Pacific Northwest
NATIONAL LABORATORY

# BATTERY SAFETY

This factsheet presents an overview of battery safety considerations for energy storage systems, or large stationary batteries installed in residential, commercial, and industrial settings.

## KEY TAKEAWAYS

A Battery Management System (BMS) is a required component in all multi-celled batteries that **controls and monitors** the operation of the battery to ensure its safe operation. The BMS is designed to **shut off the battery if it detects the early signs of battery failure to prevent safety incidents**.

Battery fires can occur due to internal malfunction or proximity to extreme heat or external fire. Thermal runaway occurs when a **battery heats up faster than the heat can be dissipated**, resulting in the **venting of hazardous gases** and the potential for **ignition** or **explosion**.

Robust and continuously updated safety codes and standards exist to **ensure the highest quality of battery manufacturing** and the **safe operation** of battery systems for every application.

Organizations like the Fire Safety Research Institute publish easy-to-follow **battery safety tips for everyday battery use**, like those on their *Take Charge of Battery Safety* website.

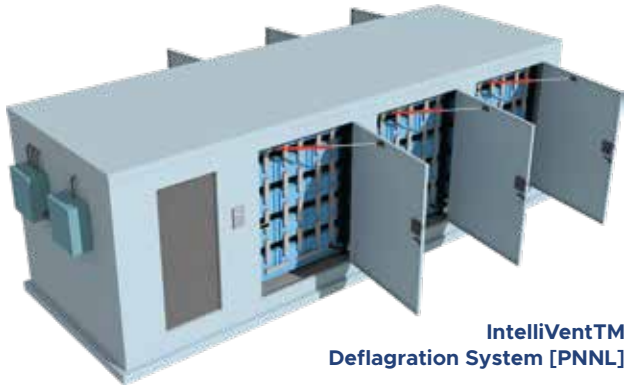
PNNL-SA-214285

## Battery Management Systems

Batteries are regularly used in many of the devices and systems in our homes and daily routines. To ensure those systems remain safe and secure, high safety standards for battery manufacturing and operation are necessary. Large scale stationary batteries, like those used in residential, commercial, and industrial battery energy storage systems, are similar to the lithium-ion batteries used in many other consumer products, but batteries used for energy storage systems have a much higher capacity and energy density. This is achieved by stacking multiple smaller battery cells within a single enclosure or battery unit. Since these larger batteries contain multiple battery cells operating together at higher energies, they are required to be controlled by a **Battery Management System**, or BMS. Any battery system that contains multiple battery cells must have a BMS, including small power tools, e-bike packs, electric vehicles, and battery backups. The BMS controls and monitors the operation of the battery, including its current, voltage, state of charge (SOC), and its status (charging, discharging, or idle). The role of the BMS is to ensure that the battery operates safely and according to specifications, as well as to detect potential battery failures and power off the device to prevent safety incidents. The batteries in electric vehicles are required to have sophisticated **BMS to control and protect the energy storage system**, as well as to alert the driver of any potential failures or safety risks. While the BMS serves as a critical safety and control system, **it does not protect the battery from misuse or physical impact**, which are the main cause of battery failures in smaller transportation devices like e- bikes and scooters.

## Battery Fire Awareness

Even with a BMS and proper use, safety incidents and battery failures can still occur. Battery fires can start from a cell or other internal electrical failures, or if the battery is exposed to extreme heat or fire. It is important to note that a BMS cannot dissipate the heat of an active fire that reaches the battery. **If a fire reaches a battery, immediately evacuate the building, call the emergency fire dispatch, and inform them of the presence of a battery system. A battery fire will also release toxic gases similar to those emitted by a house fire that are dangerous and should not be inhaled.** In the case of a battery fire, evacuate to a ventilated area upwind of the fire.



**IntelliVentTM Deflagration System [PNNL]**

If the battery itself fails and begins to overheat, this can cause a chain reaction called **thermal runaway**, where the **battery begins to heat up so rapidly that it catches fire**. If this happens, the safety protocol is the same—evacuate, call emergency response, and notify emergency services of the battery fire. The National Fire Protection Association (NFPA) mandates that the BMS of all batteries are designed to detect overheating before it leads to thermal runaway and vent the system, as well as implement fire suppression measures and planning. Systems designed to reduce the potential for explosions do so by exhausting flammable gases, known as deflagration prevention, or by directing pressure waves through passive vent openings.[1]

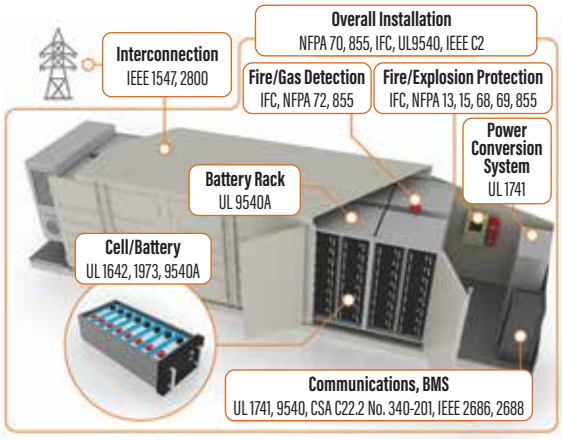
[1] While the international fire code (IFC) that references these NFPA deflagration (NFPA 69 and NFPA 68) and fire suppression (NFPA 855) standards is updated regularly, these updates are inconsistently adopted across the United States. For example, Puerto Rico adopts the International Codes (I-Codes), which are on the 2018 edition of the IFC.

## Safety Codes and Standards

UL Safety Logo

Standards and safety organizations like UL Solutions exist to ensure batteries are rigorously tested and manufactured to the highest safety standards. The most common battery failures occur with batteries that are purchased from countries that do not adhere to the latest UL safety standards. Before purchasing a battery or a product that contains a battery, be sure to check that it is UL Listed or Certified. Look to see that the product has a UL label like the one pictured here. A product with this label is required to meet specific safety standards and undergo rigorous safety testing.

There are numerous safety codes and standards that battery manufacturers are required to follow when producing batteries for sale in the United States. Stationary batteries, like those in residential, commercial, and industrial sectors, must adhere to siting and permitting requirements that vary based on local regulations and type of system. For example, commercial and industrial batteries are subject to strict requirements to ensure that these larger systems have proper ventilation, access, and protection from the weather and other hazards[2]. The following resources provide additional details on standards and safety:




Key Codes and Standards for battery energy storage systems (BESS)

- **UL Solutions**
  *https://www.ul.com/resources/battery-standards-overview &*
  *https://www.nfpa.org/codes-and-standards/nfpa-855-standard-development/855*
- **National Fire Protection Association**
  *https://www.nfpa.org/education-and-research/home-fire-safety/lithium-ion-batteries*
- **National Electric Safety Code**
  *https://standards.ieee.org/products-programs/nesc/*
- **International Fire Code**
  *https://codes.iccsafe.org/content/IFC2024V1.0/chapter-12-energy-systems*

The key codes and standards for stationary energy storage systems are depicted in the figure above. These standards cover everything from fire and smoke detection, fire suppression and smoke containment, ventilation and thermal management, egress and access, electrical safety and emergency shutoffs, protection from hazards, necessary signage, spill containment and disposal, and communications and management. Project planners can engage with local first responders and permitting authorities during the project development process to help increase situational awareness, share lessons learned, and foster a collaborative approach to safety.

When a battery system is **commissioned** for use, critical **safety and verification procedures** are performed to ensure safe operation of the battery. All components, controls, and safety systems will be verified for correct installation and operation, the system will be inspected for any defects, and the commissioner will ensure that the owner has been provided with the complete documentation to ensure smooth ongoing operations, including maintenance and troubleshooting procedures.

[2] For more information on how safety influences planning and zoning considerations, see: Twitchell, Jeremy B., et al. "Energy Storage in Local Zoning Ordinances.", Oct. 2023. https://doi.org/10.2172/2204502

## Battery Safety Tips

While this factsheet is primarily focused on larger stationary batteries, the most common devices to suffer battery failures that lead to fires and safety incidents are smaller consumer products such as battery-powered scooters, bikes, and skateboards, followed by laptops, cellphones, tablets, and power tools. Each of these devices is relatively light-weight and mobile. With this mobility and ease of use comes the risk of physical damage to the battery. Below are some important safety tips to reduce the risk of battery failures:

- **If the battery is damaged, do not use or charge it**.
- **Never charge a battery with the wrong cable**. Avoid extension cords, and never daisy-chain or link multiple extension cables. Charging or discharging a battery with a cable other than what it is rated to use can lead to overcharging, overheating, and rapid failure.
- **Place batteries on a flat, well-ventilated surface while charging to avoid overheating**.
- **Store batteries in a cool, dry place**. It may not be best to store batteries in a garage, as garages can get significantly warmer or cooler than the rest of your home during the summer or winter.
- **Do not store the battery fully charged or completely empty**. It's best to store batteries between 30 – 80% charged.
- **Do not store batteries plugged into their charger**.

## Further Reading

For additional safety tips, and to learn more about battery safety, check out:


- Paiss M.D., V.L. Sprenkle, L. Khair, and M. Leitman. 2024. *Battery Energy Storage System Safety Report; Design Considerations for Electric Cooperatives*. PNNL-36330. Richland, WA: Pacific Northwest National Laboratory
- Twitchell, Jeremy B., Powell, Devyn W., and Paiss, Matthew D. "Energy Storage in Local Zoning Ordinances.", Oct. 2023. https://doi.org/10.2172/2204502.
- *Take Charge of Battery Safety*. Fire Safety Research Institute, UL Research Institutes. 2025. https://batteryfiresafety.org/#section-1.


PNNL-SA-214285