavoring, and (sometimes) nicotine when the user inhales. With nearly 500 different brands of e-cigarette to choose from (Zhu et al., 2014), Americans have widespread access to a multitude of vaping products. In 2018, the National Center for Health Statistics at the CDC found that nearly 15% of Americans had used an e-cigarette at least once, with over eight million adults actively using e-cigarettes (Villaroel et al., 2020).

E-cigarettes can be rechargeable or non-rechargeable, but both formats contribute batteries to the waste system. Users of non-rechargeable e-cigarettes may incorrectly assume these devices can be discarded in their household trash because they are often branded as “disposable.” This leads to the entire device, including its (often lithium metal) battery, entering the municipal waste. Meanwhile, users of rechargeable vaping devices sometimes modify their device by switching out components, including

[17] See facility 40: Western HW Landfill

the battery.[18] This creates the additional potential that rechargeable vape devices are contributing LIBs to municipal waste even before the e-cigarette itself reaches end of life. Compounding the problem, these LIBs may be damaged during the removal process, increasing their likelihood of ignition. Between this large and growing source of end-of-life LIBs and mistaken consumer perceptions that e-cigarettes and their batteries are disposable in household trash, vape batteries could pose one of the greatest fire risks to the waste system.

Granted, some technological advancements and standards have been made to address the fire threat posed by e-cigarette LIBs, but these efforts have not fully succeeded. Many vapes include timeout devices to prevent overheating and locking mechanisms to prevent unintentional activation, but anecdotal evidence indicates those safety devices do not always prevent a fire.[19] These measures also do nothing to prevent fire caused by damage done to the e-cigarette's LIB during waste processing. To address the potential damage from use and handling, Underwriter Laboratories, a technical standards-setting organization, has issued Standard 8139, Electrical Systems of Electronic Cigarettes as a voluntary set of guidelines and testing criteria specific to e-cigarette batteries (Underwriter Laboratories, n.d.). However, these standards focus on consumer safety and do not extend to end-of-life considerations.

Similarly, regulatory standards applied to e-cigarettes focus much more on their use and direct health effects than on the safety issues they create at end of life. In 2016, the Food and Drug Administration (FDA) issued a final rulemaking regulating e-cigarettes as tobacco products, but these regulations do not address waste issues. The FDA also considered creating a requirement for e-cigarette manufacturers to test the safety of their products' electronic systems (including LIBs) but has not done so. Rather, FDA has encouraged e-cigarette manufacturers to adhere to Underwriter Laboratories Standard 8139 (Food and Drug Administration [FDA], 2019).

To investigate this issue, the United States Fire Administration (USFA, 2017) collected data on nearly 200 incidents in which e-cigarette batteries started a fire or exploded. In two-thirds of these incidents, the battery caused ignition of some other material—reflecting the potential danger e-cigarette-derived LIBs pose in the waste management process, where the batteries will be mixed with other combustible materials like wastepaper and textiles. The frequency of these events has increased drastically in recent years as e-cigarettes become more prevalent, mirroring a similar increase in LIB-caused fires at waste facilities (USFA, 2017).[20] Many of these non-waste e-cigarette incidents were relatively minor because people were around to respond, but that is not always the case once LIBs get disposed and escape close supervision.

1.5.2) Hoverboards with Counterfeit Batteries

Hoverboards are LIB-powered transportation devices that made headlines in the 2010s due to their tendency to catch on fire. These incidents caught the attention of the Consumer Product Safety Commission (CPSC), a federal agency charged with protecting the public from injury or death due to consumer products. CPSC has elevated hoverboard safety concerns to the level of other, more well-

[18] The Consumer Product Safety Commission (2021) has issued a warning to discourage consumers from using individual lithium-ion cells that have been separated from LIB packs to power e-cigarettes, as doing so can lead to fires and their associated hazards.

[19] See facility 52: Westonka Library Battery Drop-off Bin, Mound, MN

[20] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and Industry Experience 2 and facility 45: Pacific Northwest Landfill

known consumer concerns: hoverboards have their own category on CPSC's website, along with other broad categories of products like cribs, bicycles, and toys.

This elevated level of concern is due to high incidence of injuries and fatalities. There have been over 250 fires or overheating incidents involving hoverboards since 2015. CPSC estimates there have been 13 burn injuries, three smoke inhalation injuries, and more than $4 million in property damage related to fires from hoverboard batteries. In March 2017, a 2-year-old girl and her 10-year-old sister died in a house fire ignited by a hoverboard in Harrisburg, Pennsylvania (Consumer Product Safety Commission [CPSC], 2020). As a response to these incidents, there were 20 hoverboard recalls in 2016 and 2017.

Hoverboard fires are linked to the issue of counterfeit or poorly made LIBs. Batteries or devices purchased online may bear a brand name but in fact be counterfeit products. These counterfeit batteries may not be produced at the same level of quality and could pose a danger to consumers. The U.S. Customs and Border Patrol has stepped up enforcement of this issue at ports of entry, and has seized hoverboards containing counterfeit batteries valued in the millions of dollars (U.S. Customs and Border Patrol, 2016).

Hoverboards and counterfeit batteries can continue to pose a danger after disposal as part of waste processing. Three incidents of waste hoverboard fires have been noted in our report, in New Jersey, Washington, and Oregon.[21] Two of these fires occurred in garbage trucks and were extinguished by local fire departments, and the other occurred in a landfill and was extinguished by a staff member. Such incidents illustrate how products causing fires in use can continue to cause fires in the waste management process.

1.5.3) Lithium-ion Batteries on Planes

The Federal Aviation Administration (FAA) has noted that LIBs pose a threat to passenger aircraft when present in passenger luggage or cargo (Federal Aviation Administration [FAA], 2017). There have been at least 300 incidents of fires started by lithium metal and lithium-ion batteries on planes between 2006 and 2020 (FAA, 2020). For example, a plane flying from Newark, New Jersey, to The Bahamas in early 2020 had to make an emergency landing in Florida when a passenger's external charger caught on fire (Jones, 2020).

This problem exists in part because passenger-held Portable Electronic Devices (PEDs) pose a greater risk than the same devices do when shipped by the manufacturer. When PEDs are shipped from the manufacturer, batteries are either not installed or are at a reduced state of charge (about 30%), and protected from damage per DOT regulations (FAA, 2017). When passengers carry PEDs on planes, the LIBs are installed in devices and likely highly charged, potentially with minimal protection from damage. To counter these risks, FAA recommends that laptops should be turned off when in transport, as the risk is greater when devices are in standby/sleep mode since the battery can overheat. FAA also requires that spare LIBs and e-cigarettes be held in the cabin, rather than in checked bags in the cargo hold (FAA, 2016), so that if a fire occurs, it can be addressed quickly without damage to the aircraft.

LIBs can also pose a threat to cargo planes, even though batteries should theoretically be packaged safely by the manufacturer. Some incidents have even been fatal, such as the tragic UPS cargo flight in Dubai that crashed due to a fire believed to have been started by LIBs (Jansen, 2013).

[21] See facility 29: Atlantic County Utilities Authority Truck, Brigantine, NJ; facility 34: Municipal Garbage Truck, Bellevue, WA; and Industry Experience 2 and facility 45: Pacific Northwest Landfill

1.5.4) Samsung Galaxy Note 7 Recall

In 2016 Samsung issued a total recall for all units of the Galaxy Note 7 in what may be the most famous case of fires from LIBs in consumer electronics. Samsung's internal investigation of the event found that two different faults with the phones' LIBs were to blame. First, LIBs with crimped edges allowed the electrodes to make contact, creating a short circuit that rapidly heated up and triggered a thermal runaway in the rest of the cell. Samsung recalled these units, but soon found that a different battery type—used in other versions of the Note 7 and in the replacement units Samsung distributed following the first recall—also suffered short circuits and thermal runaways caused by rough edges on the cathode of the LIB. The recall itself was an overwhelming success, with over 96% of all phones collected (Gikas & Beilinson, 2017), but this event illustrates the severe ignition potential of LIBs in phones and other devices.

Making matters worse, some commentators argue that the trend toward thinner phones is driving manufacturers to use thinner separators in their LIBs, increasing the likelihood of a separator puncture that in turn triggers a short circuit and thermal event (Gikas & Beilinson, 2017). If this is the case, improperly disposed LIBs in cell phones and other devices will be even more prone to ignition caused by physical abuse as they pass through the waste system.

1.6) Existing Waste Incident Surveys

The waste industry has seen the frequency of LIB fires grow for years, but the problem has remained largely anecdotal. To attempt to quantify the scope of this issue, some organizations have recently conducted surveys of waste management facilities to gather data on the growing number of facility fires. These surveys vary from targeted efforts in California, to a broad survey of North American waste facility fires, to a 2017 effort that directly targeted MRFs. As our goal was to collect up-to-date data on fires caused by LIBs in the waste management process using open data and news articles, our effort is complementary to these surveys and further illustrates the growing problem of LIB fires throughout waste management.

1.6.1) California Product Stewardship Council Survey

The California Product Stewardship Council is an organization that supports stronger end-of-life management for products and Extended Producer Responsibility (EPR) programs. The group conducted a survey in 2018 on fires at waste management facilities in California (California Product Stewardship Council, 2018). Of the 26 surveyed waste facilities, 83% reported having a fire at their facility in the past two years. Forty percent of those fires were caused by LIBs, with another 25% sparked by other types of batteries (figure 4). These incidents were not reported as being caused by LIBs to the media according to our research, which means that they may have been small fires and not newsworthy. However, surveys of this kind shed light on a growing problem which may not be fully reflected by the media.

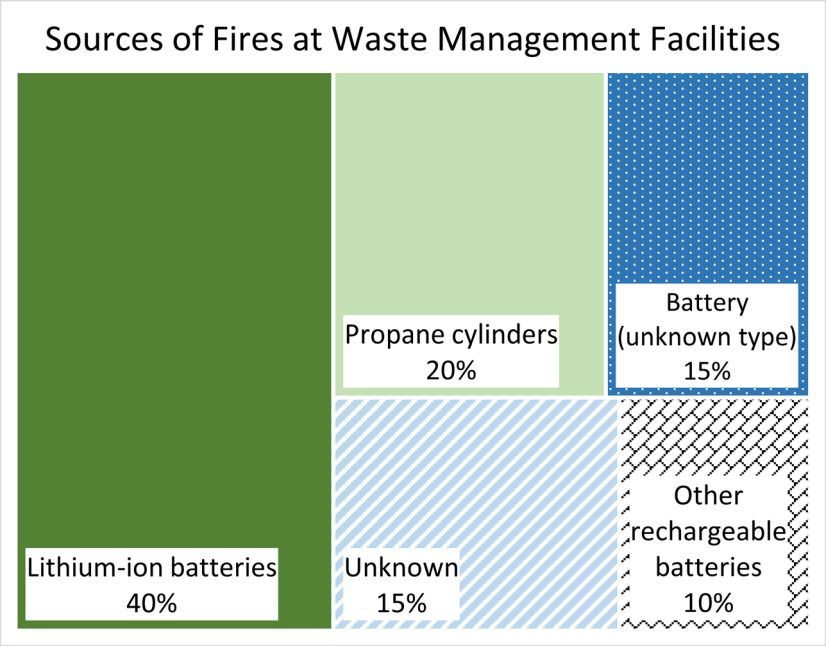

Figure 4: Sources of Fires at California waste management facilities, according to a 2018 survey by the California Product Stewardship Council

1.6.2) Fire Rover Report

Fire Rover, a firm that produces fire prevention products, tracks the number of fires at waste and recycling facilities across the United States and Canada and publishes their data in an annual report. The report includes fires from sources other than LIBs but shows an alarming year-over-year increase in waste fires. There were 343 fires reported at waste and recycling facilities in the United States and Canada in 2019, causing 49 injuries and two deaths. This represents a 158% increase in injuries from Fire Rover's 2018 report (Fogelman, 2020).

The report's author believes that fires are underreported, and that there were actually more than 1,800 facility fires in 2019, or five times the reported figure. He cites LIBs as one of the four causes of the increasing number of facility fires, along with heat and dryness, the recycling export market tightening up, and seasonal spikes (Fogelman, 2020).

1.6.3) Resource Recycling Systems and South Bay Waste Management Authority Survey

Resource Recycling Systems (RRS) and the South Bay Waste Management Authority (SBWMA) surveyed 31 operators of 119 MRFs in 2017 across the United States. Respondents reported at least 168 fires in the previous two years at their facilities. Lithium-based batteries were found to be the most prevalent source of facility fires, ahead of pressurized propane, even though 83% of the surveyed facilities do not accept material from communities that include batteries in their curbside collection. The most common location that LIBs were reported to be found at MRFs was the tipping floor. Almost all of the operators were concerned about this issue, with a majority reporting that they were "very concerned" (South Bayside Waste Management Authority [SBWMA], 2017).

2) Methodology

Internet research was used to find incidents of LIB fires from news articles and waste facility websites. In limited cases, direct outreach to members of the waste management industry and searches of internal EPA records were used to locate additional incidents. Fires across the full spectrum of the waste management process were included, ranging from fires in recycling bins to fires in landfills. An incident was considered a fire if flames, smoke, or a smoldering battery were present. Incidents were only included in the report if LIBs or lithium metal batteries were mentioned as the definite or likely cause of the fire. Often, the exact cause of a given fire cannot be pinpointed after the incident, so fire inspectors and facility operators use their best judgement to determine the most likely cause. According to a landfill supervisor interviewed for this report, who has seen at least 124 LIB fires, fires described as "likely" caused by LIBs have a very high likelihood of actually being caused by LIBs.[22] Therefore, "likely" cases were included in the report so as to not exclude fire incidents that have a very high likelihood of being caused by LIBs. Cases were classified as likely being caused by LIBs if articles referred to LIBs with language deeming them the "suspected" or "likely" cause of the fire.[23] Incidents that were identified but ultimately not included in the report due to missing information can be found in Appendix 1.

This methodology necessarily introduces uncertainty into the number and nature of LIB fires actually occurring. When news articles gave a range of fire quantities at a facility, the lower end of the range was recorded to prevent over-counting. As such, the number of fires that occurred in the included facilities could be higher than we report. More broadly, many fires occurring at waste management facilities may go uncounted because data reporting for such incidents is neither required nor systematic. Relying on news sources therefore likely underestimates the number of fires that occur and may bias our results toward more extreme cases, as incidents causing severe damage or requiring emergency response are more likely to receive media attention. Thus, our analysis presents an illustration of the severity of the issue of LIB fires in the waste management process rather than a rigorous quantitative analysis.

The list of incidents was then analyzed, and four common fire impacts were identified. These impacts included "injury," "service disruption," "monetary" impacts, and "emergency response." "Injury" cases included incidents that resulted in anyone being sent to the hospital or being medically treated at the scene. "Service disruption" was used to indicate that waste collection or management operations were halted for a significant period of time. When news articles stated that a facility was closed for at least a day, a facility was destroyed, battery or recycling collection service was interrupted, or recyclables were landfilled, this is considered a disruption of waste collection and recycling services. For instance, a MRF that closed for a week for repairs or a battery collection program that was halted after a fire both would be considered "service disruption" cases. This impact category also includes instances where vehicles dumped trash in the street for the fire to be extinguished, as transportation service was interrupted until the fire is extinguished and dumped trash could be cleaned up. Those incidents that involved "monetary" impacts were flagged when a financial loss or hardship was caused by the fire. This could include structural damage that required repairs, increased insurance costs, or otherwise required the organization to spend funds that it otherwise would not have spent. Finally, cases that required

[22] According to this landfill operator, instances in which an LIB was thought, but not known, to be the cause of a fire have at least a 90% chance of truly being linked to an LIB.

[23] A list of uncertainty language was compiled from all included cases categorized as likely caused by an LIB. The terms included "likely," "expected," "assumed," "suspected," "believed," or "possible" cause of the fire, with one additional reference to a fire that "may have been" caused by an LIB.

firefighters, emergency medical services, police, or any other emergency personnel to respond to the incident were marked as requiring "emergency response." Any other impacts or items of note were recorded and are presented in the Details and Impacts columns of the tables presented in section 3.4, Incident Tables.

Because news articles rarely provide exact information for these incidents, each incident was rated according to the likelihood of each impact having occurred as a result of the fire.[24] Incidents that likely or explicitly caused a given impact were recorded as having suffered that impact. For instance, if an article reported severe structural damage to a MRF but did not assign a dollar value to the damages, the incident would be recorded as likely having a "monetary" impact and would be included in counts and other data analysis of that impact.

Fire incidents were analyzed by the type of facility in which they occurred. This approach was selected to mitigate the effect of missing data; often, reports of a fire at a given facility mention other LIB fires at that location, but the impacts of the additional referenced incidents are rarely discussed. Thus, the impacts of LIB fires were analyzed by quantifying the number and proportion of facilities that have experienced each impact *at least* one time.[25] Facilities were categorized as MRFs, landfills, transportation, or other.[26]

Numerous representative cases were then selected for more in-depth qualitative data collection. EPA interviewed individuals familiar with five of the facilities to gather more information and learn about conditions on the ground at various waste management facilities. Interviews included both standardized questions asked of each facility representative and specialized questions that were intended to reveal greater information about the specifics of the facility or incident in question. The information gathered through these interviews is presented in the Industry Experiences sub-section of the Results section below.

[24] Ratings were made on a scale of likelihood. Impact categories explicitly stated in the article were marked 'yes,' while incidents that likely but not explicitly suffered an impact were marked 'likely yes.' Incidents in which an impact was unclear, unlikely, or stated not to have occurred were marked 'unclear,' 'likely no,' and 'no' respectively. Only 'yes' and 'likely yes' incidents were categorized as having suffered the impact.

[25] Geographically separate facilities owned or operated by the same overarching entity were treated as different facilities (e.g., Rumpke's operations in Cincinnati, Ohio and Bloomington, Indiana were treated as different facilities). Likewise, co-located facilities of different types (e.g., Shoreway MRF and Shoreway transfer station) were also treated as different facilities.

[26] 'Other' facilities included transfer stations, convenience centers, waste-to-energy plants, battery collection bins, electronics recyclers, and scrap metal yards.

3) Results

Quantitative data in the form of descriptive statistics are presented in the Findings and Charts section below. Trends in the reported impacts of the fires are then discussed in the Impacts section, after which qualitative information from industry interviews is presented in the Industry Experiences section. However, it should be noted that the collected data are neither a random sample nor a complete count of the myriad of LIB-related fire incidents at waste facilities across the United States between 2013 and 2020. Thus, these results illustrate the scope and intensity of this problem, but do not constitute a full accounting of recent LIB-linked fires in the nation's waste systems.

3.1) Findings and Charts

The research methodology uncovered 245 fires associated with LIBs at 64 waste management facilities. The most common facility category was MRFs (23), followed by transport facilities (13), then landfills (10). LIB fires were also recorded at 18 other facilities, including scrap yards, electronics recyclers, and WTE plants. Of the 64 total facilities covered by this report, 17 (27%) reported more than one LIB fire in recent years. However, it should be noted that stakeholder interviews (see section 3.3, Industry Experiences) and anecdotal evidence indicate that LIB-caused fires in the waste management process are severely underreported; therefore, both the frequency of LIB fires and the number of facilities affected by them are likely much higher.

Of the 245 fires recorded here, 68 took place at MRFs, 139 at landfills, 15 in transport, and 23 at other facilities. Most of these fires (89%) were definitely caused by LIBs, while the remainder were reported as likely caused by an LIB. The most common LIBs noted as the cause of fires were cell phone batteries, followed by tablet and laptop batteries. However, LIB fires often burn the battery beyond recognition, so most fires caused by LIBs in this report do not have a specific battery type noted. In these cases, the recovered battery may have been too charred to make determining a specific type possible, or a battery may not have been recovered at all, and a fire professional may have determined that the fire was caused by an LIB based on their expertise and prior experience.

Both the number of facilities affected and number of fires have increased dramatically in recent years, growing from only two fires being reported at a single facility in 2013 to 65 fires reported across 16 different facilities in 2020 (figure 5).

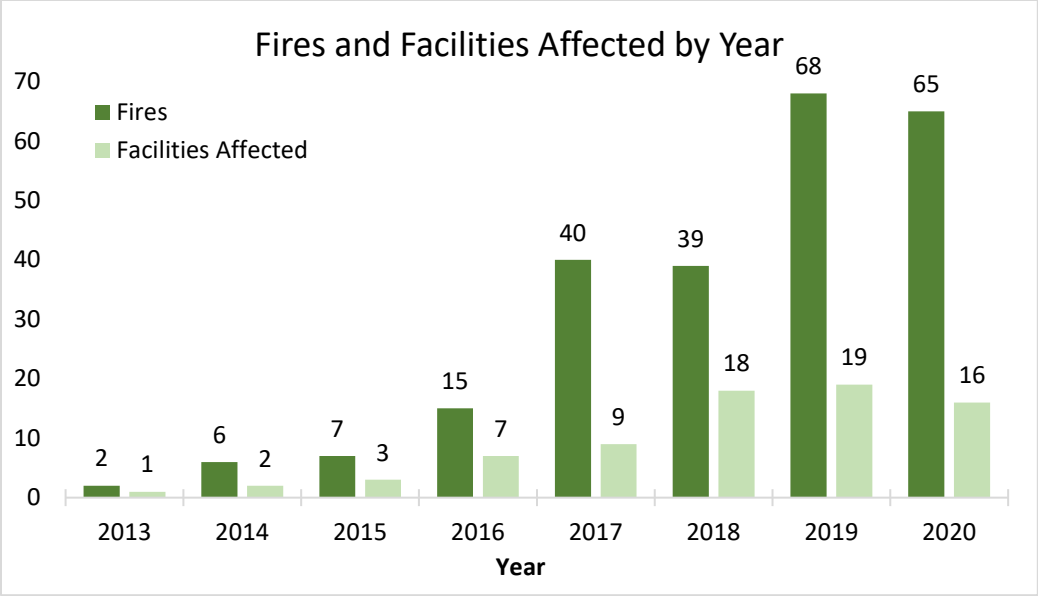

Figure 5: Facilities affected and number of fires by year

Much of this growth in incidents appears to have occurred at landfills and MRFs, though our data collection methodology may skew this result.[27] Regardless, all four facility types saw an increase in the number of facilities affected between 2013 and 2020 (figure 6). Affected facilities were located in 28 different states spread across the country, reflecting the nationwide impact of this issue (figure 7).

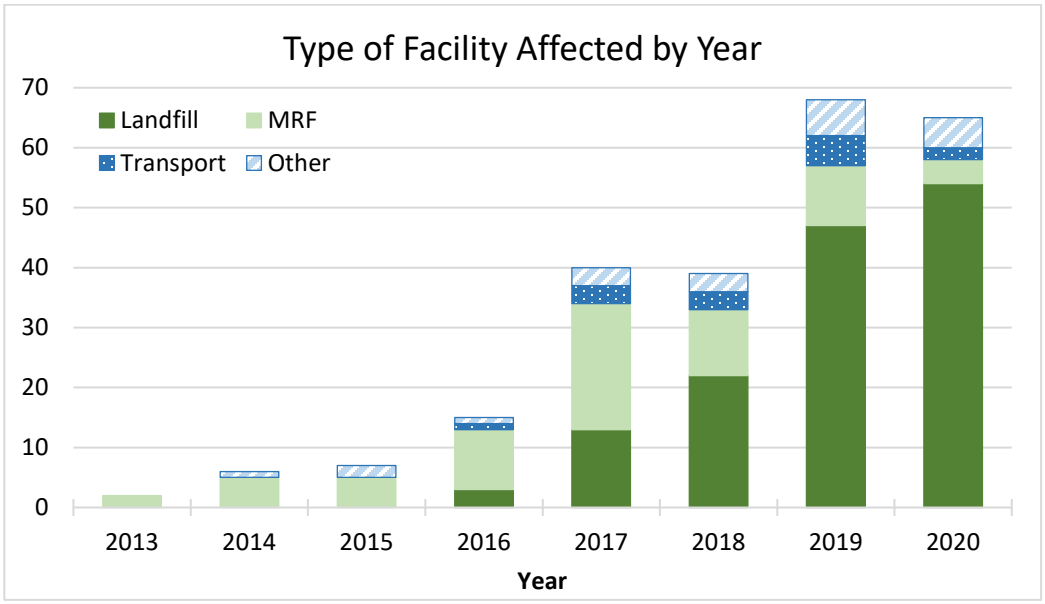

Figure 6: Fires by year and facility category

[27] These data may seem to imply that fires occur more frequently at MRFs and landfills than at other waste management facilities, but this trend results at least partially from our mixed data collection methods. In addition to compiling cases from news sources, we used data from one MRF and one landfill that kept detailed records of the LIB fires they experienced over numerous years. Thus, LIB fires at these types of facilities are overrepresented relative to the number of unique facilities.

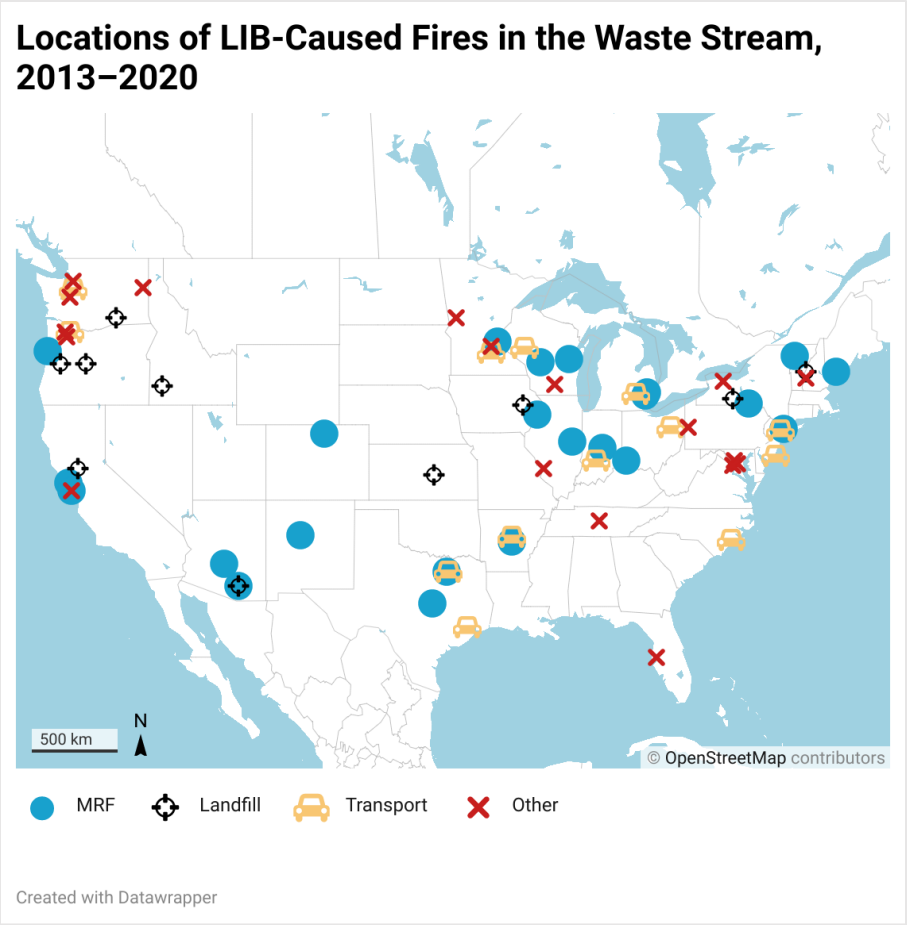

Figure 7: Locations of LIB-caused fires across the United States, 2013–2020

Although we know the location where fires occurred, the data do not include the origin of the discarded LIBs. We do not know in detail which fires were started by batteries discarded at homes, or at workplaces such as offices or hospitals. Most of the facilities and organizations that suffered fires receive waste from multiple sources, such as the New York City Department of Sanitation (DSNY). DSNY collects waste from a variety of sources in New York City, including residential MSW and institutional waste (New York Department of Sanitation, n.d.). Therefore, it is difficult to establish if the LIB that started a fire in a DSNY garbage truck was disposed in household waste or institutional waste, e.g., from a public school.[28] Additional information on the source of waste batteries could help establish the root cause of this issue, so future research in this area would be useful. However, our findings do show that most battery fires originated from LIBs collected from waste streams that include MSW. Household batteries are part of MSW, so it is likely that many of these fires started from a household battery that was improperly discarded. Additionally, many of the existing efforts to address this problem have focused on consumer education,[29] reflecting a general sentiment in the industry that many LIBs entering the waste management system originate from households.

[28] See facility 30: DSNY Truck, New York, NY

[29] See, e.g., Industry Experience 3 and facility 6: Larimer County Landfill's Recycling Center, Fort Collins, CO

3.2) Impacts

The cases included in this report illustrate the most common outcomes caused by LIBs at waste management facilities: injury, service disruption, monetary impacts, and emergency response. LIB-caused fires also have the potential to lead to many other impacts. Most news articles did not go into this level of detail, but LIB fires could ruin the recycling potential for batteries, paper, and plastics if material is scorched or saturated with water and foam, and could lead to increased carbon dioxide, particulate matter, or dioxin emissions (EPA, 2020a).

Every category of facility included in this report has experienced these four main impacts, but at different scales (figure 8). The most common impact was emergency response: 42 (66%) facilities where LIB-related fires occurred called emergency services at least once. MRFs most frequently required the assistance of fire departments or other first responders. In contrast, landfills rarely required external help with their LIB fires; staff members were generally able to extinguish the fires on their own. Service disruption and monetary impacts were both fairly frequent outcomes of an LIB fire, with 17 (27%) facilities experiencing the former and 19 (30%) experiencing the latter at least once. Seven facilities (11%) experienced at least one injury as the result of an LIB fire. Across the board, MRFs appear to be the most dramatically affected type of facility, as they experienced the highest amount of impacts.

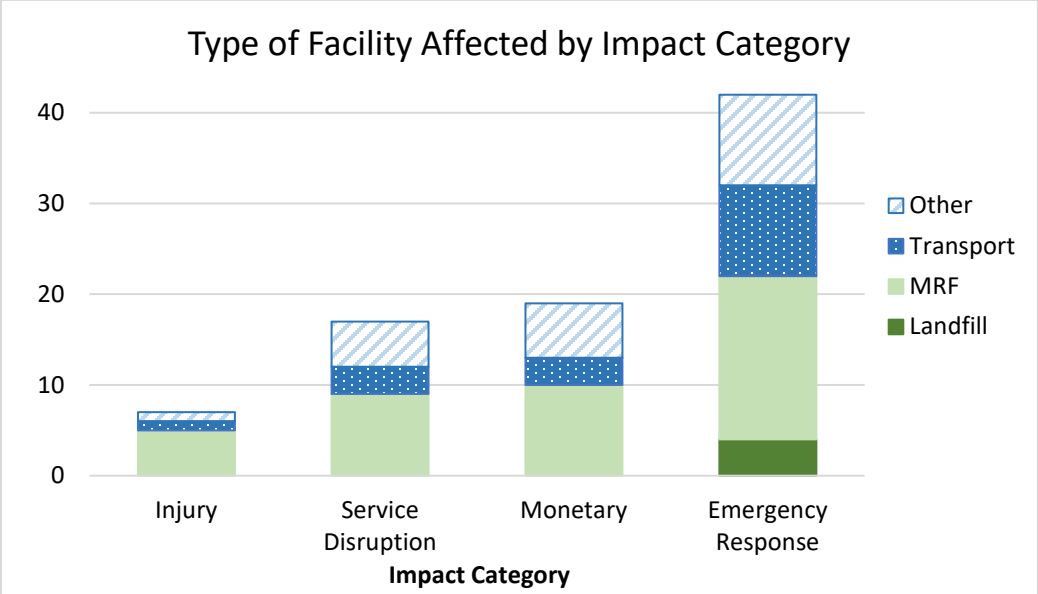

Figure 8: Fire impacts by facility type

However, this trend may be a result of the frequency with which MRFs experience LIB fires rather than a reflection of elevated risk at MRFs compared to other waste processing facilities. Regardless of the type of facility, a large proportion of most facilities affected by LIB fires have experienced many of the impacts considered. For instance, more than three quarters of LIB fires required assistance from emergency responders for both the MRFs and transportation facilities included in this report. In general, a large proportion of facilities that have experienced an LIB fire have experienced at least one of the negative impacts of these fires, though landfills seem to be more resilient than other waste management facilities (figure 9). This apparent trend may reflect the unique context of landfills. Landfill

fires are relatively common occurrences but do not often make the news, as they are usually small and regularly handled by staff rather than local fire departments. Landfills are also not located inside a structure, so the scope of property damage from a fire would be different than at an enclosed MRF.

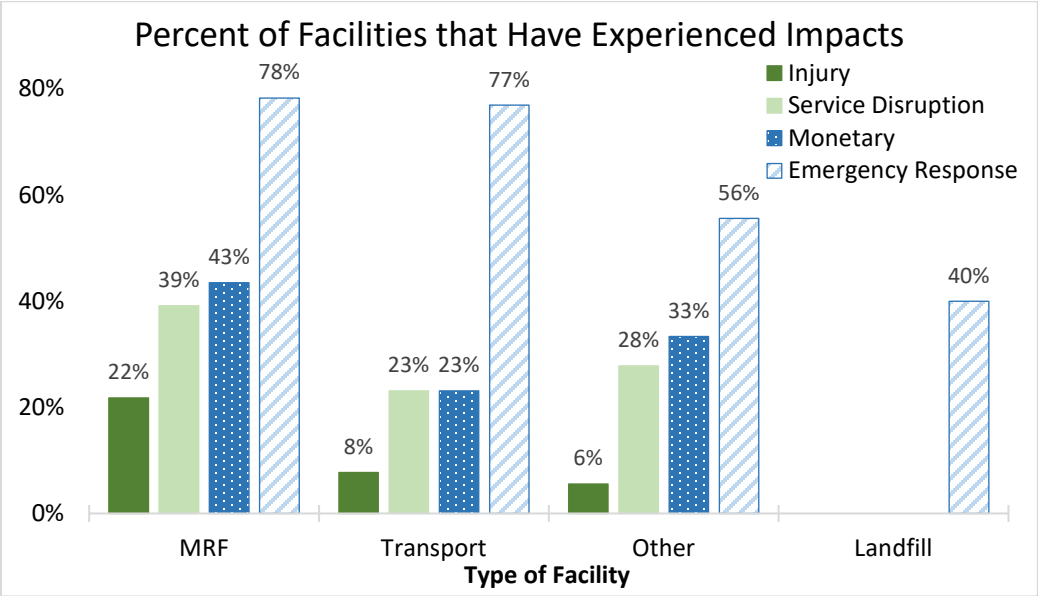

Figure 9: Percent of facilities that have experienced impacts

While not comprehensive, these data are illustrative because incidents at facilities that create major negative effects (e.g., millions of dollars of damage or terminated collection programs) are more likely to be covered by the media and therefore more likely to have been included in this report due to our methodology. However, the large number of LIB fires at waste facilities and widespread negative impacts revealed by this report's simple methodology indicate that LIBs that are discarded either through normal curbside trash, recycling, or dumpsters present a significant and growing threat that can be broken into four main categories.

3.2.1) Injury

Fires in the waste management process can quickly grow and become dangerous with high heat and smoke conditions, threatening the safety of firefighters, facility workers, and bystanders. Any fire has the potential to grow unsafe, and fires occurring during waste processing pose unique safety hazards. Many waste facilities are filled with materials with high heat value (like paper products or plastic recyclables), making them highly combustible and likely to burn aggressively. Landfills may have natural gas collection systems that are prone to ignition or explosion if they are directly impacted by a fire—a serious hazard for responding personnel. Fires that ignite while waste is in transit can also present unique hazards for first responders, as they may occur along busy roadways or in other high-traffic locations. It is due to the quick work of firefighters and facility staff that there were not more injuries caused by the 245 fires.

We found seven facilities where injuries were caused by fires: five MRFs, one garbage truck, and one other facility (a dedicated battery recycling operation). Firefighters and staff were treated for chemical

burns,[30] smoke inhalation,[31] heat exhaustion,[32] and other minor injuries[33] due to these LIB fires, either on site or at hospitals. There were no injuries found resulting from LIB fires at landfills.

The research also found numerous incidents that were close calls and could have resulted in injuries to firefighters, bystanders, or facility workers. For instance, a train carrying LIBs exploded in Houston, Texas, with enough force to destroy windows in the surrounding buildings and caused a local resident to be thrown up against the side of his house.[34] No bystanders were seriously injured in this incident, but the event could have been much worse. Electronics recyclers have also reported close calls with LIB fires to the media, such as when an iPad battery exploded while being disassembled at an electronics recycler in Wisconsin.[35] No employees were injured, but the area had to be evacuated. Such events are not uncommon. One out of every 3,000 mobile device batteries that this facility handles experiences a thermal event (Fowler, 2018).

Another potential risk of injury arises from exacerbated occupational hazards. For instance, landfill employees face an inherent danger in exiting a vehicle on top of active landfill cells. When there is a fire in the landfill, such as any of the dozens catalogued in the Pacific Northwest landfill cases,[36] employees are at risk of injury when they exit their vehicles to extinguish the fires. Similarly, MRF employees may be exposed to increased risks of slips, trips, and falls when evacuating the facility during an LIB fire.

3.2.2) Service Disruption

Facility fires can also lead to disruptions in waste and recycling collection services. When a fire starts, the waste processing stops until the fire is extinguished either by firefighters or staff, and services can remain stalled for a long time. The duration of a service disruption is usually proportional to the severity of the fire, but even small fires can cause services to be temporarily interrupted.[37] Service interruptions can lead to material either being landfilled, incinerated, or stored until service is restored. Typically, both the fire and firefighting tactics will damage the recyclable material present in a facility during a fire, as occurred in Fort Hood, Texas.[38] This fire damaged thousands of pounds of recyclables located at the MRF and caused twenty dumpsters filled with damaged recyclables to be landfilled. For longer service interruptions, even more material will be diverted from recycling. Such an interruption happened at a transfer station in Clearwater, Florida, when recyclable material was temporarily sent to a waste-to-energy plant after a fire interrupted facility service.[39]

LIB fires can also lead to facilities ending battery collection programs, depriving consumers of access to convenient waste collection services and causing environmental damage. In this case, LIBs may be landfilled or improperly recycled, propagating the cycle of negative effects from improper LIB disposal.

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[30] See facility 2: Friedman Recycling, Tucson, AZ; and facility 57: Inmetco, Ellwood City, PA
[31] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and Industry Experience 3 and facility 6: Larimer County Landfill's Recycling Center, Fort Collins, CO
[32] See facility 22: John's Disposal, Norway, WI
[33] See facility 15: Royal Waste Services, Queens, NY; and facility 26: Sunview Logistics Truck, Livingston County, MI
[34] See facility 33: Union Pacific Train, Houston, TX
[35] See facility 64: Cascade Asset Management, Madison, WI
[36] See Industry Experience 2 and facility 45: Pacific Northwest Landfill
[37] See facility 35: Waste Connections Truck, Washougal, WA
[38] See facility 19: Fort Hood Recycle, Fort Hood, TX
[39] See facility 48: Ybor City Waste Management Transfer Station, Tampa, FL

As a result of a large fire in an Urbana, Illinois, MRF that destroyed one of the facility's buildings, the facility ended its collection of LIBs.[40] Likewise, a dedicated battery drop-off program in Minnesota discussed earlier had to be halted after an e-cigarette's LIB started a fire in a battery collection bin located in a local library.[41]

Large fires can lead to temporary, or even permanent facility closure. This means that some recyclable material could be landfilled. If local agencies can find other facilities willing to accept the stranded recyclables, these other MRFs could be overloaded, which could lead to more fires. For example, a recycling facility in Scottsdale, Arizona, was destroyed after a fire, and the town sent its recyclable material to the local landfill until another MRF agreed to take over the town's recycling service.[42] In other instances when alternative MRFs can be located, travel distance for collected materials is likely to increase, to the detriment of both quality of life and environmental health of the surrounding communities. More miles for garbage trucks results in increased road usage and congestion for nearby drivers and increased air pollution emissions and road hazards for pedestrians.

Services can also be disrupted by LIB fires during the transportation of waste. When a fire breaks out on a garbage truck, the driver is often forced to empty their vehicle's contents onto the roadway so the fire can be extinguished by firefighters. This situation not only creates hazards for first responders and pedestrians, but also disrupts the garbage collection route, as happened when a garbage truck's load caught fire in Bellevue, Washington (figure 10).[43]

Figure 10: Photo of the aftermath of an LIB fire in a garbage truck. An LIB fire in a garbage truck forced the driver to empty garbage onto the street to be extinguished, disrupting service for customers and creating a traffic hazard for community members and first responders. Photo courtesy of Bellevue Police Department.

3.2.3) Monetary Impacts

Fires caused by LIBs at waste facilities also can have significant monetary impacts for both the owners and the employees of waste facilities. Most immediately, these fires can cause damage to structures and

[40] See facility 8: Mack's Twin City Recycling, Urbana, IL
[41] See facility 52: Westonka Library Battery Drop-off Bin, Mound, MN
[42] See Facility 3: Republic Services MRF Located at Salt River Landfill, Scottsdale, AZ
[43] See facility 34: Municipal Garbage Truck, Bellevue, WA

expensive equipment such as sorting machines, bulldozers, or garbage trucks. The largest LIB fires have caused entire facilities to be burned to the ground, requiring millions in repair or replacement costs. After a MRF in Plano, Texas, was destroyed by a fire likely started by an LIB in 2016,[44] a replacement facility costing $30 million opened in 2019 (Pyzyk, 2019). Other fires have also caused structural damages to MRFs totaling in the millions, such as those that occurred at the Shoreway facility in San Carlos, California, and the Dem-Con facility in Blaine, Minnesota.[45] Many news articles do not list the monetary value of damages, but some fires have caused substantial cost. For instance, incidents at a MRF in New York and a battery recycler in Pennsylvania caused such costly damage that the facilities were declared total losses.[46] Beyond the damage done by the flames, waste facility fires can also leave behind soot residues that further corrode equipment if not cleaned up thoroughly.[47] The direct financial impacts of an incident could extend to the workers at the facility and their families as well, as they may have to be furloughed or laid off entirely if the facility closes for repairs—or for good.

LIB fires also have indirect financial implications, particularly through increases in the cost of the insurance that many facilities carry. When the number of discarded LIBs increases, the likelihood of a fire increases, in turn making damage more likely. Insurers offering coverage to waste facilities may reasonably estimate a high risk of a severe fire breaking out, leading them to pass the financial burden of that danger to their customers. Multiple MRF operators consulted for this report indicated that their insurance premiums and deductibles have increased in recent years.[48] Not only are prices increasing, but insurers are leaving the market, making it more difficult for MRFs to get insurance. The industry, which had almost 50 insurance options as little as three years ago, now has fewer than 10 (Fogelman, 2020). This trend will likely continue if fires continue to increase. For example, after the fire at their MRF, Shoreway now relies on seven separate policies because no single insurer is willing to bear the risk.[49] One MRF operator consulted called this "*the* existential threat" to the recycling industry.[50]

In municipalities where the waste system is publicly owned and operated, the local government may self-insure their waste facilities.[51] However, municipalities taking this tack must consider what a total loss could mean for them. Setting aside another reserve of funds to self-insure again after a fire would be a major financial burden to state and local governments that are already facing significant funding shortfalls in the wake of the COVID-19 pandemic (Auerbach et al., 2020).

Strategies exist to combat this threat, but they may not be enough to solve the problem. Some waste facilities may try to prevent insurance rate increases by investing in prevention measures like automated fire suppression systems or employee safety training.[52] However, these efforts constitute a major outlay

[44] See facility 20: Republic Services Recycling Center, Plano, TX
[45] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and facility 13: Dem-Con Recycling Facility, Blaine, MN
[46] See facility 16: Taylor Garbage, Apalachin, NY; and facility 57: Inmetco, Ellwood City, PA
[47] See facility 5: Shoreway Environmental Center, San Carlos, CA
[48] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and Industry Experience 4 and facility 17: Rumpke Waste & Recycling, Cincinnati, OH
[49] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA
[50] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA
[51] See Industry Experience 3 and facility 6: Larimer County Landfill's Recycling Center, Fort Collins, CO
[52] See Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, ; and Industry Experience 4 and facility 17: Rumpke Waste & Recycling, Cincinnati, OH

for the facility—shifting where monetary expenditures occur rather than preventing monetary impacts entirely.

All these increased costs could also impact average households' expenses. As the ultimate consumers of waste services, American families may well face higher prices for their waste collection and management as a result of these fires. Between surging insurance prices, increased risks to self-insured systems, and the destabilized recycled commodities market (Katz, 2019), operators of waste facilities may have to raise their rates to continue functioning profitably. This could leave Americans stuck with the bill for addressing the myriad issues created by LIBs inappropriately entering the municipal waste management process.

3.2.4) Emergency Response

Firefighters and other emergency responders expend valuable time and resources fighting LIB fires, potentially limiting their ability to respond to other emergencies. Some LIB fires are so large that scores of firefighters are required, such as the three documented incidents in which 100 or more firefighters responded.[53] This pressure could, in turn, strain agency budgets, as departments seek to obtain the resources needed to protect valuable but potentially high-risk facilities like MRFs.

LIB fires may also behave unusually, which may require more time and resources spent on training by fire departments. For example, firefighters in California extinguished a fire in a Tesla electric vehicle, only for the fire to reignite once the vehicle was brought to a scrap yard.[54]

In this report, emergency response was the only impact seen at every type of facility. This was also the most common of the four impacts, with 42 of 64 facilities having relied on external response for their fires at least once.

3.3) Industry Experiences

Facility operators and other industry experts were interviewed to get a more in-depth view of this problem. Twelve facilities were contacted and five responded, representing three MRFs, one landfill, and one scrap metal yard. The following sections are summaries of conversations held with representatives of these facilities. Almost every facility representative mentioned that the problem was getting worse in their industry and that other waste management facilities likely see LIB fires to a similar degree. These industry experiences help provide more detail on the scope of the LIB problem at end of life.

3.3.1) Industry Experience 1: Shoreway Environmental Center, San Carlos, California

Shoreway Environmental Center is a large MRF located in the Bay Area of California and operated by RethinkWaste, a joint agency of numerous local waste management authorities. The facility handles 80,000 tons of commingled recyclables per year using highly mechanized processes. Both storage and processing of the collected items occur on site, creating a large stockpile of material that could act as fuel if a fire breaks out. Shoreway employs around 100 workers, with 50 to 60 employees being present in the facility at any given time.

[53] See facility 2: Friedman Recycling, Tucson, AZ; Industry Experience 1 and facility 5: Shoreway Environmental Center, San Carlos, CA; and facility 15: Royal Waste Services, Queens, NY

[54] See marginal case 4 (Appendix 1)

The Shoreway facility experienced a devastating fire in September 2016 that is thought to have been caused by an LIB. The incident is believed to have started when processing machinery crushed an LIB and it ignited, setting fire to nearby paper recycling materials. As the nascent fire spread through the facility along a conveyor belt, employees initially attempted to extinguish the blaze; when these efforts failed, the facility was evacuated. Despite employees' efforts to halt the fire's spread by shutting down the conveyor belt, flames moved through the facility. The four-alarm fire damaged machinery and structures. Fortunately, Shoreway had installed a fire mitigation device comprised of heat-activated ceiling vents. When triggered by the fire, these vents opened to create a chimney-like effect that was designed to limit the fire's horizontal spread. Eventually, the blaze was extinguished by numerous local fire departments.

This incident illustrates many of the common impacts caused by LIB-ignited fires at waste facilities. The fire required significant involvement from external emergency responders, as about 100 firefighters were called to the scene. In the aftermath of the blaze, RethinkWaste was forced to close the Shoreway facility for repairs, burdening the rest of the area's waste management system as recycled materials had to be rerouted to three different facilities. Finding MRFs to pick up the excess recyclable materials was particularly difficult, as Shoreway accepts commingled materials that other recycling facilities do not. These disruptions were limited in duration because the facility was able to reopen some months later, but they could have lasted three to four years if the structure had been destroyed completely.

The most dramatic impacts of the event, however, were the monetary repercussions caused by the fire damage and subsequent facility closure. The fire itself racked up $8.5 million in damages as it tore through the facility's structures and processing and support equipment. These initial damages were subsequently compounded by soot residues and their corrosive effect on equipment. Replacing this equipment and repairing the building, which luckily remained structurally sound, required large outlays from RethinkWaste. RethinkWaste was also forced to furlough 50 employees while the plant was closed, potentially creating financial hardship for these individuals and their families.

The facility experienced monetary losses that extended beyond the direct costs of damages. After the fire, Shoreway was dropped by its previous insurer; in looking for a replacement, RethinkWaste learned that dozens of likely candidates opted not to bid for the contract. The agency now relies on seven different insurance sources because no one individual firm would take on the risk. Insurance costs skyrocketed as well, reflecting this hesitancy. RethinkWaste's annual insurance premium increased six-fold after the fire, while their required deductible rose by nearly 300-fold—and their leadership fears these rates may continue to rise. This deductible spike effectively forces RethinkWaste to partially self-insure the Shoreway plant, leading them to keep over $1 million extra in their reserves in case of a similar emergency in the future.

In addition to holding these funds in reserve, RethinkWaste has responded to the growing threat of improperly discarded LIBs through strategic changes in operations. They now undertake extensive emergency response training with the contractor operating the facility. Employees have also developed a set procedure for dealing with ignited LIBs, involving removing the LIB and surrounding materials from the waste pile, retrieving the battery, placing it in a barrel filled with sand or another neutralizing material, and leaving it to burn itself out. Operators no longer rely on trying to quench these fires, as they have found the tactic often fails to suppress the fire or allows the LIB to reignite.

RethinkWaste has also applied technological advancements to address this growing issue. After the fire, they installed countermeasures at Shoreway that they say "wildly exceed" minimum standards set by the relevant fire codes. These tools include sprinklers installed over all major equipment, an increased number of high-powered hoses, and heat-activated ceiling vents, which they credit for saving the structure from being completely engulfed in the fire.

RethinkWaste has also become an advocate for policy-based solutions. They support California legislation that they believe will increase producer responsibility for LIBs at end of life (the "take back bill"). This bill seeks to establish a drop-off program at the point of purchase and set up a dedicated process for handling collected batteries. The agency is also an active participant in industry groups like the Solid Waste Association of North America, and it now partners with non-profits and advocacy groups that share similar concerns about LIBs in the waste management process.

RethinkWaste's unfortunate experience in 2016 serves as a potent illustration of the severe damage that a single LIB tossed in a household recycling bin can create, though it was far from a worst-case scenario. The Shoreway facility is large, but not nearly the largest MRF in the United States; one listing of the largest North American recycling facilities in 2019 does not even rank Shoreway in the top 75 (Toto, 2019). Further, RethinkWaste's leadership indicated that the region they serve tends to be well-informed about waste issues, so they likely receive fewer batteries per ton of material than the average MRF. Taken together, these indicators imply that this issue could be an even greater threat in other scenarios, like at larger MRFs or in regions with residents who are not as well informed on waste management and recycling issues.

3.3.2) Industry Experience 2: Landfill in the Pacific Northwest

One Pacific Northwest landfill has seen 124 LIB fires in the past three years. [55] According to the landfill supervisor, LIBs were not a problem 10–15 years ago, when they were less common in consumer products. As LIBs grew in popularity, the landfill started seeing more fires caused by these batteries. Although LIBs are now widespread, many consumers do not realize the difficulty that LIB fires pose to landfills and continue to discard batteries in the trash.

On June 12, 2017, the landfill supervisor started tracking every fire caused by LIBs in the landfill. Every time an employee pulled a smoldering LIB out of the landfill, he kept a meticulous record of the date, and if the battery had not been burned past recognition, the source of the battery (tablets, cell phones, etc.). These LIB fires have increased over time, from 21 in 2018 to 47 in 2020.

The most common sources of LIBs that caught fire were cell phones (17), followed by tablets (6) and laptops (6). Although all the recorded fires were definitely caused by LIBs, the specific type of battery was often hard to ascertain, with most fires (91) caused by LIBs from unknown sources. When a battery burns for too long, it can become charred enough that it is impossible to determine what type of device it originated from.

Most fires caused by LIBs at this facility occur on the surface of the landfill. This means the fires are often easy to spot, and employees usually tackle them right away, according to the following protocol.

[55] The landfill supervisor who provided data for this facility requested that the facility remain anonymous, given negative public perceptions regarding landfill fires. We believe that the public benefit of including the detailed data this landfill provided justifies withholding the name of the landfill.

First, the facility ensures every vehicle that goes out onto the landfill has a fire extinguisher. When a fire starts, a worker douses the area, recovers the device, puts it in a steel bucket, and sends the LIB to a hazardous waste facility.

When this protocol is followed, battery fires at the landfill remain small and manageable—as long as they start within business hours when an employee is present. However, at night, fires have the chance to grow large beyond the surveillance of landfill employees. The facility had two such larger fires in May 2019 and May 2020 during off hours and required the help of the local fire department.

The operator has gone beyond only tracking incidents and now also educates consumers about the dangers of LIBs. Occasionally, large quantities of returned electronics from retail stores end up at the landfill. These goods cannot be sold, and store owners incorrectly believe that electronics with batteries can be thrown away in the trash. When this occurs, the landfill supervisor reminds stores that these items should not be discarded with their batteries inside. He has also educated the public by participating in local radio and TV news segments, where he explains the different types of batteries and the damage they can cause to a landfill. He hopes that getting the word out on LIBs will reduce the amount of fires at landfills and other waste management facilities.

Fires have become commonplace at this facility, and the operator assumes other landfills are most likely seeing the same frequency of fires. However, LIB fires are often small and go unreported, like other small fires at landfills. They are routine and not newsworthy, as they are easy to put out if noticed immediately. This attribute of LIB fires contributes to the lack of publicly available information on landfill fires in news reports.

3.3.3) Industry Experience 3: Larimer County Landfill's Recycling Center, Fort Collins, Colorado

In August 2018, a fire broke out at a recycling facility in Larimer County, Colorado, that fire inspectors believe was ignited by an LIB. Fortunately for the facility, an experienced operator noticed the fire and used processing equipment to move the burning pile of recyclables outside the facility.

This quick thinking likely saved Larimer County from experiencing many of the detrimental effects often caused by LIB-induced fires. The fire department arrived and was able to subdue the blaze outside the building, saving the valuable equipment inside and sparing the structure from damage (figure 11). In fact, the fire department indicated that the entire facility likely would have been lost if not for the quick response by the operator. The facility also didn’t see any increased insurance rates from this fire: it is self-insured by the county.

Figure 11: Photo of firefighters battling the Larimer County LIB fire. Firefighters hosing down the Larimer County LIB fire after the combusted pile of recyclables was moved outside by a MRF operator. Photo courtesy of Larimer County Solid Waste Department.

The fire did result in some undesirable outcomes, though they were mitigated. Multiple employees were treated at the scene for smoke inhalation, but fortunately none had to be hospitalized. Additionally, the facility was forced to shut down for the remainder of the day, temporarily disrupting the county's recycling collection services.

Since the 2018 blaze, Larimer County has experienced numerous fires at their various waste and recycling facilities, often due to LIBs. A representative from the county indicated that they feel the frequency of such fires has been increasing to the point that their landfill sees multiple fires per week and their recycling facility experiences a few per month. Furthermore, the county's Solid Waste Department staff fear that this issue, and the threats associated with it, will intensify as the county plans to close their landfill and transition to using a transfer station. There, processing conditions may increase the frequency of fires while the facility's characteristics (i.e., being inside a structure) may exacerbate the negative impacts if one of these fires gets out of control.

Between the near miss of the 2018 fire and the general trend of increasing risk, Larimer County decided to adopt a multifaceted consumer education campaign to respond to the threat of LIB-caused fires in their facilities. Their response, a battery safety campaign, focuses on raising the community's awareness about the importance of properly disposing of batteries of all types. In late 2020, the county Solid Waste Department invited high school- and college-age graphic design students to submit potential designs for the graphic component of the campaign's promotional and informational materials. This contest was intended to get younger generations involved in the issue and create a vested interest in addressing it.

Likewise, Larimer County is working with a student intern to develop an educational presentation and video for the county's website. The battery safety campaign has also developed a QR code that leads to their battery safety webpage. Larimer County has already targeted distribution of their educational messaging to battery retailers and e-cigarette stores in the hopes of educating consumers about proper disposal methods once LIBs and LIB-containing products reach end of life. Given the increasing prevalence of vaping and the frequency with which e-cigarette batteries enter the waste management process, the county adopted this approach to target their outreach and maximize the effect of their limited educational resources. They have also compiled a series of resources, called the Be Alert Campaign Toolkit, that other municipalities facing these problems can use.

The ultimate success of Larimer County's efforts is as of yet unknown, but their experiences overall illustrate the challenges that local waste management authorities are facing and the innovative strategies some of them are adopting to attempt to combat this nationwide issue.

3.3.4) Industry Experience 4: Rumpke Waste & Recycling, Cincinnati, Ohio

In conversation with the waste management firm Rumpke, representatives indicated that their organization has experienced many fire incidents like the ones presented in this report. Speaking from their industry experience, they shared how garbage truck loads can ignite when LIBs are crushed by the compacting machinery. In these cases, the increased airflow from the truck driving down the road then fans the flames and creates additional risk. Likewise, Rumpke representatives indicated that fires happen "all the time" at their MRFs, though it is often challenging to determine the exact cause of each fire. Preliminary data and anecdotal operator experiences indicate these fires are often tied to LIBs.[56]

When fires occur, Rumpke facilities encounter many of the same impacts featured throughout this report. Rumpke drivers always call the fire department when fires break out on their collection routes. When vehicle fires cause drivers to dump their truck's material for safety reasons, service can be disrupted as other trucks are rerouted to cover the interrupted routes. Likewise, when MRF fires are extinguished with water or foam, the doused recyclables must be sent to the landfill for disposal, driving down recycling rates.

From a monetary standpoint, each fire incident detrimentally affects the company's bottom line. A Rumpke truck has not been destroyed by any LIB-caused fires to date, but a total loss of a garbage truck would cost the company an estimated $250,000. Smaller costs can also stack up when a garbage truck experiences a fire, from the cost of cleaning up the site to the cost of repairing any mechanical or cosmetic damage caused by the event. Rumpke's MRFs are also experiencing monetary pressures, as insurance becomes harder to obtain and the company is forced to invest more resources in fire suppression systems, alarms, and emergency training for operators.

Rumpke has responded to these threats operationally, at both its MRFs and collection fleet. Truck drivers are instructed to perform a "visual audit" of the waste they pick up and notify customers who dispose of flammable materials like LIBs improperly. Meanwhile, at MRFs, ignited LIBs are removed from the conveyor belt with tongs, placed in a bucket filled with sand, and left outside for 24 hours to burn

[56] The data collected in this report (see section 3.1, Findings and Charts) and other data from surveys of California waste management facilities, Fire Rover, and RethinkWaste have all provided evidence of this correlation (California Product Stewardship Council, 2018; Fogelman, 2020; SBWMA, 2017). See also Industry Experience 2 and facility 45: Pacific Northwest Landfill

themselves out. Rumpke's representatives indicated that their employees have become used to and adept at dealing with these fires because they occur so frequently, though they are often caught in the early stages while the flames are small or the battery is only smoldering. For fires on the tipping floor (where waste is initially deposited at the facility), Rumpke has invested in water cannons to inundate nascent fires. Employees also experience on-the-job training via walk throughs of the facility that allow operators to stay up to date on emerging issues and address any problems early, before they become exacerbated.

Rumpke also supports public awareness as a solution to municipal waste fires. In addition to encouraging drivers to leave informative notes for customers who improperly dispose of ignitable wastes, the company sends targeted letters to geographic trouble areas when they notice routes with particularly high levels of inappropriately discarded materials. Rumpke facilities also host tours to inform the public about the waste system, and their representatives report that they have seen increasing levels of interest in and awareness of waste management issues. In the rare occurrences when fires in their trucks or at their facilities garner media attention, Rumpke tries to use the situation as a teaching opportunity to raise public awareness.

Although these events are becoming frequent, media attention is inconsistent, indicating that the problem is likely much larger than it initially appears. Rumpke's representatives indicated that media attention to fires depends heavily on where they occur and the amount of other news to cover on any given day. While large fires may attract the attention of local media, most incidents garner no coverage whatsoever. Considering that most fires occur at MRFs or landfills—locations not frequently considered in most people's day-to-day life—these fires frequently go under- or un-reported by the media.

3.3.5) Industry Experience 5: Pacific Coast Shredding, Vancouver, Washington

A scrap metal yard outside of Portland, Oregon, does not accept LIBs, but this doesn't mean that the batteries do not get into the facility. According to the operations manager of Pacific Coast Shredding, LIBs are a big problem in the management and processing of scrap metal. The facility has seen multiple incidents start due to improperly disposed LIBs.

LIB fires at this facility occur about once every other month and start most often in or near the shredder. Fires can also start on the concrete tipping floor, in piles of materials. The causes are often small LIB-powered devices like laptops. Fires are small enough that staff can usually isolate the item before the fire spreads, as long as the device is accessible in the pile.

The facility has experienced two recent fires assumed to be caused by LIBs. One fire in October of 2020 started in a big box of scrap metal. The manager assumed it was caused by a battery based on his prior experience with fires. An employee saw the smoke while operating a mobile shearer unit and drove over to investigate the incident. The fire was small enough for the employee to extinguish, and the fire department was not needed.

Another fire started in the facility's automobile shredder in 2019. A car caught on fire when it went through the shredder and was put out by the local fire department. A definite cause was not found, but it was suspected to be caused by an LIB. The fire resulted in monetary impacts of $20,000 in building damages and increased insurance rates. The fire also interrupted the shedder's service, as it took the facility down for a day. The building has since been rebuilt to be more fire-resilient, using steel and

concrete. The building is also now cleaned out each evening to prevent fires from starting inside at night.

The LIB problem is not limited to this single scrap metal facility: when interviewed, the operations manager stated that any scrap yard with a shredder has certainly seen LIB fires. The operations manager also stated a desire to see something done about this problem. For example, batteries could be labelled so they could be better spotted on the belt. Current labelling does not provide such instant recognizability, but if LIBs were bright yellow, as he suggested, more of them may potentially be spotted before being crushed.

3.4) Incident Tables

This section contains the comprehensive results of this damage case research effort, grouped by the type of facility and ordered alphabetically by state abbreviation. The incident tables contain information about each incident including the facility name, location, date of fire(s), whether the fire was definitely or likely caused by an LIB, quantity of fires, and a "details and impacts" column with more information.

Impacts are broken down into four categories: injury, external response, service disruption, and monetary losses, as represented by the icons shown below in the key. Icons are shown in the chart if an impact occurred or likely occurred. Incidents with no or unknown impacts are noted as such.

Key

Impacts	Impact Icons	Impact Detail
Injury		Incidents that resulted in anyone being sent to the hospital or being medically treated at the scene.
External Response		Any response by firefighters, emergency medical services, police, or other emergency personnel to the incident.
Service Disruption		Waste collection or management operations being halted for any significant period of time due to the incident.
Monetary Impacts		Any financial loss or hardship caused by the incident, including structural damage that required repairs, increased insurance costs, etc.

3.4.1) Materials Recovery Facilities

Waste Management Little Rock Recovery Facility, Little Rock, AR		**1**
12/19/2016		
Likely or Definite	Definite	*Details and Impacts*: None or unknown
Battery Type	Unknown LIB	LIB was wrapped up in plastic bags that were tied up in the sorting equipment. Staff was able to extinguish the fire, and damage is unknown (*Waste Management urges public to 'recycle right'*, 2016).
Fire Count	1	

Friedman Recycling, Tucson, AZ		**2**
5/21/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	About 100 firefighters were called to the scene of this fire, which spread quickly through a pile of cardboard and grew large due to high winds. One firefighter was taken to the hospital and three were evaluated at the scene for heat exhaustion (*3-alarm fire at recycling plant*, 2018; Greaber & Smith, 2018).
Fire Count	1	

Republic Services MRF Located at Salt River Landfill, Scottsdale, AZ		**3**
10/19/2019		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	The fire burned for over a day and destroyed the facility, which caused the town of Fountain Hills, AZ, to suspend its recycling program. Recyclable material was taken to a landfill temporarily until the town found another MRF. The fire was so large that a nearby highway closed for several hours (*Republic halts recycling after fire*, 2019; Stone, 2019).
Fire Count	1	

Marin Recycling Center, San Rafael, CA		4
9/17/2018		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Cell phone battery	A large fire started during working hours and was extinguished by the local fire department. The cause was determined to be a cell phone battery initially found at the transfer center (Smalley, 2020).
Fire Count	1	

Shoreway Environmental Center, San Carlos, CA[57]		5
2013-2017		
Likely or Definite	Definite	*Details and Impacts*: None or unknown
Battery Type	Unknown LIBs	Half of all fires seen at this MRF between 2013 and 2017 were caused by LIBs. Damages unknown (SBWMA, 2017).
Fire Count	21	
9/9/2016		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	$8.5 million in damages. Nearly all the facility's equipment was destroyed, along with its electrical system, but the building survived. 100 firefighters were called to the scene. Shoreway was later dropped by its insurer after this incident (Timpane et al., 2017; Taylor, 2018).
Fire Count	1	

[57] See Industry Experience 1 for more detailed information.

Larimer County Landfill's Recycling Center, Fort Collins, CO[58]		6
8/6/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Cell phone battery	Facility had to be closed for the day after fire started in loose recyclables. The level of smoke created by the fire led two employees to be evaluated for smoke inhalation (Marmaduke, 2018).
Fire Count	1	
8/23/2018		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Cell phone battery	Employees quickly extinguished the fire after seeing a smoldering LIB on the tipping floor (Marmaduke, 2018).
Fire Count	1	

Scott Area Recycling Facility, Davenport, IA		7
12/19/2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	The fire started in a pile of non-recyclables that had been pulled off the line. The MRF was closed for two hours while the fire department extinguished the fire (Gaul, 2020).
Fire Count	1	

[58] See Industry Experience 3 for more detailed information.

Mack's Twin City Recycling, Urbana, IL		8
11/29/2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	This fire most likely started from an LIB that exploded on a shelf and destroyed one building at the MRF. 30 firefighters responded to the fire. After this incident, the MRF stopped accepting LIBs; cardboard balers had been housed in the destroyed building so the MRF also stopped accepting cardboard for some time (*Lithium battery could have caused fire*, 2019; Schenk, 2019).
Fire Count	1	
12/2/2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	This fire was the second within one week at this MRF. Firefighters responded and there were no injuries (*Another fire*, 2019).
Fire Count	1	

Republic Services Recycling Center, Indianapolis, IN		9
3/27/2018		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	Fire started when LIBs sparked on the MRF's conveyer belt. The facility was damaged and was closed for a few days after the fire, but there were no injuries (Allbrittin, 2018).
Fire Count	1	

Ecomaine, Portland, ME		10
12/1/2017		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Laptop battery	The fire is believed to have been started by a damaged laptop battery. Staff extinguished the fire in about 40 minutes (Fredericson, 2017).
Fire Count	1	

Resource Recovery and Recycling Authority of Southwest Oakland County (RRRASOC), Southfield, MI		11
7/29/2018		
Likely or Definite	Definitely	*Details and Impacts:* 
Battery Type	Unknown LIB	19 firefighters responded to the incident, which originally started in the MRF's conveyer system. Although the fire was initially difficult to access, the fire was eventually extinguished (Dimick, 2018).
Fire Count	1	

Southeastern Oakland County Resource Recovery Authority (SOCRRA), Troy, MI		12
2018		
Likely or Definite	Definitely	*Details and Impacts:* None or unknown
Battery Type	Lithium metal battery	A small fire with unknown damages started when machinery compressed a lithium battery (Laitner, 2018).
Fire Count	1	

Dem-Con Recycling Facility, Blaine, MN		13
6/29/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	A large fire started by what was likely an LIB during this MRF's off-hours. The fire grew large, and multiple local fire crews were on scene for over 24 hours. When the fire was extinguished, the building was a total loss. The facility faced financial losses of millions of dollars (*Common recycling mistake is causing fires*, 2019).
Fire Count	1	

Friedman Recycling, Albuquerque, NM		14
9/29/2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	A stack of recyclables that were about to be shipped caught on fire, which was caused by a discarded LIB. No injuries or property damage resulted from the fire, although the local area issued an air quality warning due to the amount of smoke caused by the fire. The facility was back in service the next morning (Wilham, 2020; see also Panas, 2021).
Fire Count	1	

Royal Waste Services, Queens, NY		15
3/16/2018		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	This large fire was started by a disposed LIB and was exacerbated by strong winds and 15-foot high piles of newspapers and cardboard. 198 firefighters from 44 companies arrived at the scene and one firefighter sustained a minor injury. Four nearby train lines were delayed for 4 hours (Cook & Levy, 2018; Gannon, 2018)
Fire Count	1	

Taylor Garbage, Apalachin, NY		16
1/3/2020		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	The fire, started by either a phone or laptop battery, destroyed the facility and required a response from over 30 fire departments. There were no water hookups in the area, so the fire departments had to truck water in repeatedly. No injuries were reported (Gilroy, 2020a, 2020b).
Fire Count	1	

Rumpke Waste & Recycling, Cincinnati, OH[59]		17
2016		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIBs	Six fires were caused by improperly disposed LIBs in 2016 at this MRF. The fire department responded to each incident, with damages unknown (Caproni, 2016).
Fire Count	6	
2017		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIBs	Over a dozen fires were caused by improperly disposed LIBs in 2017 at this MRF, with damages unknown (Jennings, 2018).
Fire Count	12	
3/29/2018		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	A fire sparked from a small LIB, but there was no damage and no injuries (Jennings, 2018).
Fire Count	1	

North Lincoln Sanitary Service Recycle Center, North Lincoln, OR		18
9/14/2020		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	A fire started in the facility's compacter, likely from an LIB. The fire department responded and was able to extinguish the fire (Kirkendall, 2020).
Fire Count	1	

Fort Hood Recycle, Fort Hood, TX		19
5/9/2019		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIBs	The facility experienced four fires in 2019, one of which damaged thousands of pounds of recyclables which had to then be landfilled (Luciano, 2019).
Fire Count	4	

[59] See Industry Experience 4 for more detailed information.

Republic Services Recycling Center, Plano, TX		20
12/28/2016		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	A fire started in this facility in the winter, after the facility's sprinkler system was damaged by a freeze. The fire department responded but were unable to stop the fire, which ended up destroying the MRF. The facility was rebuilt after the fire (Mock, 2020).
Fire Count	1	
2019		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Laptop battery	A small fire started from a laptop in the new facility, after the old building had burnt down due to the 2016 fire (Mock, 2020).
Fire Count	1	

Chittenden Solid Waste District's Recycling Facility, Williston, VT		21
7/30/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Lithium metal battery	A fire started on the MRF's tipping floor after staff had left for the night, with lithium batteries a likely suspect. The alarm system automatically called the fire department, who extinguished the fire. The fire damaged an exterior wall and disrupted service for two days (Gribkoff, 2018).
Fire Count	1	

John's Disposal, Norway, WI		22
7/1/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	This large fire was possibly started from an LIB in a bale. Firefighters from four counties used almost 2 million gallons of water, and one firefighter was transported to the hospital with heat exhaustion. Local roads were closed during the blaze, and the facility was closed after the incident. However, local recycling service was uninterrupted due to other facilities filling in the gaps (*Massive fire at recycling facility*, 2018; Mauk & Sadowski, 2018).
Fire Count	1	

Outagamie County Recycling & Solid Waste, Appleton, WI		23
9/13/2019		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	An LIB started a fire in a trash compactor at this recycling facility. Staff quickly extinguished the fire without injury or damage (Haines, 2019).
Fire Count	1	

3.4.2) Transportation

Waste Management Truck, Little Rock, AR		24
2016		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	A small fire started inside of a recycling truck due to an LIB (Mershon, 2016).
Fire Count	1	

Rumpke Truck, Bloomington, IN		25
11/27/2018		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Lime scooter battery	Fire forced the driver to dump the truck's load of garbage in a church parking lot. The fire was extinguished by a local fire department shortly afterwards (Christian, 2018).
Fire Count	1	

Sunview Logistics Truck, Livingston County, MI		26
9/17/2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	Used LIBs caught fire in a semi-trailer, forcing emergency responders to close an interstate highway for five hours. One firefighter suffered a minor injury (King, 2020).
Fire Count	1	

Dem-Con Truck, Belle Plaine, MN		27
7/29/2020		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	A truck hauling scrap metal dumped its load after the material onboard caught fire. Firefighters were called to the scene (*Scrap heap catches fire*, 2020).
Fire Count	1	

Jacksonville Sanitation Truck, Onslow County, NC		28
11/14/2019		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unclear if LIB or lithium metal battery	An LIB improperly placed in a curbside garbage can started a fire in a garbage truck, which then emptied its contents into the street. The fire department was called to extinguish the fire (Levine & Basden, 2019).
Fire Count	1	

Atlantic County Utilities Authority Truck, Brigantine, NJ		29
2018		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Hoverboard battery	A hoverboard thrown away in a household trashcan started a fire aboard a garbage truck (Atlantic County Utility Authority, 2019).
Fire Count	1	
11/26/2019		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	E-cigarette battery	An e-cigarette's LIB caused a fire in a garbage truck. Local authorities responded to put out the fire (Atlantic County Utility Authority, 2019).
Fire Count	1	

DSNY Truck, New York, NY		30
1/13/2017		
Likely or Definite	Definite	*Details and Impacts* 
Battery Type	Unknown LIB	A box of LIBs exploded when it was compacted by the garbage truck, prompting nearby civilians to call 911. Workers threw the box of LIBs into a puddle to extinguish the fire (Garger, 2017).
Fire Count	1	

FedEx Truck, Jackson Township, OH		31
6/5/2017		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Lithium metal batteries	A box truck filled with LIBs being sent for recycling caught fire while on the road, seriously damaging the vehicle. The fire department responded, and the turnpike was closed for several hours (O'Hara, 2017).
Fire Count	1	

Republic Services Recycling Center Truck, Plano, TX		32
2019		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Cordless vacuum battery	An LIB from a cordless vacuum ignited as waste haulers were picking up recyclables. The LIB was extinguished on the customer's front lawn (Mock, 2020).
Fire Count	1	

Union Pacific Train, Houston, TX		33
4/23/2017		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIBs	LIBs being shipped for recycling ignited and exploded, resulting in a blast that blew out the windows of nearby buildings and damaged one container on the rail car. Firefighters extinguished the blaze after two hours and the affected car was taken out of service (Beausoleil, 2017; *Neighborhood residents concerned following train car explosion*, 2017)
Fire Count	1	

Municipal Garbage Truck, Bellevue, WA		34
4/4/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Hoverboard battery	An LIB from a hoverboard thrown in the garbage ignited in transit, forcing the truck to dump its load in the street. Two firetrucks were called to the scene (*Police: Faulty hoverboard starts fire*, 2018).
Fire Count	1	

Waste Connections Truck, Washougal, WA		35
11/15/2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	An LIB tossed in the recycling ignited after being crushed by a truck compactor. The truck dumped its load into street, creating an obstruction that took four hours to clean up. A representative from Waste Connections also mentioned that LIB fires are "routine" in its vehicles, without mentioning how many total fires the waste management company has seen (Mize, 2019).
Fire Count	2	

Eau Claire Garbage Truck, Eau Claire, WI		36
Unknown		
Likely or Definite	Definitely	*Details and Impacts:* None or unknown
Battery Type	Cell phone battery	An LIB ignited in a recycling truck, whose operator then put out the fire with a water bottle (*Warning issued after discarded battery starts truck on fire*, 2018).
Fire Count	1	

3.4.3) Landfills

Los Reales Landfill, Tucson, AZ		37
June 2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIBs	Multiple fires in a short span of time were attributed to LIBs. Hot temperatures may have also contributed to these fires (City of Tucson, 2020).
Fire Count	3	

Yolo County Central Landfill, Yolo County, CA		38
10/1/2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	An LIB improperly discarded in this landfill started a late-night fire, which grew to be a half-acre in size as it burned tires and other material. The fire department had the fire under control by morning (Keene, 2020).
Fire Count	1	

Linn County Solid Waste Agency, Marion, IA		39
2016		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Drone battery, computer battery, lithium metal battery	Numerous fires were caused by LIBs over the course of six weeks, often after compactors drove over the batteries and cracked them open (McCarthy, 2016).
Fire Count	3	

Western HW Landfill		40
2019		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Lithium metal battery	Incompatible wastes, including lithium batteries and pool chemicals, mixed and self-ignited. Landfill personnel were able to extinguish the fire, using water and clay (EPA, personal communication, 2019).
Fire Count	1	

McPherson Area Solid Waste Utility, McPherson, KS		41
October 2019		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	Few details were available, though staff report that fires are occurring more frequently, often due to LIBs (*Some batteries causing fires*, 2019).
Fire Count	1	

Lebanon Landfill, Lebanon, NH		42
7/24/2018		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Car starter booster	An LIB used for jump-starting cars ignited after being run over by the landfill's compacting equipment. Staff put out the fire right away (Lebanon, New Hampshire, 2018).
Fire Count	1	

Steuben County Landfill, Bath, NY		43
7/9/2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Cell phone battery	Four fire companies responded to an LIB fire that was exacerbated by high heat (Day, 2020).
Fire Count	1	

Knott Landfill, Bend, OR		44
9/17/2018		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Toy car battery and unknown LIBs	This landfill experienced three LIB fires in a single week and averages about two to three LIB fires a month. Thus, the fire count of 3 is very conservative (Sievert, 2020).
Fire Count	3	

Pacific Northwest Landfill[60]		45
June 2017 - December 2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Cell phone battery: 17 Hoverboard size battery: 1 Laptop battery: 6 Remote control airplane battery: 1 Tablet battery: 6 Watch battery: 1 DVD player battery: 1 Unknown LIBs: 91	One landfill consulted for this report noticed an increasing number of LIBs causing fires, so a supervisor began keeping a record of each LIB-caused fire. Over roughly three years, the facility experienced 124 fires known to be caused by LIBs from a variety of devices. Most were extinguished by staff, but a few fires required assistance from firefighters. A representative from the facility indicated that this number of fires is not abnormal for landfills (landfill supervisor, personal communication, 2021).
Fire Count	124	

Horn Rapids Landfill, Richland, WA		46
1/19/2019		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIBs	Few details were available, but this landfill reported that numerous LIB-caused fires broke out in a single year (Cary, 2019).
Fire Count	3	

[60] See Industry Experience 2 for more detailed information. The landfill supervisor who provided data for this facility requested that the facility remain anonymous, given negative public perceptions regarding landfill fires. We believe that the public benefit of including the detailed data this landfill provided justifies withholding the name of the landfill.

3.4.4.) Other

Shoreway Environmental Center Transfer Station, San Carlos, CA		47
2015 and 2017		
Likely or Definite	Definite	*Details and Impacts* 
Battery Type	Unknown LIBs	Once in 2015 and twice in 2017, LIBs started fires in the Shoreway Transfer Station, which is co-located with the Shoreway MRF (SBWMA, 2017).
Fire Count	3	
Facility Type	Transfer station	

Ybor City Waste Management Transfer Station, Tampa, FL		48
3/26/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	Around 25 firefighters responded, and the fire caused extensive damages. The facility was unable to accept recyclable material for some time, and recyclables were sent to the Pinellas County Waste-to-Energy Plant until the facility was able to operate again. (City of Clearwater, 2020; McManus, 2018).
Fire Count	1	
Facility Type	Transfer station	

Midwestern Electronics Recycler		49
2020		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	Unknown LIB	No injuries were reported but the fire caused extensive damage, including the collapse of three buildings. 80 firefighters responded to the incident (EPA, personal communication, 2021).
Fire Count	1	
Facility Type	Electronics recycler	

UMD Business School, College Park, MD		50
11/12/2014		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	E-cigarette battery	An e-cigarette thrown in a trash can started a small fire inside a building. Four fire engines, two fire ladders, a heavy-duty rescue squad, an ambulance, and an incident commander all responded to the incident (*E-cigarette causes fire*, 2014).
Fire Count	1	
Facility Type	Trash can	

Montgomery County Central Transfer Station, Derwood, MD		51
8/30/2020		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIBs	A pallet of mixed batteries caught fire while the facility was closed for the day. Firefighters responded quickly and contained the flames, which spread to the storage facility structure and appeared to damage the facility (Lindsay, 2020).
Fire Count	1	
Facility Type	Transfer station	

Westonka Library Battery Drop-off Bin, Mound, MN		52
10/14/2019		
Likely or Definite	Definite	*Details and Impacts:* 
Battery Type	E-cigarette battery	A fire ignited when an e-cigarette self-started in an LIB collection bin at a public library. The incident forced local authorities to end their LIB collection program in all public buildings (Olson, 2019; *Scrap heap catches fire*, 2020).
Fire Count	1	
Facility Type	Battery collection bin	

Otter Tail Transfer Station, Fergus Falls, MN		53
5/15/2020		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	An employee noticed a smoldering LIB in the transfer station's sorting equipment and was able to extinguish the battery before the incident spread (Otter Tail County, Minnesota, 2020).
Fire Count	1	
Facility Type	Transfer station	

American Recycling & Disposal, Claremont, NH		54
9/11/2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	A suspected LIB in a scrap car caught on fire at the facility. Two firetrucks were called to the scene, and the fire was extinguished in about an hour (Muzeroll, 2019).
Fire Count	1	
Facility Type	Scrap metal yard	

Sunnking, Brockport, NY		55
Unknown		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Pouch battery, possibly from iPad	A battery ignited as it was being handled by a staff member. The battery was brought outside and burned out (Staub, 2020).
Fire Count	1	
Facility Type	Electronics recycler	

Metro South Station, Oregon City, OR		56
8/1/2018		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	E-scooter battery	A bulldozer operator isolated a smoldering e-scooter, and other staff doused it with water. There was no damage to the facility (Cathcart, 2019).
Fire Count	1	
Facility Type	Transfer Station	

Inmetco, Ellwood City, PA		57
11/8/2015		
Likely or Definite	Definitely	*Details and Impacts:* 
Battery Type	Cell phone and radio batteries	A fire was started in a warehouse by LIBs in storage. The fire destroyed the warehouse and four firefighters suffered chemical burns and were taken to the hospital (Allen, 2015).
Fire Count	1	
Facility Type	Battery recycler	

Rutherford County Solid Waste Convenience Center, Murfreesboro, TN		58
6/3/2020		
Likely or Definite	Definitely	*Details and Impacts:* None or unknown
Battery Type	Vacuum cleaner battery	A trash compactor caught fire when an LIB-powered vacuum was crushed, causing the battery to short-circuit (Hall, 2020).
Fire Count	1	
Facility Type	Convenience center	

Covanta Fairfax, Fairfax, VA		59
2019		
Likely or Definite	Definitely	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	A small fire broke out in this waste-to-energy plant after an LIB was improperly thrown away in household garbage (Fairfax County, Virginia, 2019).
Fire Count	1	
Facility Type	Waste-to-energy plant	

Snohomish County Transfer Facility, Everett, WA		60
Unknown		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Toy battery	At least one small fire has started at this transfer station from an LIB in a discarded toy (Snohomish County, Washington, 2018).
Fire Count	1	
Facility Type	Transfer facility	

Spokane Waste-to-Energy Plant, Spokane, WA		61
2019		
Likely or Definite	Definitely	*Details and Impacts:* None or unknown
Battery Type	Possibly cell phone batteries	Two fires started on the plant's tipping floor, possibly from cell phone batteries (Blocker, 2019).
Fire Count	2	
Facility Type	Waste-to-energy plant	

Simon Metals, Tacoma, WA		62
9/17/2018		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	This fire at a scrap metal yard caused $95,000 to $115,000 in damages. Seven firetrucks were called to the scene, and it took nine hours to put out the blaze (Smalley, 2018).
Fire Count	1	
Facility Type	Scrap metal yard	

Pacific Coast Shredding, Vancouver, WA[61]		63
2019		
Likely or Definite	Likely	*Details and Impacts:* 
Battery Type	Unknown LIB	This fire was likely started by an LIB going through an auto shredder. The fire caused $20,000 of damage, increased insurance rates, and closed the facility for a day.
Fire Count	1	
Facility Type	Scrap metal yard	
10/28/2020		
Likely or Definite	Likely	*Details and Impacts:* None or unknown
Battery Type	Unknown LIB	A large box of scrap caught on fire, likely because of an LIB. The box was moved outside, and the fire was put out by staff.
Fire Count	1	
Facility Type	Scrap metal yard	

Cascade Asset Management, Madison, WI		64
2016		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Cell phone battery	An LIB began smoking and then burst into flames after an employee opened a phone to remove it at this electronics recycler (Fowler, 2018).
Fire Count	1	
Facility Type	Electronic scrap processor	
2017		
Likely or Definite	Definite	*Details and Impacts:* None or unknown
Battery Type	Tablet battery	An LIB exploded while the tablet that housed it was being disassembled. The surrounding area had to be evacuated (Fowler, 2018).
Fire Count	1	
Facility Type	Electronic scrap processor	

[61] See Industry Experience 5 for more detailed information.

4) Conclusion

It is clear from the damage cases collected in this report that LIB-caused fires throughout the waste management process are already risking the safety of workers, by-standers, and emergency responders and costing the industry money. This problem is only going to get worse in future years. LIBs are already present in a wide array of applications, and their prevalence is increasing. As devices containing these batteries reach the ends of their useful lives, they will contribute to the surging number of waste LIBs produced. Likewise, as the world transitions to electric vehicles and reliance on intermittent renewable energy that requires significant storage capacity, dealing with large scale end-of-life LIBs will also become a pressing issue.

Unfortunately, currently many LIBs are disposed of in inappropriate ways, creating major problems for MRFs, landfills, the transportation system, and other waste management facilities. Solid waste regulations, industry best management practices, and facility-level strategies have thus far fallen short of addressing these problems. Fires in these locations pose a direct threat to reliable waste management services, environmental quality, and human health. LIB fires can also introduce financial pressures, raise costs to households, and lead to furloughs or layoffs.

Indeed, many of these negative effects are already occurring, and in some cases accelerating, at waste management facilities across the United States. Other reports and surveys have hinted at these impacts, but this report specifically compiled significant evidence that LIBs are creating major problems for institutions across the waste management industry. The quantitative data collected here indicate that LIB fires at waste facilities are increasingly frequent, widespread, and harmful. Injuries, demand for emergency responders, service disruptions, and monetary impacts have all resulted from LIB fires. Across the board, a significant proportion of facilities have experienced at least one of these negative impacts in recent years. MRFs, in particular, appear to frequently suffer from LIB fires, threatening the continued availability of the environmentally beneficial waste management services they offer.

Likewise, discussions with representatives from across the waste management industry reveal that this issue is well known and pressing. Each representative consulted agreed that LIB fires pose a threat to their operations that needs to be addressed—most even declared this issue to be the most pressing problem currently facing their industry.

As this report's research methodology and discussions with industry representatives reveal, the problem of LIBs entering the waste system and the impacts they cause are severely underestimated. Relying solely on media reports of fire incidents at waste facilities will lead to underreporting of both the frequency and severity of this problem. News coverage of these fires is rare and heavily dependent on numerous external factors. When media sources do cover such events, they rarely address the full range of detrimental impacts they cause, focusing far more on the immediate response and very little on the indirect damage done to the waste system, human health, the environment, or even proper battery management.

In spite of this obstacle, this report presents ample evidence showing that LIBs in the waste management process are a major issue and it is likely that the problem is even bigger than we know. Waste facilities' pragmatic responses, heightened awareness of workers in the field, rising insurance rates, anecdotal reports, and quantitative evidence all demonstrate that the issue of improperly discarded LIBs is a serious and growing concern for members of the waste management industry. While

this report contributes to increasing general awareness of the threat posed by improperly discarded LIBs, solving this problem will require further coordination and action by the wide variety of stakeholders who share an interest in maintaining a safe, effective, and sustainable waste management system.

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Jason Kime. Pacific Coast Shredding. Teleconference. October 29, 2020.

Joe LaMariana. Rethink Waste. Teleconference. October 2, 2020.

Landfill Supervisor. A Pacific Northwest Landfill. Teleconference. October 1, 2020.[62]

Linda Hammett. Larimer County Solid Waste Department. Teleconference. November 23, 2020.

[62] The landfill supervisor who provided data for this facility requested that the facility remain anonymous, given negative public perceptions regarding landfill fires. We believe that the public benefit of including the detailed data this landfill provided justifies withholding the name of the landfill.

Appendix 1: Additional Sites Considered but Not Included

Case #	Date	Site Name	State	Reason Rejected	Source Link
1	6/11/2020	Tank's Recycling and Landfill Facility	AZ	Suspected cause of this landfill fire is HHW. Batteries listed as one of many possible causes. Unknown if LIBs were a possible cause or other batteries.	https://tucson.com/news/local/old-batteries-to-blame-for-burning-issue-at-tucson-landfills/article_5c893527-c9e6-5057-830e-8622d08750af.html
2	2019	Tank's Recycling and Landfill Facility Truck	AZ	Suspected cause of this garbage truck fire is HHW. Batteries listed as one of many possible causes. Unknown if LIBs were a possible cause or other batteries.	https://tucson.com/news/local/old-batteries-to-blame-for-burning-issue-at-tucson-landfills/article_5c893527-c9e6-5057-830e-8622d08750af.html
3	6/6/2019	Burrtec	CA	The cause of this MRF fire is undetermined, but LIBs are listed as a cause of similar facility fires.	https://www.cactushugs.com/following-that-big-fire-burrtec-would-like-to-remind-you-not-to-throw-your-batteries-in-recycling-containers/
4	12/18/2018	Los Gatos Tire and Auto Repair	CA	A Tesla vehicle caught fire twice: once in a parking lot, and again after being brought to a tow yard. Unclear if the car was considered disposed at this point.	https://www.cnbc.com/2018/12/19/tesla-model-s-catches-fire-in-los-gatos-reignites-hours-later-at-tow-yard-.html
5	4/29/2013	Shoreway Environmental Center	CA	Battery fire at a MRF. Battery type is not specified, unknown if it was an LIB or another type of battery.	https://www.smdailyjournal.com/news/local/san-carlos-fire-clears-shoreway-environmental-center/article_182fcc52-2861-5776-a35d-c43cc4e34872.html
6	9/2/2019	Truth Aquatics Boat	CA	No definitive cause for this deadly fire is known, but non-waste batteries are listed as a potential cause.	https://www.washingtonpost.com/national/california-dive-boat-fire-cause-conception/2020/10/20/97eb9bf4-12f1-11eb-9f38-35350e52c23c_story.html
7	7/18/2019	Republic Services Boise Garbage Truck	ID	The cause of this garbage truck fire is not known, but the last three truck fires for Republic Services have been caused by improper disposal of hazardous waste, including LIBs.	https://idahonews.com/news/local/city-of-boise-hazardous-waste-can-lead-to-garbage-truck-fires

8	8/6/2019	Totall Metal Recycling	IL	The media reported that a large stack of computers with LIBs caused this fire, but the facility disputed this media report.	https://www.radio.com/kmox/galleries/fire-granite-city-recycling-center-extinguished-overnight
9	3/26/2020	Rumpke Garbage Truck	KY	Two fires were started in Rumpke trucks within one week. LIBs were listed with some other common fire-starters as potential causes, but the cause was not known.	https://www.whas11.com/article/news/local/rumpke-flammable-items/417-a8431f95-fc08-4204-b0d3-861f0aff1694
10	9/27/2020	Cleanlites Recycling	MI	Source does not specify what kind of batteries started the fire. Since this site accepts e-waste, there is a good chance the batteries were LIBs, but the type of battery is not stated.	https://resource-recycling.com/e-scrap/2020/10/01/fire-damages-cleanlites-facility/?utm_medium=email&utm_source=internal&utm_campaign=Oct+1+ESN
11	7/20/2016	Wilson Trucking Shipping Center	NC	Fire was started by "non-alkaline batteries." The cause could have been LIBs or another non-alkaline battery.	https://resource-recycling.com/e-scrap/2017/03/02/e-scrap-battery-fire-leads-lawsuit/
12	3/24/2020	Salem Transfer Station	NH	LIBs were listed with wood stove ash as potential causes, but the cause was not known.	https://www.unionleader.com/news/safety/piles-of-garbage-ignite-overnight-at-salem-transfer-station/article_f3040379-e368-53ab-87ee-367e1a694011.html
13	11/9/2020	Tompkins County Solid Waste Center	NY	Fire started by an unspecified battery, but the article mentions how LIBs, in particular, are known to cause fires.	https://www.wxhc.com/small-fire-at-tc-recycling-center-likely-caused-by-batteries/
14	11/10/2020	Garten Recycling Services	OR	LIBs were listed with a propane tank as potential causes, but the cause was not known.	https://www.salemreporter.com/posts/3252/a-30-000-fire-at-garten-plant-shows-danger-of-wishful-recycling
15	5/1/2020	Pittsylvania County Landfill	VA	Landfill fire could have been started by any type of solid waste, with LIBs listed as an option.	https://www.chathamstartribune.com/news/article_1587bb1a-bbef-11ea-a43a-8f4c3891d1b8.html
16	7/25/2019	Augusta Regional Landfill	VA	The cause of the fire is unknown, but batteries are noted as something that should be recycled.	https://www.whsv.com/content/news/Landfill-fire-reminder-to-recycle-especially-batteries-513218161.html

Appendix 2: List of Questions from Stakeholder Interviews

1. Are you comfortable with us including the information we discuss here in a public report?
2. To start, can you explain to us what happened in the fire incident?
3. Did you do any sort of internal investigation of the incident? Was there any external investigation? If so, what can you tell us about what you found? Did you determine the exact cause of the fire?
4. What were some of the impacts of the fire? Has your facility experienced any of the following issues? Others not considered here?
    a. External response (i.e., emergency responders called to scene)
    b. Service disruption (e.g., temporary (or permanent) facility closure, delayed schedules, end of collection program, etc.)
    c. Monetary impacts (e.g., structural damage, fines, increased insurance rates, etc.)
    d. Injury (and/or hospitalizations)
5. How frequently are such fires occurring, and how often do they come down to batteries? Upward trends in frequency?
6. And how often do those events garner media attention? How big is this problem relative to how often it gets reported?
7. Have you made changes to procedures to prevent or reduce the incidence of fires?
8. What would you like to see done about this problem by other stakeholders? (e.g., public service campaign, development of new best management practices, new regulations, etc.)
9. Which industry associations, if any, do you interact with most? Have any associations given you guidance on this issue? If so, could you share it with us? Have you reached out to any industry associations in search of or requesting guidance or best management practices for li-ions?
10. Do you have any questions or comments for us?

Appendix 3: Linked Resources

Earth 911. (n.d.) *Recycling Search.* https://search.earth911.com/

Larimer County, Colorado. (n.d.) *Be Alert! Divert Hidden Batteries.* https://www.larimer.org/solidwaste/batteries#Toolkit

U.S. Department of Transportation. (n.d.) *Transporting Lithium Batteries.* https://www.phmsa.dot.gov/lithiumbatteries

U.S. Government Publishing Office. (n.d.) *Electronic Code of Federal Regulations.* https://www.ecfr.gov/cgi-bin/ECFR?SID=3acc0733a82912d7e842a195b18c71f6&mc=true&page=browse