THE ULTIMATE GUIDE TO FIRE & GAS SAFETY IN BATTERY ENERGY STORAGE SYSTEMS

Key Steps to a Safer Li-ion Energy Storage Infrastructure for a Decarbonized Future

BESS

Honeywell

INTRODUCTION

The battery energy system storage (BESS) industry is expanding at a rapid rate, with forecast demand continuing to rise exponentially in line with global shifts toward renewable energy sources. In Europe, this trend is driven by the E.U.'s commitment to reach net zero by 2050[1] and by the decarbonization plans set by individual countries and organizations. As power generation from renewable energy sources, like solar, wind, and tides, is intermittent by nature, battery energy storage systems is needed to store excess power and release it to the grid when user demand rises, additionally providing grid stability.

While there are several types of BESS, lithium-ion (Li-ion) based battery systems have become the go-to solution because of their excellent power density and rapid charging and discharging rates. Containerized Li-ion BESS facilities are particularly popular because of their rapid deployment for large-scale and modular solutions.

The downside of Li-ion technology is the safety risks associated with the flammable nature of Li-ion batteries. The technology is vulnerable to a condition known as thermal runaway, which occurs when an exothermic reaction generates excessive heat and gas. Several high-profile incidents have already captured public attention and have the potential to dissuade investors and insurers from the industry.

A holistic and effective safety strategy is essential to reduce the risk of BESS operation and improve the industry's safety performance. This technical guide shows how original equipment manufacturers (OEMs), and decarbonization investment funds can safeguard their assets while maximizing uptime and minimizing costs.

WHY ENERGY STORAGE IS CRITICAL TO A NET ZERO FUTURE

Attaining the United Nations net zero goal by 2050, as pledged at the Climate Change Conference in 2021, will require a radical shift from fossil fuels to renewable energy sources. According to IRENA, the total of onshore and offshore wind generation will need to reach 35% of the global energy demand to achieve this goal[2]. This figure equates to an installed capacity of 1,787 GW by 2030 and 5,044 GW by 2050 compared to 837 GW in 2022[3].

However, displacing fossil fuel derived energy capacity in the grid with renewable energy capacity is not without its challenges. Wind power is a variable energy source, meaning that the amount of electricity it generates can fluctuate depending on the wind conditions. Fossil fuel power plants, on the other hand, can adjust their output by burning more or less fuel to meet consumer demand.

When the percentage of renewable energy in the grid rises, this fluctuation in supply has the potential to introduce power generation instability. The most common way to overcome this challenge is by introducing energy storage technologies into the grid that can store excess energy and release it back into the grid when needed[4]. Pumped-storage hydropower is the most widely used energy storage technology, with a global installed capacity of 160 GW. While grid-scale battery storage solutions lag quite significantly at 16 GW, the projected expansion rate is high and accounts for the majority of new energy storage on the grid.

According to the International Energy Agency (IEA), grid-scale battery capacity needs to grow substantially to meet net zero needs[5]. In fact, the BESS capacity demands should reach 680 GW by 2030 if the growth in renewable energy meets the net zero targets over that period. Li-ion battery technology is the leading technology for grid-scale solutions, with this technology accounting for 90% of total deployment in 2020 and 2021.

Li-ion technology offers several benefits that make it attractive for BESS solutions. These include:

- A high energy density meaning that the required footprint is smaller than other battery technologies.
- Rapid charge and discharge rates that enable quick response to grid demand changes.
- Long lifespans that maximize return on investment.
- Low maintenance requirements, which lower operating costs.

Containerized solutions are proving to be popular designs for BESS facilities due to their ease of deployment and scalability. However, despite the positive characteristics of Li-ion technology, there are also safety risks associated with thermal runaway. With several cells in such close proximity, the consequences of an incident could be catastrophic.

FIRE RISK: A THREAT TO LARGE-SCALE BESS DEPLOYMENT

While the net zero demand for new BESS installations is a powerful driver, negative public perception can quickly interrupt the momentum. The industry is at risk of shifting public perception due to the number and severity of BESS incidents in recent years. According to the BESS Fire incident database, the number of incidents has been increasing each year over the last three years, with 12 incidents in 2022 alone[6]. It is interesting to note that most of these incidents occur in the first two years of operation meaning that the next few decades will be critical for safety management as the number of new BESS facilities coming online increases at a rapid pace.

BESS incidents tend to be severe because a failure of one cell can trigger a failure in the adjacent cell until an entire container or multiple containers are engulfed in a fire. An incident like this can result in millions of Euros worth of damages as well as a facility shutdown, costing millions in revenue. That shutdown could affect the grid, leading to customer supply issues and a knock-on economic effect. However, it is not only the damage to the BESS itself that affects public perception. An incident at a PG&E facility near Moss Landing in California resulted in the shutdown of Highway 1 in the area for more than 12 hours[7]. The community was advised to shelter in place due to possible hazardous gas exposure. Several BESS fires have also been recorded across Europe. In 2017, a fire broke out in a BESS container at the ENGIE Energy Storage Park in Drogenbos, Belgium, The firefighting operation lasted 12 hours and required almost 1.4 million liters of water and 400 kg of powder[8]. In 2020, a containerized BESS in Ariège, France caught fire requiring the intervention of six fire engines and over thirty firefighters and causing the closure of a nearby departmental road[9].

Injuries to personnel can also lead to negative public perception. As the technology is new, it may not be well understood by firefighters who are unfamiliar with it. In an incident in Arizona, firefighters responded to a BESS facility where the smoke alarm had triggered the automatic suppression system[10]. The firefighters took regular readings in a hot zone around the facility to detect when the concentration of hazardous gases had dropped to an acceptable threshold. However, four firefighters were seriously injured by a deflagration event on entering the BESS. The Fire Safety Research Institute produced a report from this incident to provide valuable insights for future BESS fires.

Li-ion fires are unlike other fires because the fire is fueled by an ongoing exothermic reaction in the cell, known as thermal runaway. Once the battery failure progresses to this level, it is impossible to extinguish the fire. The fire then can only be controlled until the chemicals in the cell are depleted. Failure conditions can be triggered by physical damage, overcharging, deep discharging, thermal abuse or manufacturing defects. Besides the fire and smoke, Li-ion fires also release toxic gases, which are harmful to the surrounding public. Even when BESS facilities are located in remote areas, emergency responders are at risk. At the same time, run-off from the fire suppression system can affect the surrounding environment and pollute waterways.

Growing public awareness of the risks associated with Li-ion fires may slow down the uptake of energy storage due to insurance companies' reluctance to underwrite BESS projects and a slowdown in public and private investment.

HOW DO BESS FIRES HAPPEN AND WHY ARE THEY HARD TO PREVENT?

BESS fires result from battery failures that progress from an initial trigger event to a fire. There are four stages in this progression:

1. ABUSE FACTOR

There is always an abuse factor that leads to battery failure. Electrical abuse happens when the battery voltage limits are exceeded during charging or discharging. Thermal abuse occurs when the operating temperature exceeds safe limits and can result in a breakdown of the liquid electrolyte and its conversion into the gaseous state. Mechanical abuse is caused by physical damage such as an indentation or puncture.

2. OFF-GAS

When the liquid electrolyte converts to gas, the internal pressure in the cell rises. Eventually, the battery will rupture its seals or force open a pressure relief design vent. Electrolyte solvent vapors, like diethyl carbonate, dimethyl carbonate, or other carbonate species, are released from the battery as off-gas.

3. SMOKE

As the battery continues to generate gas faster than the venting rate, the internal pressure will rise further. Eventually, the separator will melt and rupture, causing the release of smoke. Carbon monoxide, carbon dioxide, and hydrogen are released at this stage. By this stage, thermal runaway is imminent and cannot be prevented.

4. FIRE

Thermal runaway occurs when the battery catches fire. Temperatures under these conditions can exceed 1,000 degC, but a battery can enter thermal runaway at temperatures as low as 130 degC. Once a cell enters thermal runaway, it endangers all the surrounding cells and has the potential to cause a total system failure.

Even though the science behind BESS fires is well understood, these fires are still hard to prevent. One of the primary reasons is that traditional fire protection methods in the form of smoke and gas detectors are too slow to react to li-ion off-gases. By the time these systems activate, the battery failure has already reached thermal runaway. Attempting to improve the sensitivity of these devices for earlier detection leads to false positives, which is also detrimental. Nuisance alarms result in BESS downtime causing disruption to the grid and a loss in revenue.

As the BESS sector continues to expand, standards and regulations are also evolving. One of the primary reference standards developed by the National Fire Protection Association (NFPA) is NFPA855 2023: The Standard for the Installation of Stationary Energy Systems.

This has become a much referenced/global standard and has some helpful language geared towards to the use of off-gas/electrolyte solvent vapour detection. It should also be noted that an HMA(Hazard Mitigation Assessment) is required retrospectively for all those non UL 9540 compliant systems. A few notable highlights are:

1. 4.8.1 - For lithium-ion ESS, a smoke detection system can be supplemented by a listed or approved off-gas detection system. Off-gas detection can increase the effectiveness of the smoke detection system for providing early response of an off-normal condition.
2. 9.6.5 Thermal Runaway protection now specifically required for Li-ion batteries
3. G.4.3.1.1.1 Fire, Smoke, Heat, and Failure Detection. The system used in this example will include early warning smoke detection and early intervention off-gas sensors in the ESS envelope. This category can also include gas detection technologies to identify battery off-gas in the environment outside of the ESS.
4. G.7.3.6 Gas Detection and G.7.3.6.1 Cell-Level Event. Off-gas sensors or detectors must be designed to detect the variety of different gases from the many types of LIB chemistries etc.

THE WAY FORWARD: A HOLISTIC APPROACH TO BESS FIRE SAFETY

While safety standards and regulations may take some time to catch up with technology developments, BESS owners and operators can already adopt a holistic approach to BESS fire safety that will significantly reduce their risk of an incident. The table below shows the main components of an effective fire and safety architecture that should be included in a holistic approach.

COMPONENT	DESCRIPTION
Advanced electrolyte vapor detection	A system able to detect electrolyte solvent vapors before a battery failure progresses to thermal runaway.
Advanced smoke detection	A system that detects the presence of smoke as early as possible.
Battery Management System	A system that monitors voltage, current and temperatures within the battery. The BMS has control to electrically isolate the components of the ESS if potentially hazardous conditions are detected.
Fire Alarm Control Panel	A system that activates automatic fire suppression systems.
Cloud Platform	A system that connects a BMS to the cloud for access from anywhere in the world in order to monitor system health and current off-gas readings.

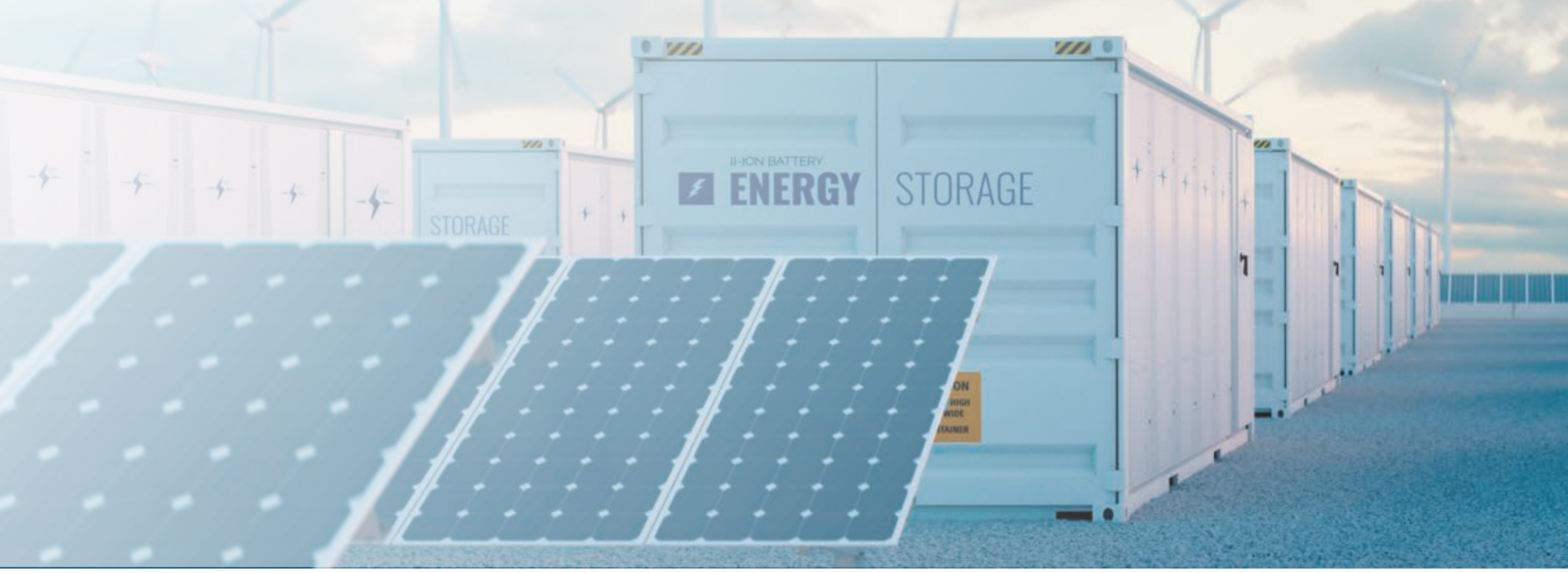
Even though legislation is not yet in place to enforce the holistic approach, regulators are constantly looking for effective ways to minimize fire risk and these components may soon become a legal requirement.

NEW REGULATIONS ON THE HORIZON

North America and Europe are introducing new standards and regulations for the energy storage sector including BESS facilities. There is a growing requirement for early warning systems that detect electrolyte solvent vapors known as off-gas, that get released in the early stages of battery failure. Find out more about changing legislation here.

FOUR STEPS TO DESIGNING AN EFFECTIVE BESS FIRE SAFETY ARCHITECTURE

Many safety professionals are implementing these components of an effective BESS fire safety architecture in a step-by-step design approach. Using four distinct steps, BESS owners and operators can minimize their fire risk and maximize uptime.



STEP 1 – PREVENT

Lowering the risk of a probably maximum loss (PML) scenario depends on the ability to prevent a fire from starting. This ability is enhanced by early warning of a battery failure using an advanced electrolyte vapor sensor, like Honeywell Li-ion Tamer. During the early stages of a cell failure, it is possible to measure the presence of electrolyte vapor from a cell before the situation deteriorates into a thermal runaway. The system can be configured to automatically electrically isolate the affected cell or battery rack using the Battery Management System. Other preventive actions can also be automatically initiated - like increasing ventilation and cooling.

STEP 2 – DETECT

Once the incident escalates to the point of generating heat and smoke, detection systems must activate as early as possible to limit the damage. Aspirating Smoke Detectors (ASD), like the Xtralis VESDA-E series, provide early warning with excellent nuisance alarm rejection. The pipework design for smoke detection can also profoundly affect performance. BESS facilities can use cooling fans combined with an HVAC to generate air movement through the battery rack. Cool air flows through the battery racks while hot air gets expelled via the HVAC. Positioning custom pipe networks feeding the smoke sensors allows for targeted detection from the most likely sources of fire.

STEP 3 – CONTROL

A fire alarm control panel is critical for managing detection devices, monitoring the system's health, and activating preventive measures. Control panels allow technicians to take individual devices out of service for maintenance and to replace components without taking the whole system offline. Modular and flexible systems allow BESS facilities to adjust their system as their needs change or as new detection technologies become available. Honeywell systems, like the ESSER FlexES control unit, offer built-in redundancy to ensure maximum system reliability and an easy-to-use operating display panel.

STEP 4 – CONNECT

Many BESS facilities are in remote locations where they support the integration of renewable energy sources, like wind farms, into the electrical grid. Remote visibility of the real-time status of the facility and the fire protection sensors is vital to enhance timely and data-based decisions. A cloud platform, like Honeywell CLSS, offers several features that improve safety. For example, push notifications to mobile devices ensure that specific staff are instantly alerted of information relevant to their role. Service and system reports allow for better planning of interventions and a reduction in downtime. Honeywell CLSS also logs device testing, servicing, and maintenance for compliance reporting.

CONCLUSION

> **The BESS industry is experiencing rapid growth, and the demand for these systems will continue to expand with the increasing deployment of renewable energy sources into the grid. Containerized li-ion based BESS solutions are the leading choice for investors and OEMs, but the technology has some safety challenges.**

Li-ion batteries are vulnerable to thermal runaway, which generates extreme heat and gas, which can lead to catastrophic fires, substantial environmental damage and PML events. It is vital for OEMs and green investment funds to protect their assets with a holistic fire safety approach. A key pillar of this approach is the use of advanced electrolyte vapor sensors to detect an imminent battery failure before it progresses into a thermal runaway. Other elements include detection, control, and cloud connectivity.

Honeywell has solutions for each component in a holistic fire safety architecture, including Li-ion Tamer for early warning and prevention, VESDA-E aspirating smoke detection systems, Honeywell fire panels, like the ESSER Flex ES control unit, and Honeywell CLSS for cloud connectivity. As such, we form the ideal strategic partner to help OEMs and green investment funds design a safety system that protects their BESS assets and lowers their risk.

Learn more about our holistic fire safety architecture for the BESS industry here.

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