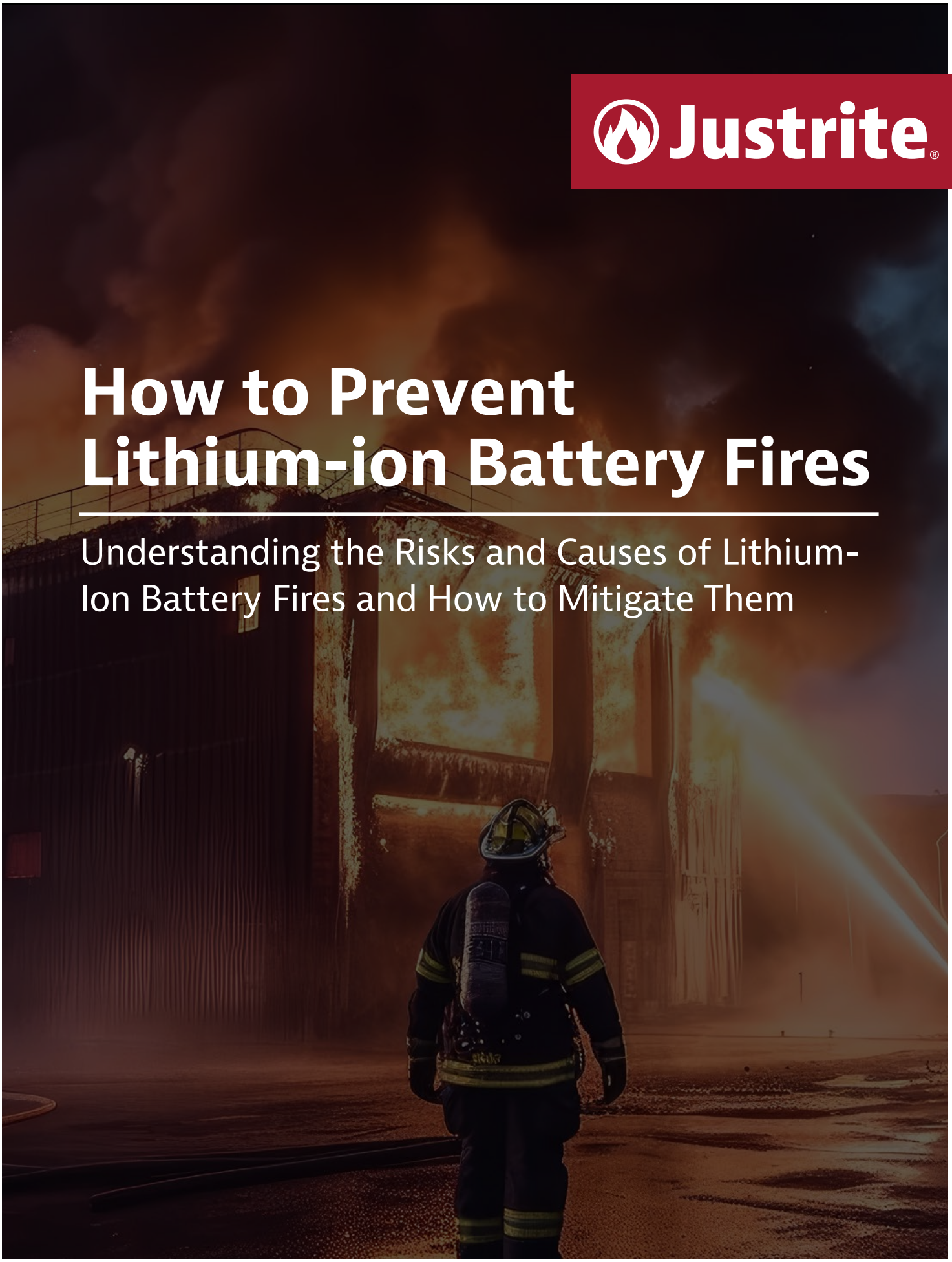

How to Prevent Lithium-ion Battery Fires

Understanding the Risks and Causes of Lithium-Ion Battery Fires and How to Mitigate Them

Battery Fire Safety

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With the proliferation of lithium-ion batteries in today's marketplace, it seems wherever you turn there's a new device using this technology. From automobiles, e-bikes and scooters to cordless power tools, radios, flashlights, and yes, even cell phones, their usage is everywhere. It's no surprise then that there's also been a rise in the number of fires caused by lithium-ion batteries. In 2018, the U.S. Consumer Product Safety Commission's Status Report on High Energy Density Batteries Project reported that there were more than 25,000 overheating or fire incidents involving more than 400 types of lithium battery–powered consumer products over a five-year period. And in 2023, the FDNY reported 150 injuries and 18 deaths from 267 fires started by lithium-ion batteries, as published by UPI News. The FDNY also reported that lithium-ion batteries are now a leading cause of fires in New York City. What's worse is that these fires start with no warning and can be incredibly damaging. As seen in the news and social media, the lithium-ion fires can be quite intense and even explosive in nature. This exploding phenomenon is known as thermal runaway and can be catastrophic. According to the NFPA, warehouse fires cause $283 million in direct property damage each year. The problem is compounded by the fact that there aren't currently any regulations or fire codes specifically for lithium-ion batteries (though they are currently under review).

How Lithium-Ion Batteries Work

First, we need to understand what's going on inside the battery. In normal operation, lithium ions (negatively charged atoms) move across the cathode to anode and vice-versa through a structure called a separator. The cathode (+) and anode (-) are internal structures, typically plates, made of dissimilar metals. A single cathode/anode arrangement is called a "cell." While cell phones generally have one cell, rechargeable tools may have up to 20. Electric vehicles may have hundreds of cells. Energy is passed through each cell; therefore each individual cell poses a risk. Cells are encased in a battery housing such as a cylindrical case or pouch and immersed in chemicals known as electrolytes. When connected to an electrical load, the movement of the ions releases energy and powers tools, phones, and computers. However, as with all energy storage devices like fuel tanks and propane gas cylinders, there is always the risk of malfunction, and lithium-ion batteries are no exception.

Most off-the-shelf lithium-ion batteries from a reputable manufacturer with strict manufacturing and quality standards are safe when used correctly. However, problems occur where there is misuse or downright abuse to the battery. After all, we, the users of these devices are human and can make mistakes. After repeated abuse, the battery (more accurately, the separator) can become compromised and is at risk of going into thermal runaway.

What is Thermal Runaway?

In normal operation of a lithium-ion battery, the transfer of ions between the cathode and anode generates a small amount of heat. This heat is absorbed by the battery case and dissipated into the surrounding air through convection. However, when the heat generated goes beyond the capability of the battery to dissipate, either due to damage or abuse, a chain reaction can occur causing excessive temperatures that lead to combustion, and potentially, explosion. When a lithium-ion battery goes into thermal runaway and explodes, it produces extremely high temperatures and significant flames. Beyond the obvious damages of an explosion, a thermal runaway condition could trigger sprinkler systems to go off and flood a production floor or the flames could ignite flammable materials being used nearby. Thermal runaway events also produce a high volume of toxic gas and smoke.

Common Causes of Thermal Runaway

When it comes to preventable causes of thermal runaway, there are three main issues, including mechanical, thermal, and electrical abuse or misuse. While these issues are caused by user error, there is one other reason lithium-ion batteries could go into thermal runaway and that's due to quality issues with the battery.

Mechanical Abuse

As the name implies, this is where something physically impacts the battery. Dropping, crushing, and striking the battery are examples of mechanical abuse. In this scenario, the physical damage, if severe enough, may deform or tear the separator. When the separator is compromised, there's the potential for an internal short (the cathode and anode contacting), causing rapid heating and subsequent thermal runaway.

Thermal Abuse

Another form of abuse is from extreme temperatures. Most if not all batteries should come with a recommended operating and storage temperature range, and it's critical to stay within these limits. In the case of thermal abuse, the separator can collapse, again paving the way for a potential internal short leading to a thermal runaway condition. This generally isn't a problem when using the battery, but in more extreme climates it's very easy to exceed manufacturer specifications. Think of a cordless drill or vape pen sitting in the hot interior of a vehicle in Arizona or Florida in the middle of July and you get the idea.

Electrical Abuse

The third form of abuse can happen when the battery is repeatedly overcharged or used with an incompatible charger. Even with "smart chargers" that shut off when a battery's State of Charge (SOC) reaches 100%, there is the possibility for damage. In this instance, microscopic structures known as dendrites can form over time. Just like the part of the nerve cells in our brain that share the same name, dendrites are like tendrils that grow, and if the growth is significant enough, can pierce the separator. Again, a compromised separator can result in a short, causing thermal runaway.

Battery Quality Issues

Aftermarket batteries that are now widely available may not have the same quality and construction standards as their Original Equipment Manufacturer (OEM) counterparts and are therefore susceptible to thermal runaway. Couple this with the fact that aftermarket batteries may be used on OEM-type chargers they weren't intended for, and the risk is compounded. Given that aftermarket batteries are typically much less costly than OEM versions, they are very attractive as replacements from a commercial standpoint and quite prolific. In fact, the number of battery fires are on the rise for this reason alone, according to an article in the Wall Street Journal. Of these causes, battery quality flaws tend to be the most common in triggering thermal runaway. Even something as simple as a tiny metal particle that gets stuck in the battery case or a design flaw in the protection circuit that is meant to prevent overcharging can cause the battery to fail. Regardless of what causes a battery to fail, it sets off a chain rection that ultimately leads to flames.

The Stages of Battery Failure

There are four stages a lithium-ion battery will go through as it fails. Though the exact process may vary depending on what triggers the failure, it will generally follow these four steps.

1. **Abuse:** Battery failure starts with electrical, thermal, or mechanical abuse as laid out above — assuming the battery was manufactured properly. Failure could also be triggered by a faulty design.
2. **Off-gas generation:** After the battery has been abused, the electrolyte solution will start to vaporize and produce flammable gasses. As those gasses accumulate, the battery's internal temperature and pressure will increase.
3. **Smoke generation:** As the battery fails, it leads to a short circuit of the cathode and anode. Energy flows through the battery rapidly, raising its temperature to more than 500°F, causing smoke to leak out of the battery. Comprised of vaporized electrolyte, the smoke is flammable, and signals the onset of thermal runaway. Because thermal runaway is a chain-reaction event, one overheated cell causes an adjacent cell to overheat until all cells within the battery are failing. It can even extend to the other batteries stored nearby.
4. **Fire generation:** The last phase of the cycle is fire. A fire may break out before or after thermal runaway, producing flames or an explosion should thermal runaway occur first. Either way, once a battery produces flammable smoke, it will almost certainly reach the fire phase and extend to nearby combustibles.

Not All Batteries Are Created Equal

Even within the category of lithium batteries, there lies a host of different battery compositions — and each has their own unique characteristics. These specific characteristics include nominal DC voltage, charge and discharge rate, lifespan, and specific energy (capacity). Different battery types are better suited for different use cases (for example, some are better suited for electric vehicles while others are better suited for cordless tools). Below are a few of the more common types of lithium battery compositions and their associated thermal runaway threshold temperatures according to Battery University.

Lithium Iron Phosphate	$LiFePO_4$ - (LFP)	270°C
Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$ - (NMC)	210°C
Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$ - (NCA)	150°C
Lithium Manganese Oxide	$LiMn_2O_4$ - (LMO)	250°C
Lithium Cobalt Oxide	$LiCoO_2$ (LCO)	150°C
Lithium Titanate Oxide	Li_2TiO_3 - (LTO)	177°C

Lithium-ion Fires Present a Unique Challenge for Fire Fighters

Thermal runaway presents a unique situation for firefighters that is a major safety concern. In the unfortunate event a battery does experience a complete meltdown, standard firefighting practices may not apply. In a "normal" combustion event as with flammable and combustible chemicals, the "fire triangle" concept applies. The three points of the triangle are ignition source, air (oxygen), and the fuel source. Remove any one of these three points and the fire is extinguished. In typical portable dry-chemical extinguishers, the fire is extinguished by "smothering" the combustion process and removing oxygen. This isn't the case with lithium-ion battery fires, as they are self-fueling by nature.

The chemistries used in the electrolyte produce flammable gases and generate their own oxygen, so they continue to burn until the fuel source is ultimately spent. If you've ever witnessed a firefighting crew trying to put out an electric vehicle fire using copious amounts of water, they aren't actually trying to extinguish the fire. They're trying to suppress it, keeping it as cool as possible to prevent it from getting hotter and potentially spreading and causing further damage.

Furthermore, even "burned out" batteries can still maintain a small SOC that's enough to re-ignite even days after the initial event. This makes disposal and transport of the batteries a challenge and another concern entirely.

The Devastating Costs of a Lithium-Ion Battery Fire

Because standard firefighting practices won't suppress a lithium-ion fire, they can be extremely destructive for businesses. Watch this short video to see how Justrite's Lithium-Ion Battery Charging Safety Cabinet could have prevented a $3M warehouse fire caused by a defective leaf blower battery.

WATCH NOW

Best Lithium-ion Battery Safety Practices

Now that we have a little more knowledge on what causes thermal runaway and subsequent fires, what can be done to reduce the risk or possibly even prevent them? Some good, simple common-sense tips are relatively easy to follow. But just like flossing your teeth, we need to remember to practice them.

1. **Keep Your Cool:** Don't allow batteries to exceed their temperature limits. Keeping the batteries in their recommended temperate environment will help keep them in their normal operating range and out of the danger zone.
2. **Pay Attention:** Don't leave batteries unattended during charging. Typically a lithium-ion battery is most vulnerable while discharging (being used) or charging. It is all too common to leave a battery on its charger for hours or even overnight when no one is around to monitor. Avoiding this situation is a simple but effective means of preventing a thermal runaway from igniting surrounding materials.

3. **Inspect Regularly:** If any damage is suspected (swelling of battery, excessive heat, visible damage) immediately discontinue use and contact your local battery recycler for proper disposal.
4. **Don't Mix:** When storing multiple batteries in the same location, do not mix battery chemistries. As with flammable chemical storage, incompatible materials should not be stored with each other due to potentially dangerous interactions or reactions. In the case of batteries, keep lithium-ion batteries separate from other battery types such as typical lead-acid batteries like the ones found in cars, motorcycles, and lawn equipment. Lead-acid batteries are notorious for outgassing and this gas is corrosive. If this comes into contact with lithium-ion batteries, it can cause corrosion and a potential short, inducing thermal runaway.
5. **Give them a safe space:** When charging or storing a lithium-ion battery, ensure they're in a suitable enclosure designed to handle a thermal runaway event, and store that container away from flammable materials. While safety regulations and codes are not currently in place, you should still take advantage of existing storage solutions. When choosing an appropriate enclosure, these elements should be included:

Structural integrity – An enclosure made of steel or aluminum of sufficient gauge to handle the percussive force of a battery explosion is critical. In addition, a door latching mechanism reinforced to maintain closure during an explosive event is also important.

Thermal insulation - The enclosure should have some form of insulation such as a double-wall design with an air-gap or insulating media with a low heat transfer coefficient (h). This helps prevent the heat transfer from the interior of the enclosure to the exterior, limiting the risk of secondary combustion of external materials.

Proper ventilation – When charging batteries, it's important to keep the chargers cool. Without sufficient enclosure ventilation, there is risk of a temperature rise great enough to cause the chargers to go into auto-cutoff mode — a safety feature. Keeping a constant flow of air through the enclosure helps ensure the chargers function as intended.

Sufficient sealing – In the event of a thermal runaway, a proper enclosure should have the necessary sealing elements for doors and vents. Heat-reactive dampers and door seals are an integral part of a well-designed enclosure. The containment of flames and limiting of smoke egress are critical.

Pressure relief – As mentioned earlier, the explosive force capable of a lithium-ion battery in thermal runaway is considerable. Therefore, it's crucial that the container include a pressure relief mechanism to maintain the structural integrity and avoid becoming a pressure vessel that can produce projectiles. A single 18650 lithium-ion battery can have over 1500 PSI of explosive force in thermal runaway, per the National Library of Medicine.

Prevent Lithium-ion Fires at Your Workplace

Nearly all these best practices can be addressed with an appropriate storage cabinet. The Justrite lithium-ion cabinet is a well-engineered solution. The patent-pending engineering and nine-layer ChargeGuardTM system of the Lithium-Ion Battery Charging Safety Cabinet model 231703 allows multiple batteries to safely charge simultaneously. The nine containment layers can be broken down into three key safety categories.

1. Explosion Protection	2. Fire Containment	3. Smoke Diffusion
• Steel Cabinet Construction	• Flame Arrestors	• Spring-Loaded Dampers
• Pressure Relief Vent System	• Double Wall with Air Gaps	• Unique Filtration
• Reinforced Steel Door Latch Plates	• Door Hinge Flame Guards	• Heat-Activated Expanding Door Seals

The safety cabinet is one of the few on the market that can prevent the costly and significant damage caused by unexpected lithium-ion battery fires. And because these batteries have high power density, are lightweight, and affordable, they are likely here to stay for a while.

So while governing bodies and technical committees are drafting standards and safety codes, we can all do our part to minimize the inherent risks of lithium-ion batteries to protect people, property, and the environment with this simple and effective solution.

Scan to learn more about Justrite's Lithium-Ion Battery Charging Safety Cabinet.