Soteria™

Understanding and Preventing Lithium-Ion Battery Fires

With Early Gas Detection

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Protect lives and equipment with early battery fire detection

Lithium-ion batteries are an essential part of modern life, powering everything from personal electronics to electric vehicles, medical devices, and power tools. However, they also pose a serious safety risk: under certain conditions, they can catch fire or even explode through a process known as thermal runaway.

Unlike typical fires which require an external ignition source and fuel, lithium-ion battery fires can start internally. When a battery is damaged, defective, or improperly used, it may overheat and begin to break down chemically. This process releases toxic, flammable gases – known as venting – which usually occurs 3 to 15 minutes before flames appear. Traditional smoke detectors and fire alarms do not detect these gases because the particle size is too small.

Figure 1: Soteria Sense device on workbench at a car repair workshop.

Soteria Sense is a device designed to detect these early warning signs. Using gas sensors and connectivity features, it identifies venting events from lithium-ion batteries and issues audible, visual, and remote alerts – giving users 3 to 15 minutes of advance notice before a fire. This time window allows people to act, isolate equipment, evacuate the space, trigger suppression systems, and call for help.

This whitepaper provides a foundation for safer adoption of battery technology in homes, businesses, and public infrastructure as we walk through:

- How lithium-ion battery fires start, what makes them different from other fires, and why early intervention is difficult with conventional safety equipment.
- What gas vent detection is, the types of gases released during battery failures, and how these can be used to identify a threat before thermal runaway begins.
- Who benefits from early detection, including first responders, EV repair shops, warehouses, hospitals, assisted living facilities, contractors, and anyone else storing or using battery-powered items.
- The design and function of Soteria Sense.
- Results from controlled testing, where different battery types were triggered into thermal runaway at different distances.
- Real-world feedback and testimonials, demonstrating the device's practical value across industries concerned with battery safety.

Introduction: anatomy of a lithium-ion battery fire

Lithium-ion battery fires are not like other fires. Most fires require an ignition source, a fuel, and oxygen—all of which generally come from different places and thus provide ways to prevent the fire, and to extinguish it by starving the fire of one of the critical ingredients. But lithium-ion batteries have all three in a single package:

- Electrical energy can provide the ignition source if a short circuit occurs inside the battery
- The electrolyte and lithium are good fuels, as often is the anode
- The cathode generally contains enough oxygen to allow the battery to ignite and burn

Batteries are designed to be stable, requiring something to go wrong to cause ignition. If there is a problem, they can self-ignite, which can result in unpredictable, immediate and ferocious—and sometimes explosive—flames, or thermal runaway. This generally is the result of an internal short-circuit, which can be caused by mechanical, electrical or thermal abuse of the battery, or by a manufacturing defect. In general, about 1 in 1 million cellphone or laptop batteries will self-ignite, but the probability can be much higher for other devices like power tools, lawn & garden tools, e-bikes, scooters, golf carts, vacuum cleaners, toys, drones and other small, powered devices.

Figure 2: Example of a cell phone post-battery fire.

Before a battery self-ignites, the battery is usually heated by a slow release of electrical energy. This sets off chemical reactions that are both exothermic—so they increase the heating—and also gas generating. As the battery heats, the electrolyte also evaporates, causing a pressure build up in the battery. Battery makers know this and build a weak point in the case designed to burst and allow the gases to exit the battery.

A person in the room when this happens will hear a pop, followed by a hissing sound and a distinct smell of burned cherries. The quantity of gas from even a small cellphone battery can be quite large—up to many liters of gas. Unfortunately, these gases are invisible to smoke detectors, which do not detect molecular contaminants in the air, but rather particles of smoke.

However, there are sensors that can detect the vent gas. Several types of gases can make up the vent gas, depending on the battery chemistry and the state of charge of the battery. They include carbon

monoxide, carbon dioxide, hydrogen, and volatile organic compounds, or VOCs. Sometimes, the venting of the battery will prevent the ignition of the battery. In other cases, the vent gases will be trapped in a confined space, which can result in a very energetic explosion if ignited. The time from venting of the battery to ignition depends strongly on the type of battery, the state of charge, the age, the amount of abuse, and other factors—but can range from seconds to many minutes. A reasonable expectation might be 3 – 15 minutes.

Potential benefits of a vent gas detector

Thus, it might be very beneficial to have the ability to detect a lithium-ion battery venting event and receive a remote warning. Some people who could benefit include:

- **EV Repair Shops:** the battery and car arrive in an unknown state, potentially damaged, and could self-ignite at any time. Having advanced warning would allow the repair technicians to isolate the EV, remove it from the shop, and take measures to contain any potential fire and protect nearby personnel.
- **First Responders:** First responders enter into situations in an unknown state, and may pass battery powered equipment that is potentially being heated by the fire. Placing a vent detector near batteries can give them warning if something is going wrong, while they attend to more urgent matters. In addition. Their own equipment is routinely exposed to various conditions, and a vent detector can be used to monitor it while charging or unused, potentially protecting valuable trucks, buildings, etc.
- **Battery and Equipment Manufacturers:** Sites that make batteries, and that make devices that use batteries, can benefit from monitoring their manufacturing site, both as a quality control measure as well as to provide warning in the case of any potential event.
- **Warehouses:** Warehouses that either hold or ship battery operated equipment, or that use battery operated material handling devices such as fork trucks or autonomous robots would benefit from advanced warning, allowing the protection of the goods being warehoused.
- **Golf Courses, Lawn & Garden Maintenance:** More and more, golf carts and lawn and garden maintenance tools are powered by lithium-ion batteries, and both experience a variety of use and abuse conditions, and so represent a higher probability of failure than smaller devices, and also a higher risk factor due to the size of the battery. The authors know of a golf course that lost its entire inventory of golf carts and lawn & garden equipment in an overnight fire.
- **Electric Fleet Owners:** Whether the fleet is work trucks, delivery vans or e-bikes and scooters, the fleet and batteries are often stored in a dense charging network undergoing overnight charging, and this represents a large potential loss in case of a fire. Advanced warning can trigger sprinkler systems and give first responders valuable notice to contain any event.

- **Charging Stations:** EV charging stations can often be near other vehicles, both electric and ICE. This can be especially exacerbated in a parking garage, which may not have enough ventilation to disperse vent gases, leading to potential explosions. Several companies are working on automatic responses for containment of events in parking deck charging stations, and a gas warning can give valuable minutes before smoke or other sensors might trigger the system.
- **Assisted Living:** More and more, care for the disabled and elderly is being assisted by powered wheelchairs, scooters, medical devices and other battery powered devices. In addition, those benefiting are often not able to mobilize quickly in the event of a fire, and so advanced warning can provide critical minutes to get them to safety and isolate any potential event, protecting both the people and their living environment.
- **Hospitals:** Similarly, hospitals are filled with battery powered medical carts and other battery powered devices and similarly filled with people who may not be able to care for themselves in the event of a fire. Advanced warning can be lifesaving as people are moved to safety under the care of their providers who know best, and can use those extra minutes to keep the services continuous while moving them to safety.
- **Personal Garages:** Many individuals have a large array of battery powered devices in their garage or other parts of the home, including power tools, lawn and garden tools, neighborhood electric vehicles, recreational vehicles such as jet skis, scooters, e-bikes and other devices. Because of the use, these devices all have a higher probability of failure than consumer electronics and advanced warning of an event can give valuable minutes to get loved ones out of the house and call first responders.
- **Contractors:** Contractors often charge or store lithium-ion batteries for power tools, lights, drones, and survey gear inside enclosed vans, site boxes, or temporary trailers. A single pack entering thermal runaway can ignite surrounding combustibles (lumber, solvents, fuel cans) before anyone notices. Advanced warning can protect significant damage as it buys time to remove people and combustible material to help contain the event.
- **Maritime & Aviation Cargo:** Freighters and cargo aircraft carry pallets of lithium-ion battery powered products in rugged and extreme environments. When a thermal event occurs, it happens quickly and there is not much time to act. Advanced warning can save lives, giving time to relocate to safety.
- **Rental & Equipment Depots:** Tool counters, e-bike fleets, and lawn equipment depots host batteries abused by unknown users. Packs can return hot, with swelling, or water-logged and are tossed into communal charging bays overnight. Advanced warning can trigger sprinklers and alert first responders, allowing additional time to take action.

Figure 3: Soteria Sense on a construction site monitoring power tools in use.

As can be seen, there are many potential benefits to having warning that a battery venting has occurred, and so Soteria undertook to design a versatile detector that could be used in any of the above situations, and many more.

Soteria Sense™ Battery Vent Detector

The Soteria Sense™ battery vent detector has several features, including:

- **Sensors:** gas sensors, other sensors for temperature, humidity and visual/audible triggers
- **Warnings:** audible and light warnings to alert those in the nearby area
- **Remote Warnings:** an app is provided that can use the internet to provide both monitoring of the system from a remote cellphone or computer, which can also receive warnings
- **API:** for advanced users, an API is provided that can be programmed into a building security system

The device itself consists of only a few parts, including:

- **Circuit Board:** a circuit board holding all of the sensors, a radio for Wi-Fi and Bluetooth communication, a processor and power controls
- **Battery:** an 18650 battery so that the device can be used remotely
- **Reset Button:** a reset button to stop the audible alarm in the case of a false positive alarm
- **USB-C Power:** a USB-C power plug to power the device and recharge the battery
- **Fan:** a fan to pull air through the battery for faster detection around damaged batteries
- **Case with Vent:** a flame-resistant plastic case with vents to allow gases to reach the sensors

The device, with its distinct hexagon shape, is reminiscent of a smoke alarm, but also distinct in both form and function.

Vent detection tests

Batteries that go into thermal runaway will be emitting toxic gases. Whilst various safety measures can significantly reduce the risk of a thermal runaway, this risk will not be zero. Depending on battery type and cathode materials, different gases will be emitted. The volume of gas as well as its composition depends on the battery chemistry that is affected by the thermal runaway. The graphs below show a summary, what can be detected, comparing NMC-, NCA- and LFP-cathodes.

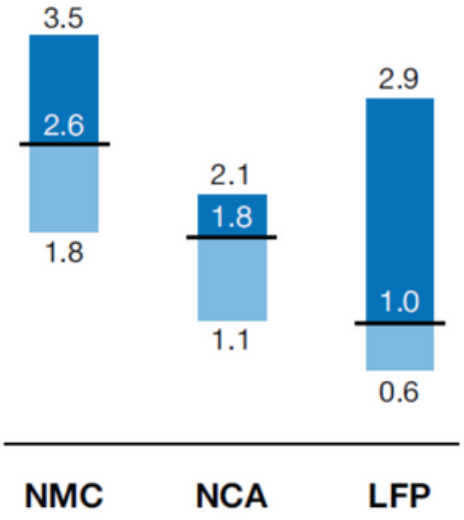

Figure 4: Specific gas volumes released in l/Ah [1]

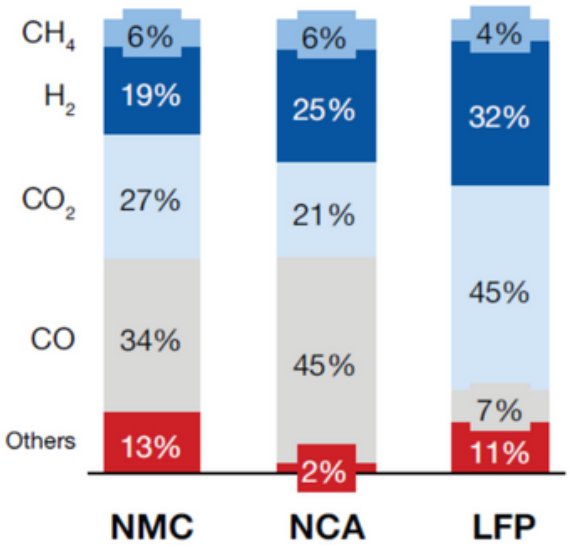

Figure 5: vol. gas composition in thermal event [1]

This is where the Soteria Sense™ battery vent detector comes into play since it will offer very useful early warning by detecting gases already prior to the ferocious fires resulting from the thermal runaway.

The full device has been tested with batteries that have been deliberately vented, and also against other potential events that could cause a false positive alarm. Note that it is possible to receive an alarm that is not an indicator of a battery vent event. In such a case, there will be the use of other volatile organic compounds (VOCs) nearby, like gasoline, kerosine, spray paint, acetone or other solvents. These will be readily available, and the app will provide the ability to turn the alarm off for a period of time to allow cleanup of the solvents, ventilation, or completion of whatever tasks required their use.

The test consists of different cells Being placed 3, 6, and 9 feet away from the device. Each cell is placed into thermal runaway with a heater. As each cell heats and starts to vent, the gases produced are measured. After each test, the area is well ventilated so that no remaining gases are left. Solvents such as acetone and paint thinner are also tested at different distances.

Test results continued on next page.

Reference (1): Challenges and Solutions in Battery Safety, PEM from RWTH Aachen University, 2023

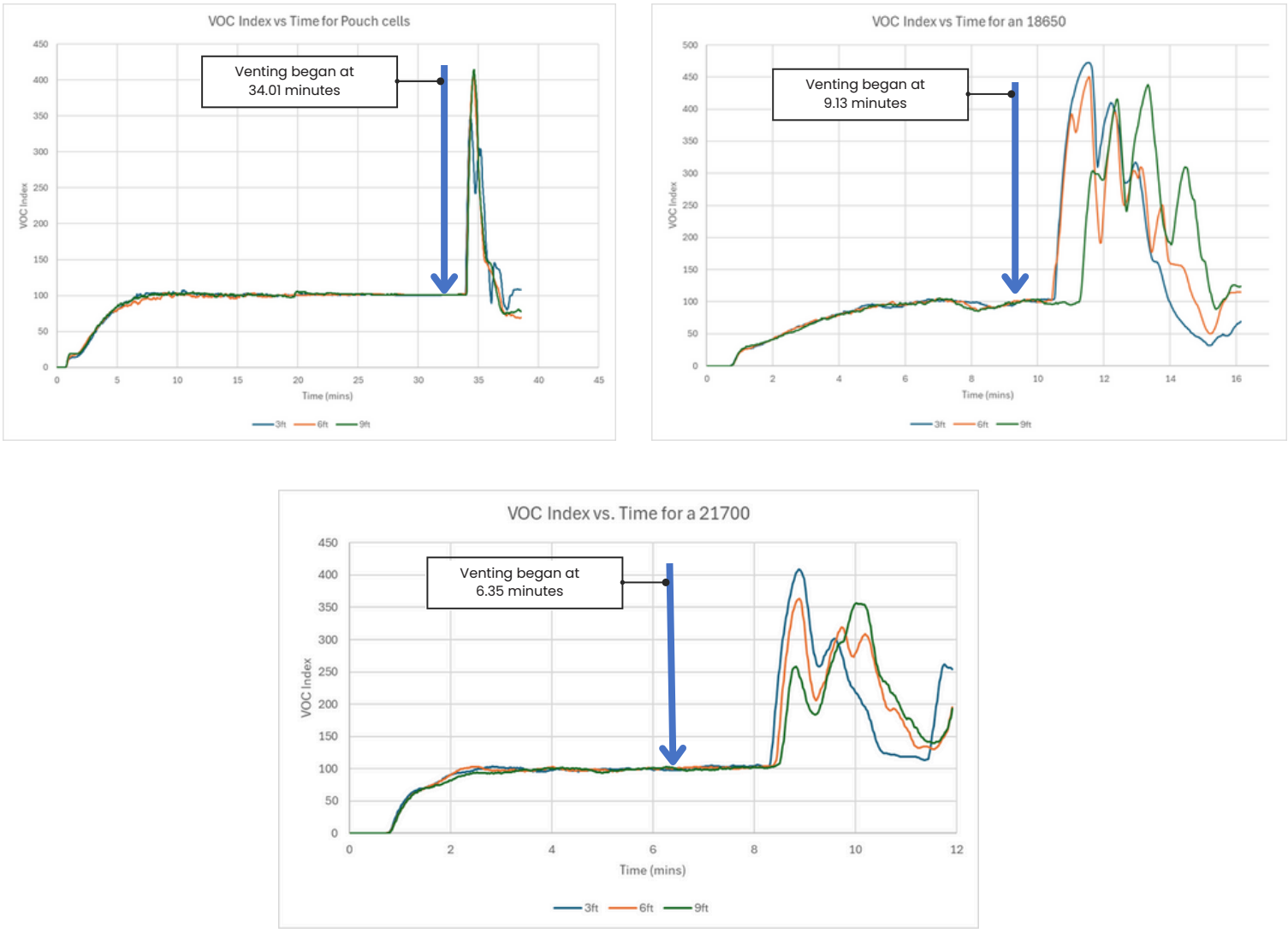

Figure 6: VOC index vs. Time results for pouch cell (upper left), 18650 cell (upper right), and 21700 cylindrical cell (lower).

The above plots illustrate different types of batteries off-gassing at specific distances from Sense. The plots clearly show how VOC values spike as soon as the batteries start to vent. The VOC Index is calculated by taking several factors into consideration such as VOC raw values, CO_2, H_2 and NO_x values.

Testimonials

The vent detector has been designed under the guidance of several members of the first responder community, as well as others from the battery community. Several comments and use cases have driven the design of the vent detector, and they have agreed to share their thoughts here.

> "As a member of the Soteria Battery Innovation Group Consortium and a manufacturer committed to advancing battery safety, we are excited about the launch of Soteria Sense. This standalone lithium-ion battery sensor is a game-changer for both residential and commercial environments. By detecting early signs of a potential cell vent event—before thermal runaway occurs—Soteria Sense provides an unprecedented layer of safety and peace of mind. It's a smart, proactive solution that empowers consumers and businesses alike to monitor battery health without needing to integrate into the battery pack itself. Soteria continues to lead the way in making energy storage safer for everyone."
>
> — John Warner, *American Battery Solutions*

Summary & path forward

Clearly, the device is satisfying a serious need in the market. Battery powered devices are infiltrating every aspect of our lives, from how we wake up in the morning, brush our teeth, communicate, drive to work, perform our jobs, and mobilize everything we do. Cords are being cut everywhere, and each time the cord is removed, an invisible battery appears that powers our life. This explosion of battery-powered devices also explodes the safety risk due to potential thermal runaway, but from the number of potential fires and the ferocity with which they start and spread. The ability to provide advanced warning is growing in importance and will only become more so as this trend continues.

Soteria's philosophy is always to address safety first, and company success second. Thus, the device is for sale, the circuit board can be integrated into other devices as a trigger or alarm system, and the technology, including both patents and trade secrets, can be licensed for integration into broader security systems, fire suppression systems, etc. Please contact us to receive devices for use or test, to receive circuit boards to be integrated into your own products, or for licensing information.

Learn more:

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