SECURITON

Battery Energy Storage Systems (BESS)

Early Warning Fire Detection

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1 Introduction

Battery Energy Storage Systems (BESS) and smaller Uninterruptable Power Supply (UPS) systems play a number of crucial roles in modern society, and Lithium-ion batteries are increasingly the technology of choice for these systems. Despite currently offering the best density of energy storage, li-ion batteries pose a serious fire safety risk due to their immense energy density and the savage intensity with which they burn.

A li-ion battery fire releases the stored chemical energy in the battery, causing a rapid increase in temperature known as “thermal runaway”. This then progresses to an explosive combustion of the battery electrolyte vapor, with intense heat and highly toxic smoke. Such battery fires are not only intense and dangerous, but they are also particularly difficult to put out – so much so, that in many cases firefighters prefer to leave them to burn out. The heat generated can cause significant damage, even to building structures.

Several methods and technologies are employed for fire detection and prevention in lithium-ion batteries within the battery itself. These include thermal sensors; smoke and gas sensors; voltage and current monitoring; pressure sensors; internal short circuit detection; state-of-charge monitoring; a Battery Management Systems (BMS) and/or thermal management. Additionally, research is ongoing to develop battery components that are more resistant to thermal runaway, fire, and explosion. Flame-retardant electrolytes and separators are examples of such materials.

However, for fire safety consultants involved in wider site safety, additional, independent fire detection is essential as the internal monitoring systems are not fail-safe and should the warning signs be missed, a fire can rapidly grow to catastrophic proportions. In particular, the critical nature of many li-ion BESS sites means that early warning detection and an avoidance of false alarms leading to shutdowns is imperative.

Li-ion BESS is crucial to store unreliable or cyclical renewable energy such as wind and solar power, and to manage demand and provide critical load back-up in the smart grid. Li-ion batteries are also increasingly used in the uninterruptable power supply (UPS) systems that protect critical assets such as data centres, hospitals, stock exchanges and telecommunications hubs from a power outage that would have far-reaching consequences. Increasingly, these roles are becoming inter-related as the ability of li-ion technology to be rapidly and often charged and discharged allows data centre operators, for example, to take power from their batteries at times of peak demand (and cost). This process is known as ‘peak shaving’. Additionally, li-ion batteries are sometimes used to provide power for remote communities or in disaster zones.

Li-ion usage for BESS is generally better established, and a number of documented fires at American sites serve to illustrate the risks:

- Fires at two lithium-ion battery energy storage sites in Warwick NY, smouldered for more than a week after a storm-related issue caused the newly installed units to ignite and burn in two separate incidents in June 2023.
- In 2022, a fire at PG&E’s Tesla-supplied Elkhorn Battery energy storage system at Moss Landing, California, led to road closures and shelter-in-place advisories in the surrounding area. The fire was isolated to a single battery pack but still led to the closure of a highway and local residents were advised to shelter in place with windows closed, due to the risk from airborne hazardous materials.
- A more serious incident involved a lithium-ion battery container near Phoenix, Arizona, which caught fire in April 2019 and later exploded, injuring several firefighters. The fire ignited in just one of the 27 racks of batteries at Arizona Public Service’s (APS) McMicken facility. Although it did not spread to other racks and the total flooding clean agent fire suppression system operated as intended, the fire continued and caused a buildup of explosive gas in the rack, which combusted when the first responders opened the door and let oxygen into the container. A report on the fire [1] concluded that it was an extensive cascading thermal runaway event, initiated by an internal cell failure within one battery cell in the BESS.

In response to increased concerns about li-ion battery fires and the growing popularity of the technology, Securiton has developed a best possible fire detection solution for such applications using a combination of pre-existing and bespoke products. The Securiton approach highlighted in this Case Study uses SecuriSmoke ASD, SecuriHeat d-LIST and gas sensors in combination.

The aspirating smoke detector can cover open spaces, power conversion systems and elements of the ventilation system to a VEWFD standard. SecuriHeat d-LIST is an electronic sensor cable system that can be used as an integrating or non-integrating line-type heat detector, designed according to EN 54-22. It offers high sensitivity for monitoring the battery racks and can be easily installed so that maintenance and testing does not require close access, while offering precise localisation of a heat incident. The off-gas detectors can be placed near the battery racks or the ASD pipe network to monitor the air and provide a further element of fail-safe early warning.

The approach in this Case Study provides fire safety and protection consultants, qualified fire system specifiers, design engineers or technicians, with design options to offer enhanced fire detection aimed at object protection and avoiding business interruption, while also meeting regulatory requirements.

2 Aspects of fire safety and prevention

Li-ion BESS are crucial to store unreliable or cyclical renewable energy such as wind and solar power, and to manage demand and provide critical load back-up in the smart grid. Li-ion batteries are also increasingly used in the Uninterruptable Power Supply (UPS) systems that protect critical assets such as data centres, hospitals, stock exchanges and telecommunications hubs from a power outage that would have far-reaching consequences. Increasingly, these roles are becoming inter-related as the ability of li-ion technology to be rapidly and often charged and discharged allows data centre operators, for example, to take power from their batteries at times of peak demand (and cost). This process is known as ‘peak shaving’. Additionally, li-ion batteries are sometimes used to provide power for remote communities or in disaster zones.

The risks around li-ion batteries used for the purposes of UPS is essentially that an asset intended to preserve service continuity could in fact pose a danger to the entire facility. Given that these services are presumably important enough to warrant having expensive UPS back-up, Very Early Warning Fire Detection is advisable to ensure that the batteries themselves do not compromise the facility they protect. Additionally, early warning may be needed so that an alternative source of back-up power can be arranged should a battery catch fire, as it will most likely have to be left to burn.

A li-ion battery fire releases the stored chemical energy in the battery, causing a rapid increase in temperature known as “thermal runaway”. This then progresses to an explosive combustion of the battery electrolyte vapor, with intense heat and highly toxic smoke. Such battery fires are not only intense and dangerous, but they are also particularly difficult to put out – so much so, that in many cases firefighters prefer to leave them to burn out. The heat generated can cause significant damage, even to building structures.

The following 2 sub-chapters take a detailed look at the workings of a li-ion battery, and what is known about the process that in some cases causes them to catastrophically burn when they fail (thermal runaway).

2.1 Lithium-ion batteries

A lithium-ion battery consists of an anode, a cathode, a separator and electrolyte (Figure 1) as the main components. During the initial charge the Solid-Electrolyte Interphase (SEI) is formed, which is permeable to lithium ions but not to the electrolyte. The stability of the SEI is a determining factor of a li-ion battery safety and life. Other components are described as follows [2]:

- Cathode: The composition of the cathode, a.k.a. as the cathode matrix, gives the name to the type of the li-ion battery. Lithium metal oxide such as lithium cobalt oxide (LCO), nickel cobalt aluminium oxide (NCA), lithium cobalt phosphate (LCP), nickel cobalt manganese oxide (NCM), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium iron fluorosulphate (LFSF) and lithium titanium sulphide (LTS) are used as cathode materials. The composition used determine the potential (in Volt) and the capacity (in mAh/g) of the li-ion battery.
- Anode: Graphite is the most commonly used material for the anode because it has a high negative potential.
- Separator: The separator is a crucial component in a li-ion battery. It prevents electrical short circuits between the anode and the cathode (the electrodes) but allows transport of lithium ions between them. Common materials for li-ion batteries with organic electrolytes are made of microporous polyolefin films such as polyethylene (PE), polypropylene (PP), or laminates of polyethylene and polypropylene.
- Electrolyte: The electrolyte fills the space between the electrodes and the separator; its formulation is depending in the materials used for the electrodes. The typical electrolyte for li-ion batteries is made of a flammable carbonate-based organic solvent such as ethylene carbonate (EC), dimethyl carbonate (DMC), diethyl carbonate (DEC) and ethyl methyl carbonate (EMC), and/or propylene carbonate (PC), with additives including lithium hexafluorophosphate ($LiFP_6$), lithium hexafluoroarsenate monohydrate ($LiAsF_6$), lithium perchlorate ($LiClO_4$), and lithium tetrafluoroborate ($LiBF_4$) to improve cycling.

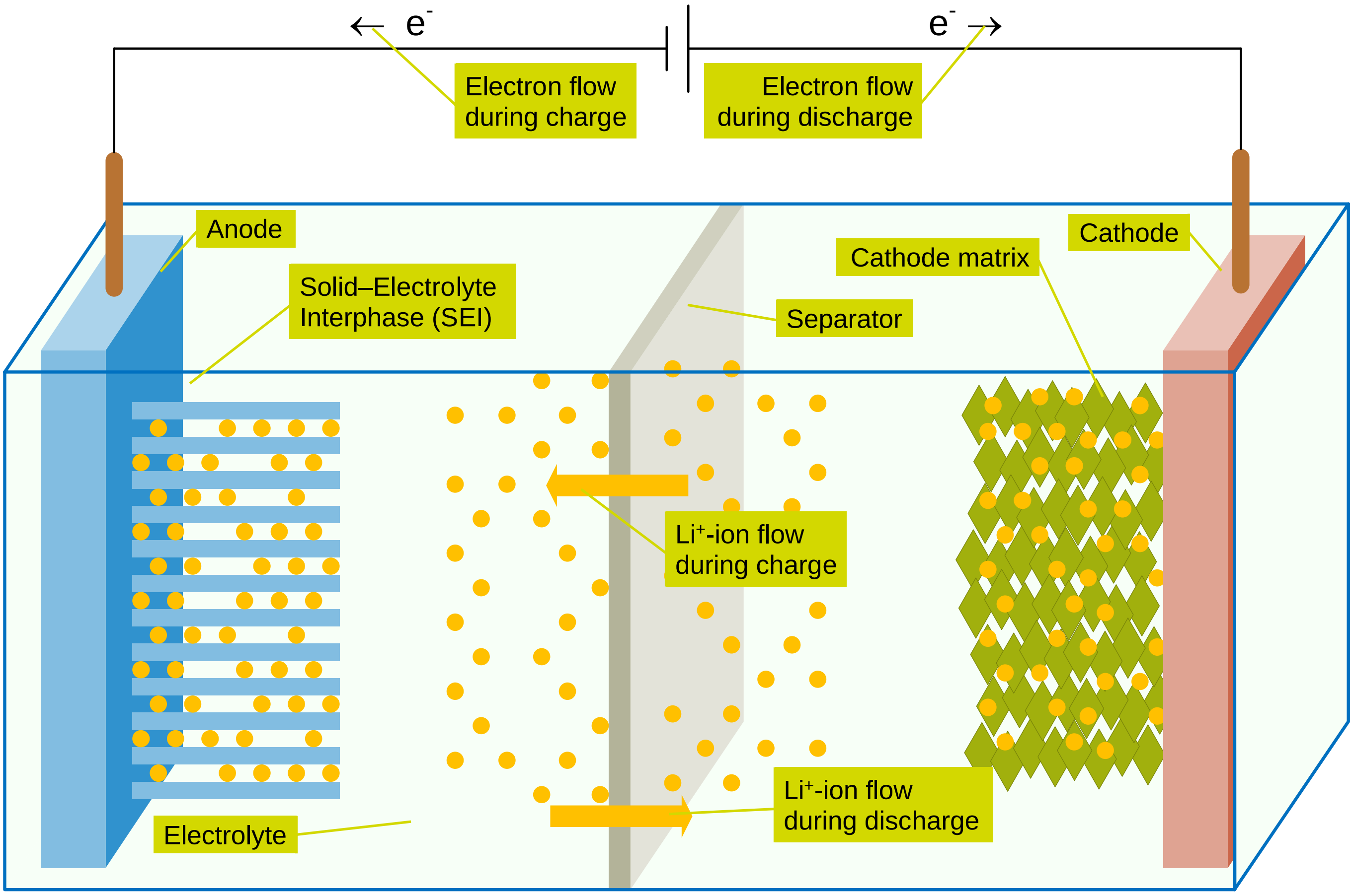


Figure 1 Principle of a lithium-ion battery

If li-ion batteries are not operated within their specification, they are prone to fail. One of the most catastrophic failures of a lithium-ion battery system is a cascading thermal runaway event where multiple cells in a battery fail due to a failure starting at one individual cell. Figure 2 schematically explains the reactions caused by raising temperatures with a li-ion battery.

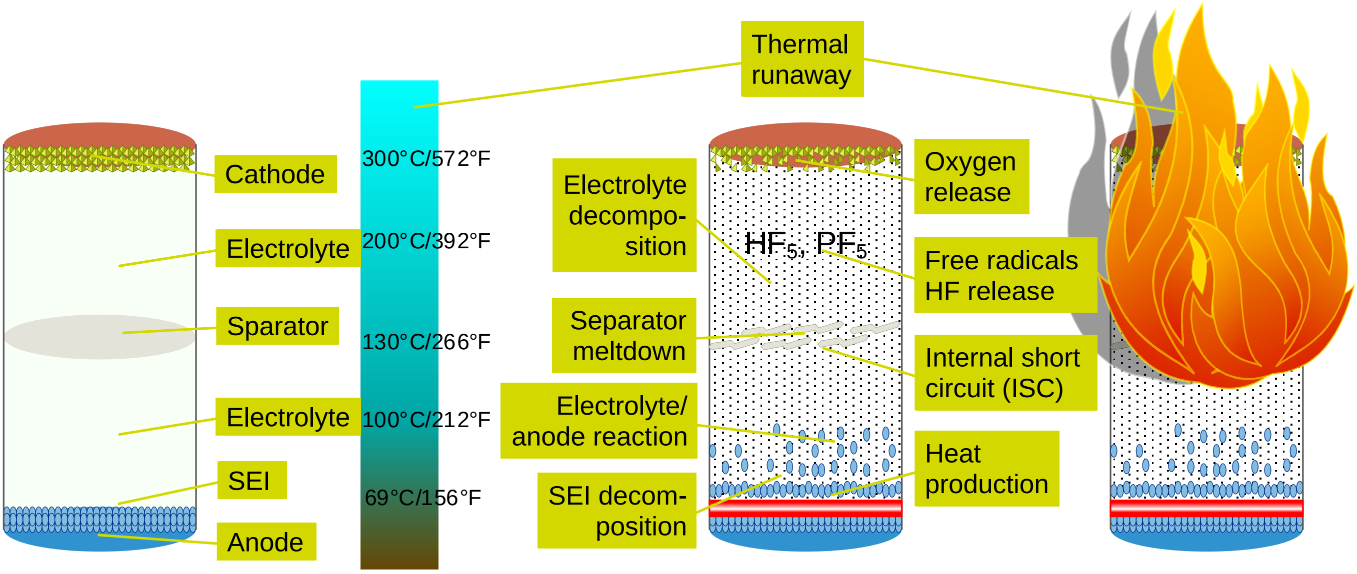
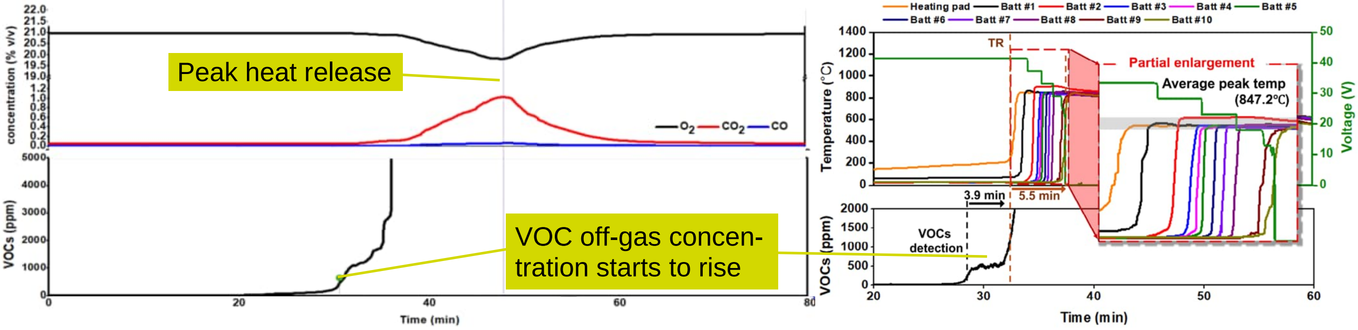


Figure 2 A schematic of thermal runaway processes in lithium cobalt oxide (LCO)/graphite cell

At temperature above 69°C (156°F), the solid-electrolyte interphase (SEI) start to decompose followed by exothermic reactions between anode and electrolyte, and anode materials and the binder. At around 130°C (266°F) the separator is melting down producing an internal short circuit (ISC), electrolyte decomposition continues, and reactions between the separator, the cathode material and electrolyte significantly contribute to the heat released in the presence of oxygen through their ignition and burn properties.

The chemical reaction within the cell during the failure produces various gasses at different stages. Studies have shown that the level of volatile organic compounds (VOC) rises at the early stage of the thermal runaway [3], and the level of hydrogen (H_2) can serve as an indicator for early detection of a thermal runaway [4]. Figure 3 illustrates the level of VOC caused by thermal abuse of the cell.



(a) Levels VOC and other gases over time

(b) VOC development v temperature development

Figure 3 Off-gas development during the thermal runaway [3]

2.2 Risk, cause and damage

Although li-ion batteries are extensively used in energy storage applications, they are susceptible to thermal runaway and fire which is the primary safety concern when used in li-ion battery systems that consist of multi-cell packs and modules, where thermal runaway in a single cell can initiate thermal runaway in adjacent cells and consequently compromise the integrity of the entire li-ion battery system.

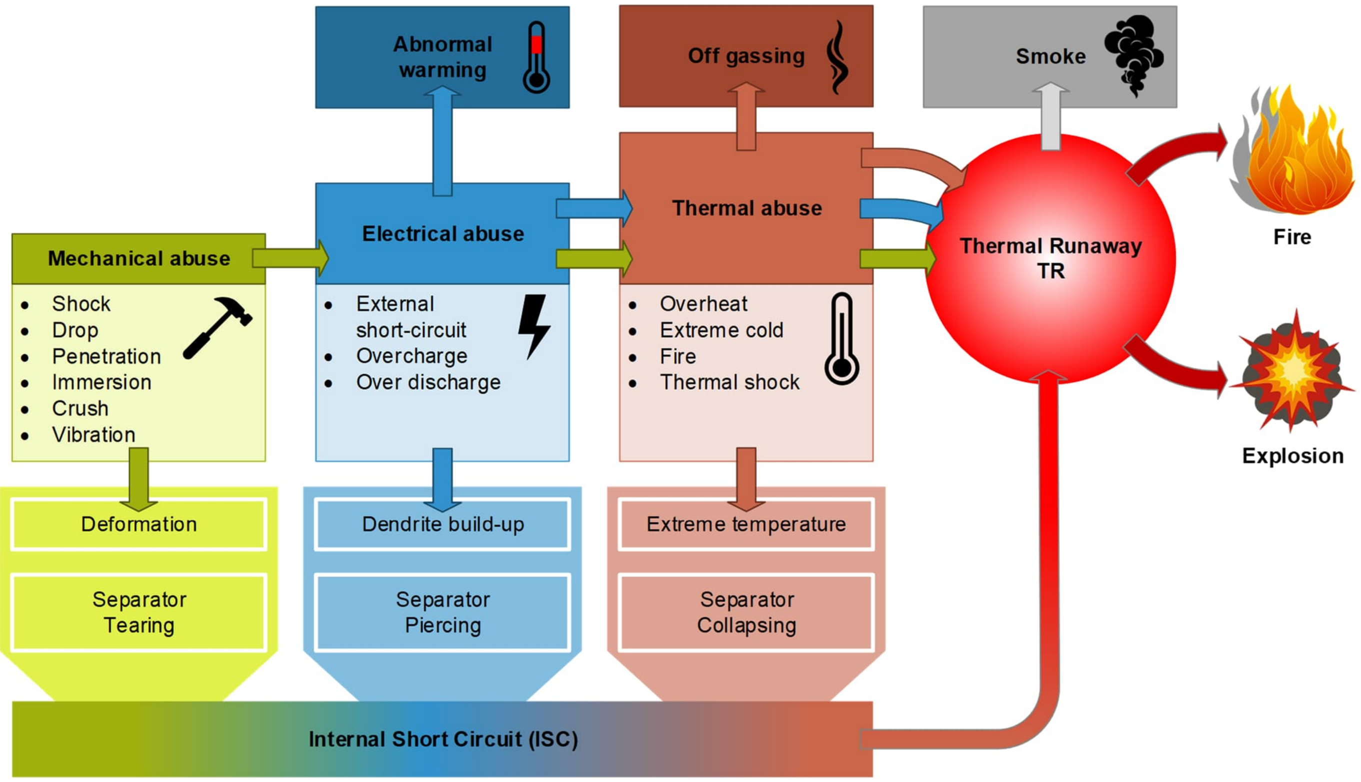


Figure 4 Various abuse conditions that can cause a thermal runaway

Causes that lead to a thermal runaway fall into one of four categories of abuse (Figure 4):

1 Mechanical abuse, usually caused by external mishap, such as shock, drop, penetration, immersion, crush or vibration can result in the deformation and can consequently tear the separator

2 Electrical abuse, mainly caused by external short-circuit, over charge or over discharge can result in the build-up of dendrite[1] which can lead to a piercing of the separator

3 Thermal abuse, mostly caused by overheating, exposing the li-ion cell to extreme cold or fire or thermal shock expose the separator to extreme temperatures that can result in a collapsing separator (see also Figure 2)

4 A material defect or a manufacturing fault cause an internal short circuit (ISC), allowing contact between the cathode and the anode via the electrolyte resulting in the thermal runaway of the li-ion cell.

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[1] A crystal dendrite is a crystal that develops with a typical multi-branching form, resembling a fractal (Source: Wikipedia)

Battery Energy Storage Systems (BESS) play an important role in critical infrastructure facilities like the power grid (power generation in solar and wind farms, peak shaving, power quality improvement, etc.), data centres, telecom infrastructure or hospitals. BESS are also used in sectors like banking and finance or manufacturing where processes rely on uninterrupted power to ensure no, or minimal down time allow for maximum business continuity.

Fires in BESS can cause severe damage to businesses affected, as the following examples show:

- India (2024) – A fire at the country's largest telecom provider led to a nationwide outage [5]
- France (2023) – A fire severely damaged a data centre, highlighting concerns about lithium-ion battery safety [6]
- Singapore (2024) – A blaze in a data centre disrupted services for multiple technology companies, among the Alibaba Cloud [7]
- South Korea (2022) – A fire at a data centre in Pangyo caused prolonged outages, prompting investigations into lithium-ion battery risks [8]
- USA (2019) – Four Firefighters Injured In Lithium-Ion Battery Energy Storage System Explosion in Arizona [9]

3 Challenges

Some challenges to protecting li-ion batteries from fire are universal: principally that a thermal runway event escalates extremely quickly, and that once it is underway there is little that can be done to stop it. However, early detection is still extremely useful in buying precious time to further isolate the battery in question and to remove any other batteries from the immediate vicinity, and perhaps to provide an alternative power source to critical assets the UPS or BESS is supporting.

As is always the case with Early Warning Fire Detection, alarm sensitivity needs to be balanced against the requirement to avoid false alarms. The best approach to this is for a detector to feature multiple levels of pre-alarm and alarm. This allows for a staged response with verification before drastic actions are taken.

Most li-ion BESS facilities generally incorporate fire retardant elements into the design and the recent examples of fires in the US show that these have been successful in preventing the spread of fire to the whole facility. For this reason, smaller, modular BESS systems are currently preferred. However, even a fire in a single rack has proven dangerous to personnel and had undesirable knock-on effects to the local community.

Given the development of a li-ion battery fault leading to catastrophic failure, thermal runaway and fire as described in detail in chapter 2 above, it is theoretically possible to detect the problem before a conventional fire (smoke and flames) is present. The relative timelines of heat, off-gas and smoke development during a battery failure leading to thermal runaway are shown in detail in the design and application section of this Case Study, see Figure 8. Each of these three detectable anomalies present challenges to designing a detection system that avoids unnecessary false alarms:

- **Heat detection:** An anomalous heat build-up should theoretically be the first sign of a serious problem in a battery, but batteries can run hot when discharging normally and BESS sites which are in the open will also be subject to significant ambient temperature changes. Multiple heat detection points very close to the individual batteries are therefore required – but of course access to battery racks is limited and undesirable.
- **Off-gas detection**: Although off-gassed compounds like CO, HF, and VOCs (e.g., ethylene carbonate, dimethyl carbonate) occur early, they can initially be in very low concentrations, making early detection difficult. Additionally, gas sensors can degrade or drift over time, especially in harsh environmental conditions typical of BESS enclosures, and some sensors react to multiple gases, potentially causing false positives or missed detections. Temperature and humidity can affect both gas production from batteries and sensor performance, while off-gases may be quickly dispersed or diluted in large or ventilated enclosures, making detection harder. As with heat detection, access to racks is a complicating factor, especially as gas detectors generally require more calibrating, testing and maintenance than linear heat detectors. Overly sensitive systems may trigger unnecessary shutdowns or fire suppression actions, causing operational downtime, so there is a need to balance sensitivity and reliability.
  Smoke detection: Lithium-ion battery thermal runaway often starts with off-gassing and localised heating before visible smoke is produced. Especially in the early phases, the smoke may not reach detectable levels. At the same time, HVAC or ventilation systems in BESS enclosures may dilute or carry smoke away from detectors. The smoke may rise or move unpredictably depending on airflow patterns, potentially missing ceiling-mounted detectors.

4 Code compliance and optimal design

Fire protection standards around the protection of stationary li-ion batteries such as those found in BESS and UPS is an evolving area, with regulatory bodies yet to fully address li-ion BESS and UPS sites comprehensively.

In the US, the often internationally followed NFPA published NFPA 855, *Standard for the Installation of Energy Storage Systems* [10], which deals with the installation of new BESS facilities, including but not exclusively those with li-ion battery technology. When it comes to existing lithium-ion batteries on a BESS, the standard requires a specific Hazard Mitigation Analysis (HMA) to be carried out.

FM Global recently updated a data sheet describing loss prevention recommendations for the design, operation, protection, inspection, maintenance, and testing of stationary lithium-ion battery energy storage systems greater than 20 kWh [11]. This data sheet also describes location recommendations for portable (temporary) lithium-ion battery energy storage systems.

In Germany, both the German Energy Storage Systems Association (BVES) and the insurance industry association VdS have published recommendations regarding li-ion BESS.

4.1 FM Global Data Sheet Recommendations

FM Global Property Loss Prevention Data Sheets 5-33 [12] deals specifically with lithium-ion battery energy storage systems and was revised in April 2025. It recommends damage limiting construction methods for buildings housing li-ion BESS and using non-combustible materials, as well as locating energy storage systems in accordance with one of the following, listed in order of preference:

1. In an enclosure outside and away from critical buildings or equipment
2. In a dedicated building containing only li-ion BESS and associated support equipment
3. In a dedicated exterior cutoff room that is accessible for manual firefighting operations
4. In a dedicated interior corner cutoff room with at least two exterior walls that is accessible for manual firefighting
5. In a dedicated interior cutoff room with at least one exterior wall that is accessible for manual firefighting

The data sheet recommends treating any prefabricated container or enclosure that is larger than 500 ft^2 (46.5 m^2) as a building. Additionally, FM recommends providing a 6 ft (1.8 m) minimum separation from the accessible face of an li-ion BESS rack to non-combustible materials, non-combustible construction elements, and the accessible faces of adjacent battery racks. The accessible face is the side that has a door, vent or can be opened, allowing fire to escape the rack of origin. A minimum 9 ft (2.7 m) separation is required from the accessible faces of battery racks to combustibles and combustible construction elements. Separation between non-accessible sides of adjacent racks should be determined by an installation-level fire test demonstrating that thermal runaway cannot propagate between racks. Where a test report is not available or the test did not result in a fire in the rack of origin, assume thermal runaway will propagate between racks.

FM 33-5 suggests that a li-ion battery rack system should have battery management systems with trip functions at cell, rack and supervisor levels. Additionally, it recommends online condition monitoring systems that will monitor battery room temperature and the following parameters, at a minimum, at the battery module and/or cell level:

- Charging and discharging voltage and current
- Temperature
- Internal ohmic resistance
- Capacity
- State of charge (SOC)
- State of health (SOH)
- Alarm or fault log

These online condition monitoring systems should, among other things, be capable of transmitting data to a constantly attended location or specific operations personnel; generate alarms when unusual conditions are detected; and analyse monitored parameters to generate a summary of the condition of the battery.

It is furthermore suggested that an early intervention system be in place to automatically and electrically isolate the li-ion BESS, using one of the following approaches:

1. High cell temperature: The cell manufacturer should provide the threshold temperature indicating an abuse condition based on 100% SOC. The majority of cells within a module should be constantly monitored.
2. Off-gas detection: Provide FM Approved gas detectors capable of detecting the volatile organic compounds associated with the off-gas event that precedes thermal runaway.

4.2 German industry body recommendations

The German Energy Storage Systems Association BVES has published a document laying out measures to protect large-scale li-ion BESS facilities [13]. It argues for a Performance-based Design PBD approach where effective measures must be defined within the framework of an individual risk analysis in order to find a suitable protection concept. Various possibilities for risk analysis are suggested, with approaches based on the safety of people; continuity of business and electricity supply; protection of valuable objects (the batteries); and protecting the environment. The latter includes consideration for water usage standards when it comes to the disposal of any water used to supress a battery fire, as this will likely be heavily contaminated.

German VdS guidelines [14] state that there is currently "no reliable information on adequate protective measures for high-capacity batteries". Protective measures are therefore to be regulated in consultation with the property insurer for the individual case. Conceivable measures here are, for example:

- Separation and quantity limitation
- Storage in fireproof separated areas or with compliance with a safety distance (spatial separation of 5 m 16.4 ft))
- Automatic extinguishing systems

4.3 NFPA and other standards

A risk-informed, PBD approach should comfortably achieve the expected level of fire safety from the following NFPA and related standards:

- NFPA 855 [15] Standard for the Installation of Stationary Energy Storage Systems
- NFPA 550 [16] Guide to the Fire Safety Concepts Tree
- Fire Risk Assessment Guidelines from SFPE [17]; NFPA 551 [18], ISO 16732-1 [19] and BS 9992 [20], Guide to Performance-Based Fire Safety Design [21]; Code Official's Guide to Performance-Based Design Review [22]
- FIA Guidance on Li Ion Battery Fires [23]

Performance-based Design (PBD) is also typically implemented when elements of a fire safety and protection system design are not covered in the prescriptive codes. This may be because of unique building structure, environmental conditions, or the need for added detection for early warning or extended egress considerations. In the case of BESS protection, special hazard and unique characteristics of battery fire ignition and development in confined spaces with very high fuel density must be taken into account when suitable fire protection and fire response plan are developed. A PBD approach is commonly adopted for either of the following:

1. As a means to determine equivalency to a prescriptive code or standard
2. As an approach to achieve broadly defined fire safety goals and objectives

NFPA 855, *Standard for the Installation of Energy Storage Systems,* deals with the installation of new BESS facilities, including but not exclusively those with li-ion battery technology. When it comes to existing lithium-ion batteries on a BESS, the Standard requires a specific Hazard Mitigation Analysis (HMA) to be carried out.

5 Optimised design and application scenarios

In response to increased concerns about li-ion battery fires and the growing popularity of the technology, Securiton has developed a best possible fire detection solution for such applications using a combination of pre-existing and bespoke products. As they fail and head into thermal runaway, li-ion batteries produce excessive heat and release off-gas before the point of smoke development. The Securiton approach highlighted in this Case Study uses SecuriSmoke ASD, SecuriHeat d-LIST, A VOC/H_2 sensor in combination.

The aspirating smoke detector can cover open spaces, power conversion systems and elements of the ventilation system to a VEWFD standard. SecuriHeat d-LIST is an electronic sensor cable system that has been specially designed for EN 54-22 and can be used as an integrating or non-integrating line-type heat detector. It offers high sensitivity for monitoring the battery racks and can be easily installed so that maintenance and testing does not require close access, while offering precise localisation of a heat incident. The off-gas detectors can be placed inside battery racks or use the airflow generated by the ASD system to monitor the air and provide a further element of failsafe early warning.

5.1 Design criteria: SecuriSmoke ASD

Airflow and required detection sensitivity are two main factors that affect SecuriSmoke ASD sampling hole spacing. Table 1 summarises some key design criteria for deploying Early Warning Fire Detection to a BESS.

To provide clarity, below are some key terminologies:

- **Transport Time:** time for (smoke) aerosols to transfer from a sampling hole to the ASD detector
- **Maximum Transport Time:** maximum time for (smoke) aerosols to transfer from the furthest sampling hole to the ASD detector
- **Response Time:** time between the generation of combustion aerosols at their source and the indication of their presence at the ASD detector
- **Reaction Time:** time between (smoke) aerosols reaching a defined level of obscurity (e.g., End-of-test EOT condition) and the notification of their presence at the ASD detector

Pipe network layout and single or aggregated pipe length also determine the transport time from each sampling hole to the detector, hence a maximum transport time from the furthest sampling hole(s). Both sampling hole sensitivity and transport time are calculated with the SecuriSmoke ASD PipeFlow design tool. PipeFlow offers to calculate a pipe layout in two modes:

1. EN 54-20 (also its derivatives ISO 7240-20 [24] and AS 7240.20 [25]): PipeFlow optimises its calculation for transport time, balance (same air volume at each sampling hole) and takes the characteristic curves of all EN 54-20 test fires [26] into consideration. PipeFlow then indicates the sensitivity to which the detector must be set in order to allow for each sampling hole to reach the required sensitivity according to the selected class.
2. NFPA: PipeFlow optimises its calculation for the required transport time for VEWFD, EWFD or SFD.

Design recommendations described in this chapter assume the transport time meets the respective sampling hole or detector unit sensitivity level in Table 1 for target Class A (VEWFD), Class B (EWFD) or Class C (SFD) design.

Model	Key design criteria		
NFPA/FM Global	**VEWFD**	**EWFD**	**SFD[2]**
Hole sensitivity	3.28% obs/m (1.0% obs/ft)	4.92% obs/m (1.5% obs/ft)	Point type over number of holes
Hole coverage	18.6 m^2 (200 ft^2)	37.2 m^2 (400 ft^2)	83.6 m^2 (900 ft^2)
Transport time	<60 sec	<90 sec	<120 sec
EN/AS/ISO/BS	**Class A**	**Class B**	**Class C#1**
Hole sensitivity[3]	0.4% obs/m (0.12% obs/ft)	1.16% obs/m (0.35% obs/ft)	6.67% obs/m (2.0% obs/ft)
Hole coverage[4]	15-25 m^2 (166-269 ft^2)	25-35 m^2 (269-388 ft^2)	Up to 7.5 m (25 ft) radius
Transport time[5]	<60 sec	<90 sec	<120 sec
Reaction time[6]	<60 sec	<60 sec	<60 sec

Table 1 Key design criteria (SecuriSmoke ASD)

In general, simply follow relevant codes and standards for the design of smoke detection system to meet prescriptive requirements. Two key considerations in design are:

1. Sensitivity requirements versus detection requirements in relation to the height of the ceiling.
2. The smoke detector spacing (or ASD sampling hole spacing as equivalent) in relation to the airflow.

Table 2 and Table 3 illustrate the design parameters commonly referred to when designing Early Warning Fire Detection with SecuriSmoke ASD in accordance with the codes such as FIA Code of Practice [27]. Smoke detector spacing based on air change rate (ACH[7]) per NFPA 72 [28] or FM DS 5-48 [29].

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[2] SFD/Class C refers to point type detectors, usually tested to an alarm sensitivity of 2.0 dB/m (36.9% obs/m (11.247% obs/ft)).

[3] For Securiton ASD products. Individual hole sensitivity can be determined using SecuriSmoke ASD PipeFlow design tool.

[4] Hole spacing is more a mixture of DtS (per point type detectors in BS 5839-1 or VdS 2095) and PBD (BS 6266, FIA Code of Practice or VdS 2095 Appendices) provisions with adjustments based on airflow and design to required sensitivity Class A, B or C.

[5] Transport Time of AS7240-20 conformed Class A, B and C are 60 sec, 90 sec and 120 sec respectively in AS1670-1.

[6] Reaction Time of 60 sec after EOT refers to EN54-20 test requirements for relevant tests to Class A, B or C sensitivity.

[7] ACH: Air Change per Hour

Parameters	Key design considerations		
EN 54-20 Class	**Class A**	**Class B**	**Class C**
ASD Sampling Type and Smoke Characteristics	Smoke is not visible due to low quantity of smoke and/or high dilution caused by air movement	Smoke is visible but insufficient to be detected by point type detectors (per [28])	Smoke visible and sufficient to be detected by point type detectors (per [28])
Primary Detection (sampling where smoke is likely to travel)			
	Best	Appropriate (Small areas only)	Not appropriate
Secondary Detection (positioning sampling holes per the codes for point type detectors)			
	For Early warning applications	For challenging applications	Appropriate
Localised Sampling (custom protection of specific equipment)			
	Appropriate for high risk	Appropriate for low risk	Not appropriate
In-cabinet Sampling (localised sampling)			
	Appropriate for high risk	Appropriate for low risk	Not appropriate
Duct Sampling			
	Appropriate for high risk	Appropriate for low risk	Not appropriate

Table 2 Sensitivity requirements vs. detection requirements (FIA Code of Practice [27])

Air changes per hour (ACH)	Spacing [m^2 (ft^2)]
60	12 (125)
30	23 (250)
20	35 (375)
15	46 (500)
12	58 (625)
10	69 (750)
8.6	81 (875)
7.5	84 (900)
6.7	84 (900)
6	84 (900)

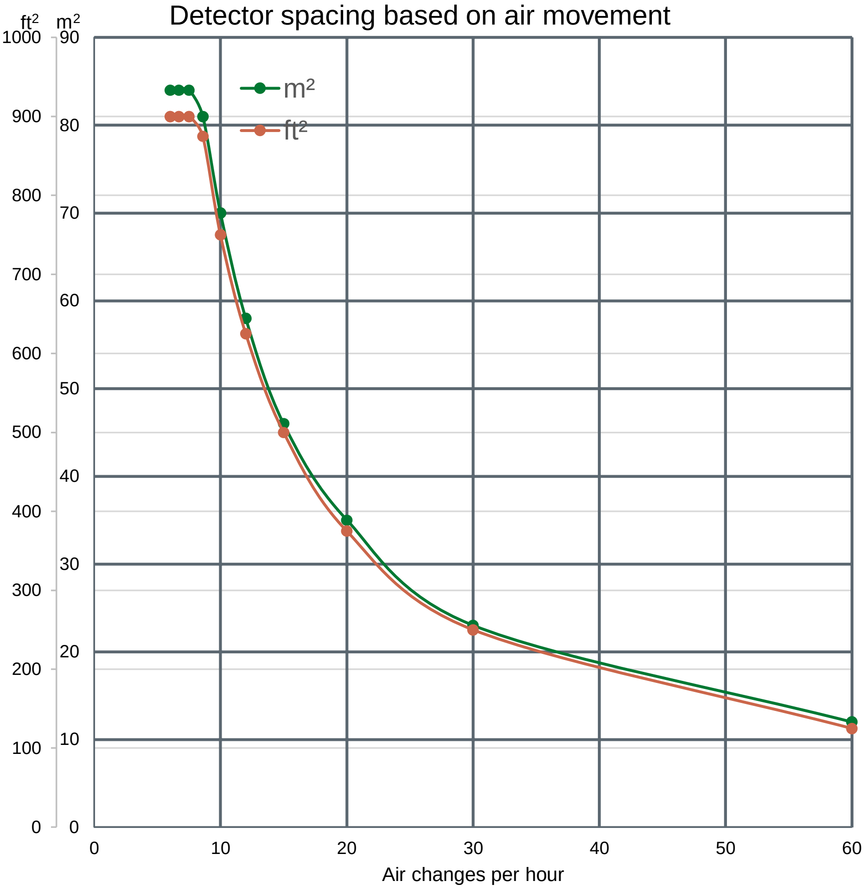


Table 3 Smoke detector spacing based on air change rate (NFPA 72 [30]/FM DS 5-48 [31])

Because each ASD sampling hole in effect represents a single point type smoke detector, the key criteria or variables included in this chapter focus on SecuriSmoke ASD design with relate to:

1 Sampling hole spacing
2 Sampling hole placement
3 Sampling hole orientation (in general perpendicular downwards to the floor unless mentioned otherwise)

5.2 Design criteria: Gas detection

This chapter describes design criteria using the gas detection products to protect battery energy storage systems. Gas sensors detect volatile organic compounds (VOC) and flammable gasses like hydrogen (H_2) and methane (CH_4). A summary of key performance parameters for the gas sensors is shown in Table 4 below.

Model	Key performance parameters	
InfraSensing® R-GAS-FLAMMABLE		
Sensor metrics	VOC measurement output range: 0-500 VOC index	
	Butane (C_4H_{10}) Ethane (C_2H_6) Hydrogen (H_2) Isobutane (CH_3) Methane (CH_4) Octane (C_8H_{18})	Pentane (C_5H_{12}) Propane (C_3H_8) Propylene (C_3H_6) Toluene (C_7H_8) Xylene (C_8H_{10})
Detection range	0-100% LEL	
Detection method	Spectrometer	
# of relays	3, programmable warning, alarm and fault	
InfraSensing® GAS-VOC, DAISY-VOC		
Sensor metrics	VOC measurement output range: 0-500 VOC index	

Table 4 InfraSensing gas detection

5.3 Design criteria: SecuriHeat d-List

This chapter describes design criteria using the SecuriHeat d-List Line-Type Heat Detector (LTHD) to protect battery energy storage systems. SecuriHeat detects temperature changes and alerts and alarms almost instantly to any potential fire incident or developing fire event. The d-List sensing cables represent sealed systems that are immune to dust and moisture. A summary of SecuriHeat d-List key performance parameters is shown in Table 5 below.

Model	Key performance parameters
SecuriHeat SCU 835 (d-List) classes, sensors and cable length	
Classes	Integrating: A1I, A2I, BI, CI Non-integrating: A1N, A2N, BN, CN
Cable length	SEC-15 cable 2 x 350 m (1’148 ft)
Addressable sensors # (Zone)	2 x 100 sensors (1-64) Sensors embedded in the cable at intervals of 1, 2, 3, 4, 5 or 10 m (3.3, 6.6, 9.9, 13.0, 16.5 and 33.0 ft), or to bespoke design
Operational data	
Measuring temperature range	SEC-15 cable: -40°C to +120°C (-40°F to +248°F) Temperature resolution of 0.1°C (0.18°F)
Sensing cable attributes	Cable diameter: 15 mm (0.59 in); Min. bending radius: 250 mm (9.8 in)
Detection and actuation	Maximum temperature and temperature changes (differential or integration algorithm)

Model	Key performance parameters
# of Relays	4 (16 – REL 835) Built-in (Expanded – Module)
Product type approval standards and compliance level	
EN 54-22:2015 + A1:2020	Integrating and non-integrating line-type heat detector; Response classes: A1N, A2N, BN, CN as well as A1I, A2I, BI, CI
UL 521 (pending); NFPA compliant	Response classes: LOW, ORDINARY, INTERMEDIATE

Table 5 SecuriHeat d-List SCU 835 controller and SEC-15 cable

5.4 Application scenarios

Battery energy storage systems (BESS) can be constructed in various ways. They can be designed in the building at the design stage, they can be retrofitted to existing an building, or they may be constructed in a modular way as 20” or 40” containers. The latter can be of fixed location or transportable. A BESS usually consist of the components shown in Figure 5.

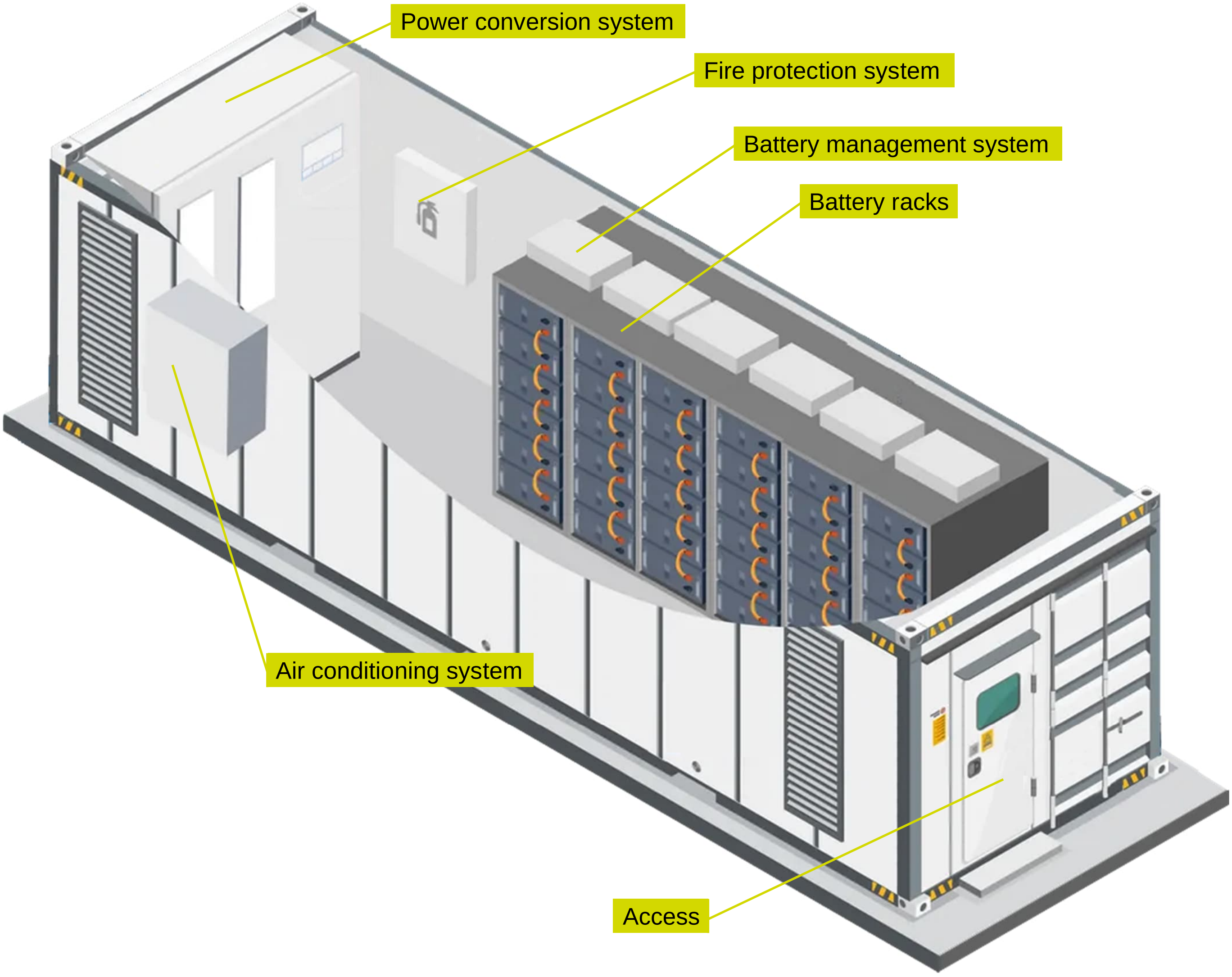


Figure 5 Components of a BESS

This sub-chapter describes the best possible fire detection for the following application scenarios:

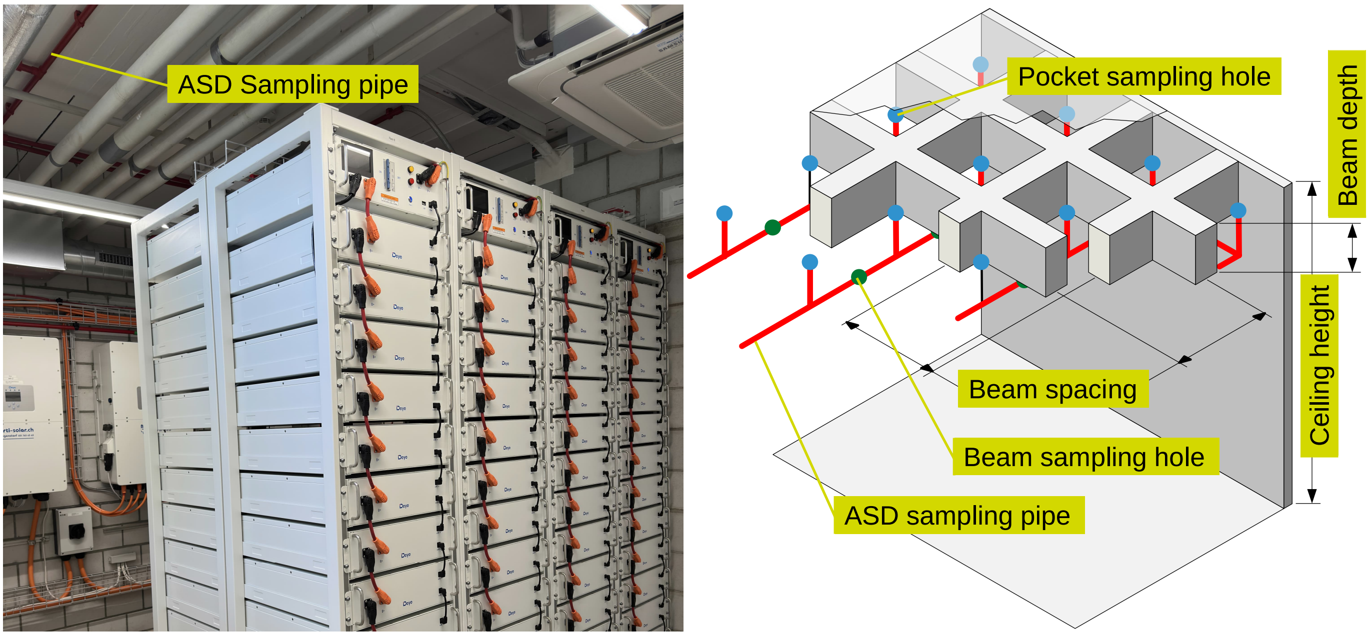
1 Open space smoke detection
2 Battery racks
3 Power conversion systems
4 Air conditioning: Return air grilles
5 Air conditioning: Ducts

5.4.1 Open space smoke detection

In the open space in a battery energy storage system SecuriSmoke ASD can be used for ceiling level detection to meet prescriptive code and Performance-based Design (PBD) safety requirements as well as enhanced detection performance designs to meet risk-based fire safety objectives, avoid losses due to fire damages and ensure operational continuity.

Ceilings can be sloped, flat or irregular. Exposed ceilings[8] are those ceilings with all the structural and MEP[9] systems (when installed) left exposed. The objective of SecuriSmoke ASD design to effectively provide ceiling level detection in the open space is to take into account the ceiling structure, potentially obstructed underside ceiling space, as well as potential irregular smoke dispersion and propagation inside the battery energy storage system.

Figure 6 illustrates how SecuriSmoke ASD sampling pipes and holes are located under the ceiling as well as under the beams or inside deep pockets for ceilings with beams or joists.



(a) Smoke detection placement underside ceiling (b) Smoke detection placement deep beam/joist

Figure 6 Open space smoke detection

Variable	Design recommendation
Spacing	For general design (Figure 6 (a)) flat or slightly sloped ceilings with regard to sensitivity class, refer to Table 2. For detection design on ceilings with beams or joists (Figure 6 (b)). Beam depth < 10% of ceiling height: smooth ceiling spacing is applied, on the bottom of the beams (see sampling holes in green) Beam depth ≥ 10% of ceiling height: i. Beam spacing < 40% of ceiling height: use smooth ceiling spacing ***parallel*** to the beams and half the spacing ***perpendicular*** to the beams, on the bottom of the beams (see sampling holes in green) ii. Beam spacing ≥ 40% of ceiling height: a sampling hole shall be placed on the ceiling within each beam pocket (see alternative sampling hole in blue). Note that more than one sampling hole may be required to cover a given beam pocket. For airflow < 60 ACH: From 84 m^2 (900 ft^2) @6 ACH down to 12 m^2 (125 ft^2) @60 ACH, refer to NFPA 72 [28] or FM DS 5-48 [29]. If a higher detection sensitivity is required, refer to Table 1 for recommendations for Class A (VEWFD) and Class B (EWFD).

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[8] Exposed ceilings are also known as open ceilings or open plenums

[9] MEP: Mechanical, Electrical and Plumbing

Variable	Design recommendation
Placement	Under the ceiling. Consider a blind end-cap to be located at a lower level, either inside or outside the room with easy access. It serves as a commissioning and maintenance test point for easy access [32].[10]
Orientation	Perpendicular downwards

5.4.2 Battery racks

Battery racks typically built up of individual components. Multiple battery cells are combined to a battery module and multiple modules for a battery pack, which is then mounted into the rack. The batteries within a rack are usually controlled by a battery management system as shown in Figure 7.

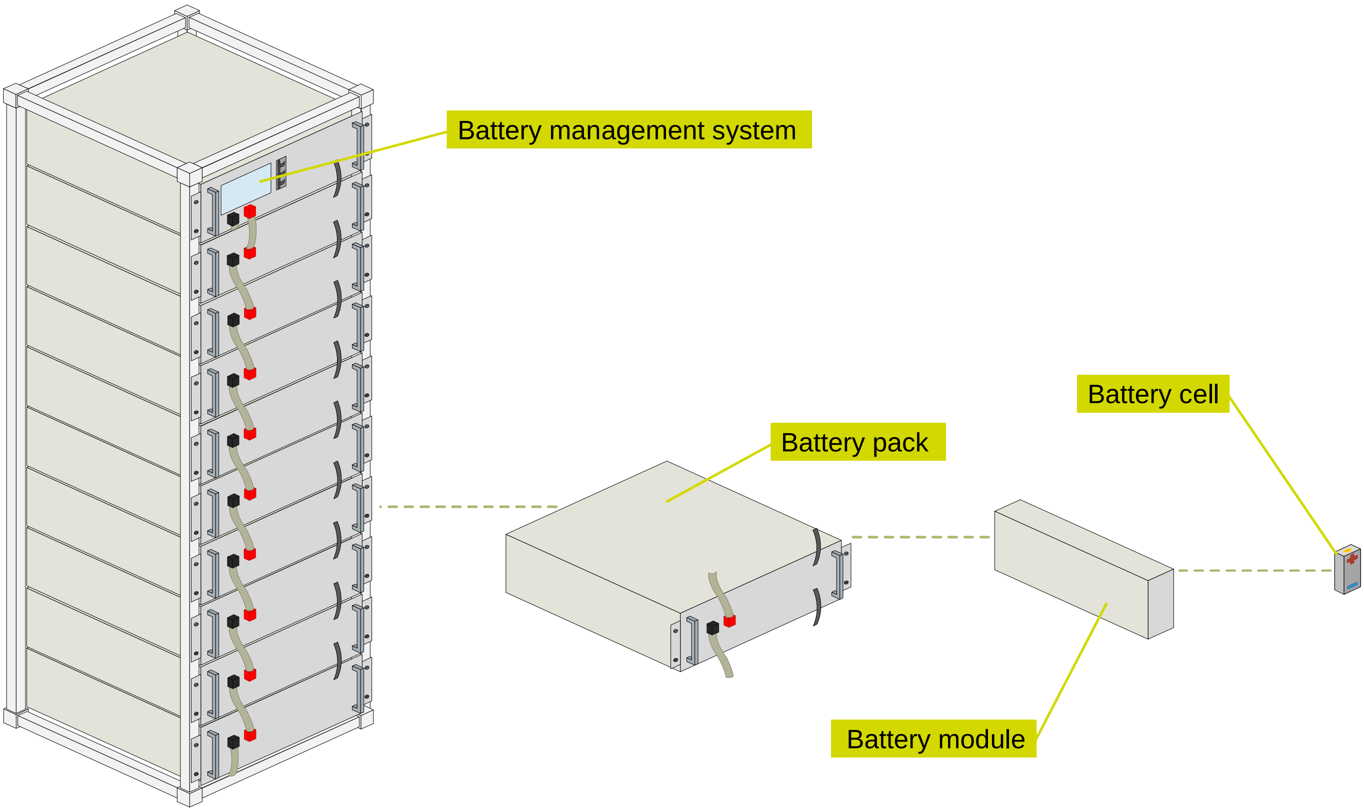

Figure 7 Composition of a battery rack

As discussed in chapters 2.1 and 2.2, all forms of abuse lead to an Internal Short Circuit (ISC) in the cell. The ISC causes an abnormal rise of the temperature and pressure within the cell and the mounting pressure leads to venting or off-gassing, followed by the formation of smoke particles in meltdown and decomposition processes (Figure 8). Consequently, early warning fire protection in battery racks is best achieved detecting all these indicators for a fire:

- Early warning smoke detection, detecting smoke particles resulting from faults in the wiring within the rack
- Off-gas detection, detecting venting incidents within battery cells
- Heat detection, detecting abnormal heat development within cells, modules or packs

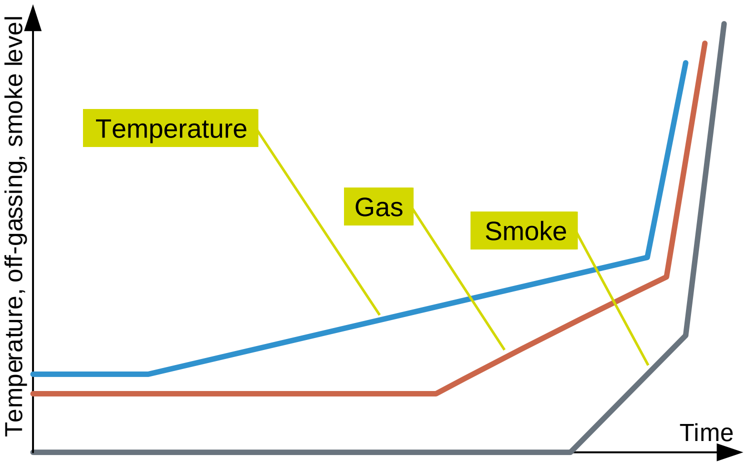

Figure 8 Abnormal temperature, gas and smoke development over time (qualitative)

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[10] For the initial commissioning and ongoing ITM (Inspection, Testing and Maintenance), the blind end-cap is replaced temporary with an end-cap with a predefined sampling hole. Measurements of transport time from the dedicated maintenance test point during maintenance should be confirmed to be within + 15% or + 3 seconds, whichever is the greater, of the same measurement taken at commissioning.

Early warning smoke detection in battery racks: Figure 9 illustrates how SecuriSmoke ASD sampling holes are positioned on battery racks.

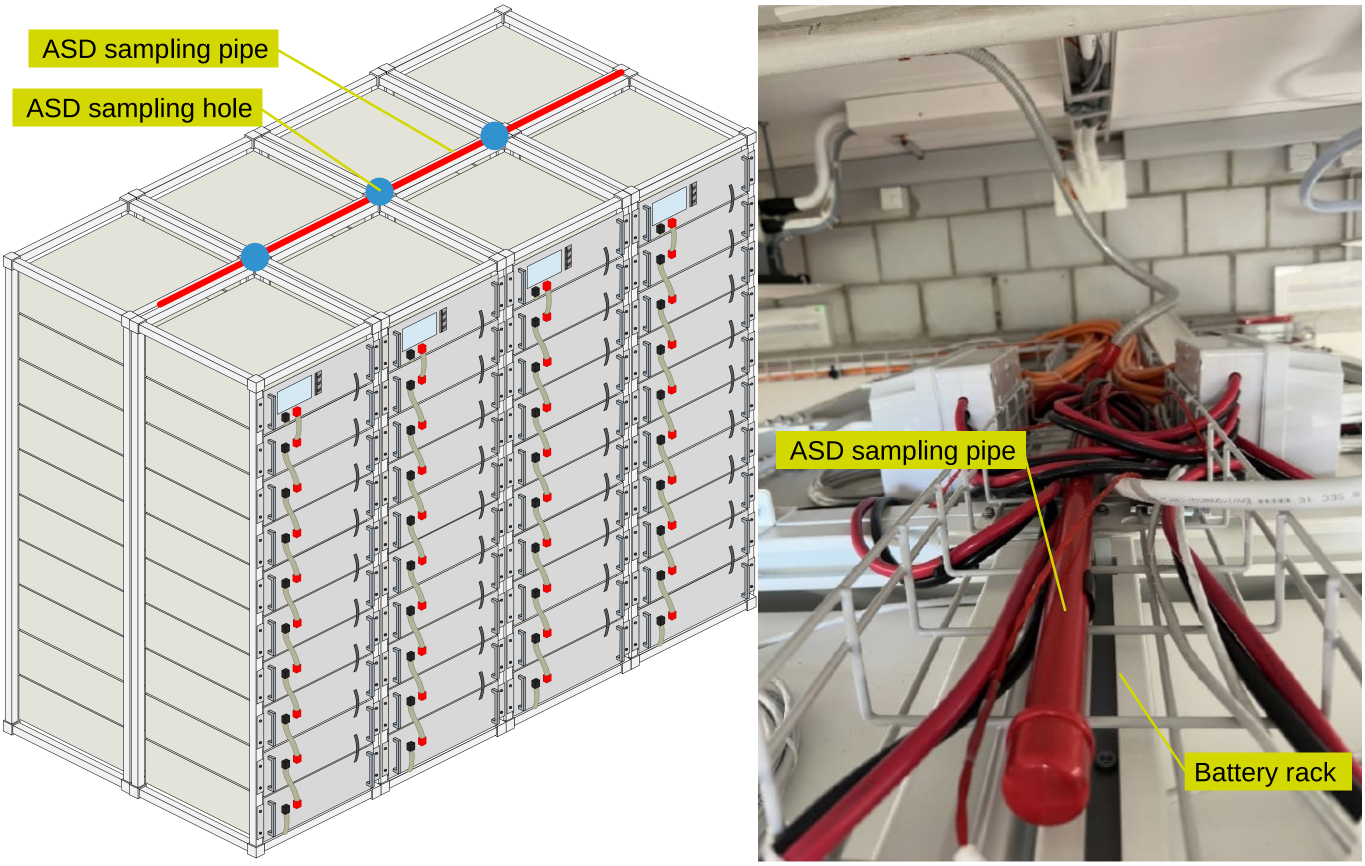


Figure 9 Battery rack: Smoke detection

Variable	Design recommendation
Spacing	In relation to the dimensions of the rack, one sampling hole in the space between the racks and on top of the racks. Consider the airflow in the room.
Placement	Above the rack, in the middle of the racks for single row, between the racks for back-to-back double rows.
Orientation	Perpendicular downwards

Early warning off-gas detection in battery racks: Both volatile organic compounds (VOC) and hydrogen (H_2) can serve as early indicators of thermal runaway within the battery rack (see chapter 2.1).

Figure 10 illustrates how VOC sensors are placed above the battery racks.

Figure 10 Battery rack: VOC off-gas detection

Variable	Design recommendation
Spacing	1 sensor at the top and 1 sensor in the middle of each rack. Consider the airflow in the room.
Placement	Above the rack, in the middle of the racks for single row, between the racks for back-to-back double rows.
Orientation	Perpendicular downwards

For the detection of hydrogen, an H_2 sensor is installed in the exhaust pipe of the SecuriSmoke ASD (Figure 11).

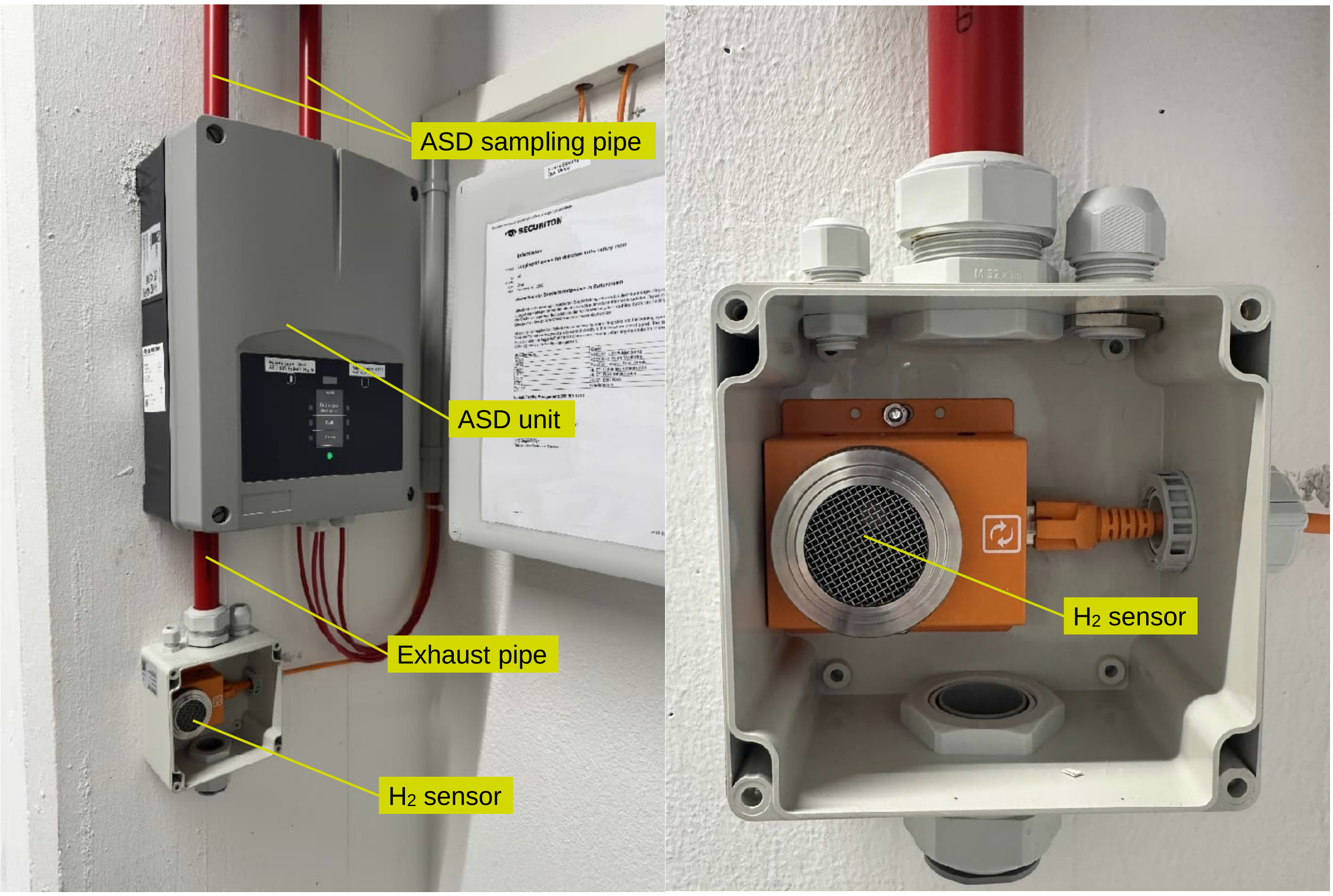


Figure 11 Battery rack: H_2 off-gas detection

Design recommendation: Consider one H_2 sensor per installed ASD monitoring the battery racks.

Early warning off-gas detection in battery racks: Figure 12 illustrates how temperature sensors of the d-List linear heat detector are placed on the battery rack.

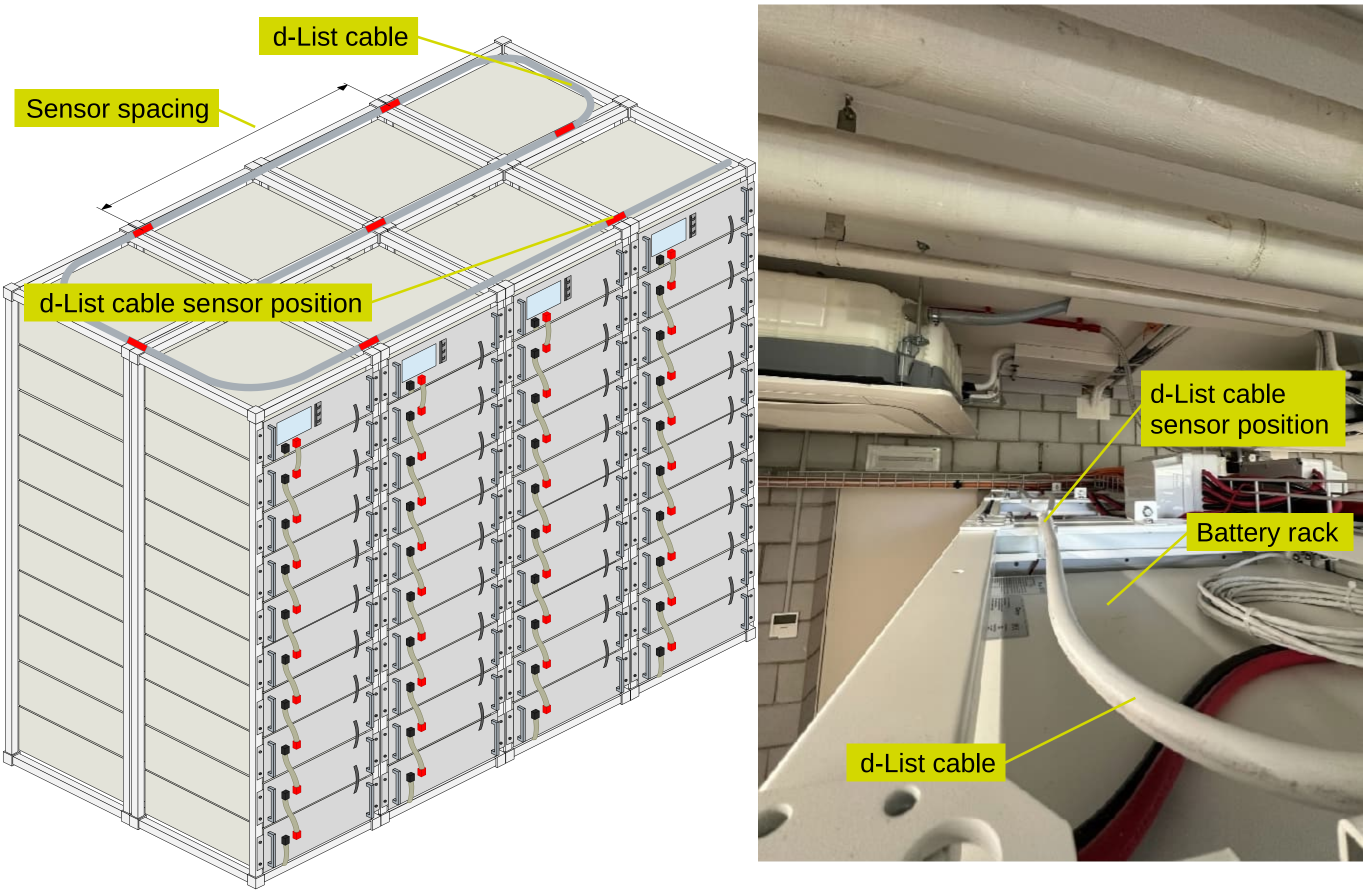


Figure 12 Battery rack: Abnormal heat detection

Variable	Design recommendation
Spacing	In relation to the dimensions of the rack, one sensor in the space between two racks above of the racks. Consider multiple loops to cover all spaces between the racks if the d-List cable with standard spacing of 1 m (3.3 ft) is used (see Figure 12). Consider the airflow in the room.
Placement	Above the rack, in the middle of the racks for single row, between the racks for back-to-back double rows.
Orientation	Perpendicular downwards

5.4.3 Power conversion systems

Power conversion systems (PCS) are characterised by a high energy density with compact housing dimensions. Depending on the usage of the BESS they work in cyclically varying loads. Figure 13 illustrates how SecuriSmoke ASD sampling pipes and sampling holes are positioned on power conversion systems.

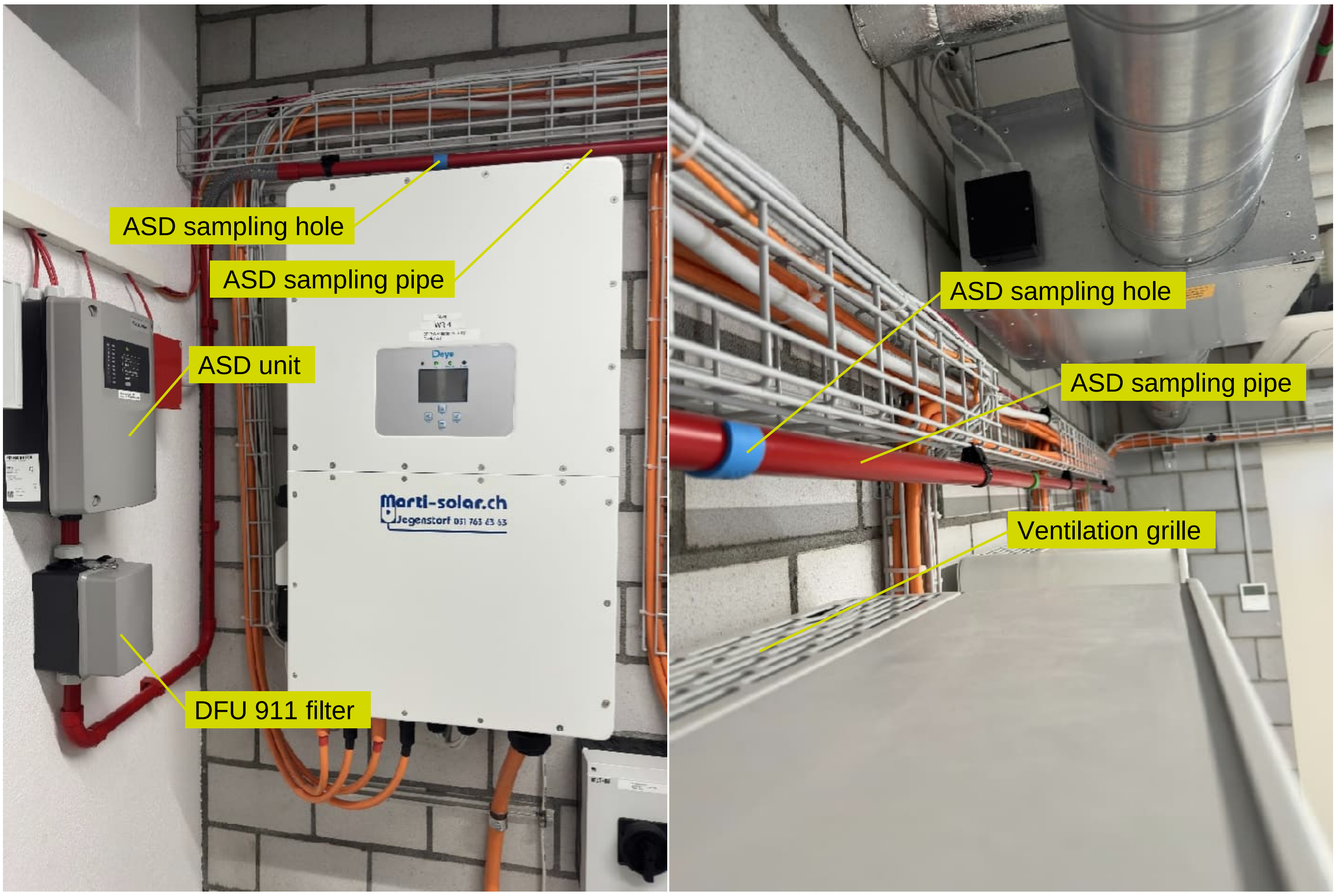


Figure 13 Early warning smoke detection for power conversion systems

Variable	Design recommendation
Spacing	Ventilated PCS: In relation to the number of power converters one sampling hole per 0.4 m^2 (4.3 ft^2) surface area of the ventilation grille. Consider installing a DFU 911 filter unit for ventilated PCS. Sealed PCS: In relation to the number of power converters one sampling hole per PCS unit. In installations with sealed PCS dust is not normally a problem, consequently a filter unit is not required.
Placement	Ventilated PCS: Across the grille at a distance of ~10 cm (~3.9 in) from the grille to avoid airflow faults in varying loads of the PCS. Sealed PCS: Above the PCS.
Orientation	Ventilated PCS: Facing the incoming airflow. Sealed PCS: Perpendicular downwards

The DFU 911 filter unit is only recommended when a high volume of dust is to be expected or when the ASD sampling holes are positioned directly in the exhaust airflow of the equipment such as the power converters (Figure 13). In IT infrastructure (data centres, server rooms, etc.) or normal office building applications the use of a filter DFU 911 is not necessary.

5.4.4 Air conditioning: Return air grilles

Figure 14 illustrates how SecuriSmoke ASD sampling points are positioned in front of return air grills.

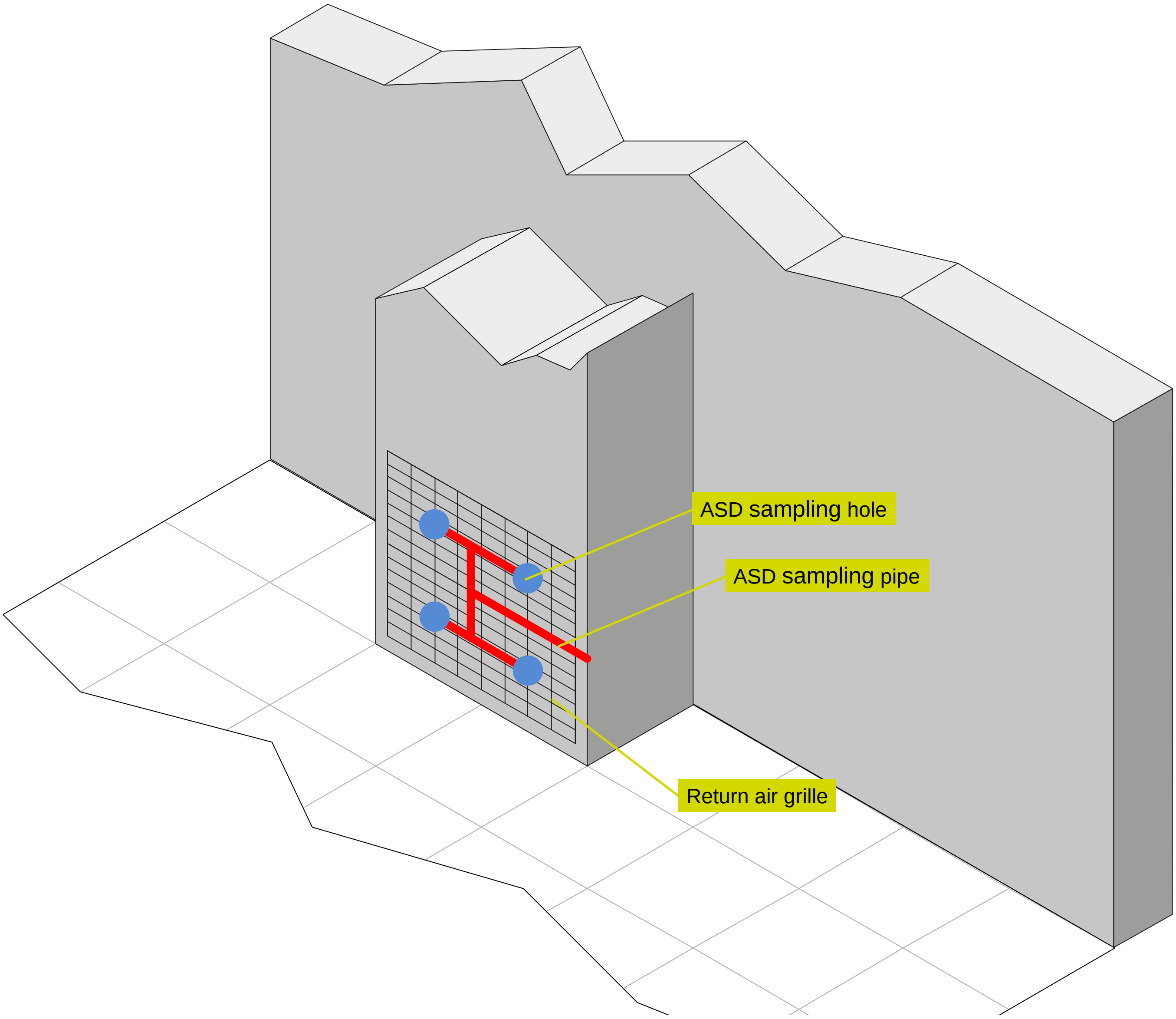


Figure 14: Fire detection placement (return air grills)

Variable	Design recommendation (return air grills)
Spacing	Maximum area coverage of 0.4 m^2 (4.3 ft^2) of the air grille per sampling hole. Typically, 2 to 4 sampling holes are used to cover a single air intake [33]. When two or more rows of sampling pipes are needed for larger grills, sampling pipes are designed to form an ‘H’ shape
Placement	Installed across the grille with pipe stand-off of ~2.5 cm (~1.0 in)
Orientation	Facing the incoming airflow; where possible, consider using Securiton sampling funnel SF ABS

5.4.5 Air conditioning: Ducts

NFPA 72 [30] specifically requires that, unless a smoke detector is recognised for use in specific airflow environments, it should not be used in airflow environments above 1.52 m/s (300 ft/min). Both BS 6266 [34] and NFPA 72 recognise the challenges of detecting smoke in high-airflow environments and stipulate reductions in spacing of detection points in such high-airflow conditions.

SecuriSmoke ASD can be used for high airflow duct detection (approved to UL268A [35] with maximum airflow of up to 20.3 m/s (4,000 ft/min). Figure 15 is a cross-section view of a duct with the sampling pipe and pipe from the exhaust port inside the duct, when using SecuriSmoke ASD for in-duct smoke detection.

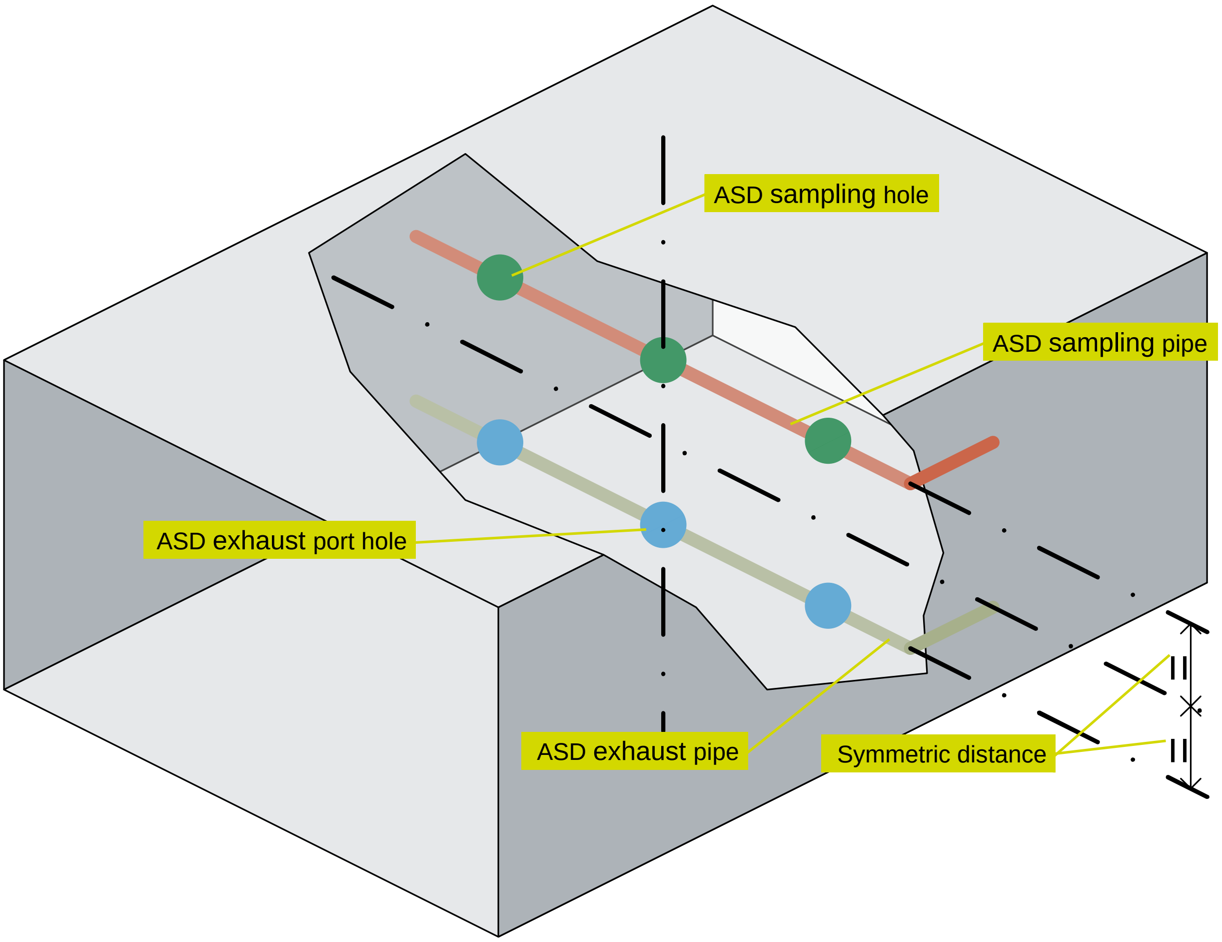


Figure 15: Pipe layout and sampling hole placement, duct detection

Refer to selected Securiton Aspirating Smoke Detector Technical Description manual for design details. As an example, SecuriSmoke 532 model Technical Description is shown in [36]. It is recommended per NFPA 72 [30] that duct smoke detectors be located in a duct section that is between 6 and 10 equivalent duct diameters from bends or openings. The total length of the sampling pipe and exhaust port pipe should be no more than 20 m (~65 ft).

Variable	Design recommendation
Sampling pipe	
Spacing	2 to 4 or more sampling holes are used, hole spacing ranges from 10 to 80 cm (~4 to 30 in)
Placement	Inside the duct, perpendicular and symmetric to the central line of the duct in relation to the pipe from exhaust port below
Orientation	Facing the incoming airflow using Securiton sampling funnel SF ABS
Exhaust port pipe	
Spacing	Exact same number of holes and identical spacing as in the sampling pipe above
Placement	In parallel and symmetric to the central line of the duct in relation to the sampling pipe, spacing is no less than 10 cm (4 in)
Orientation	Facing the incoming airflow using Securiton sampling funnel SF ABS

5.5 System integration considerations

SecuriSmoke ASD, the gas detection and SecuriHeat d-List can be integrated in different ways into fire alarm system and building management systems to cater for different applications of the battery energy storage system.

Figure 16 illustrates the integration in a SecuriFire fire alarm control panel (FACP). While the SecuriSmoke ASD and the SecuriHeat d-List controller SCU 835 are directly connected to the loop, the gas detection is interfaced to the loop using an BX-IO3 input module. For further integration to Building Management Systems (BMS), SecuriFire provides a Modbus TCP interface.

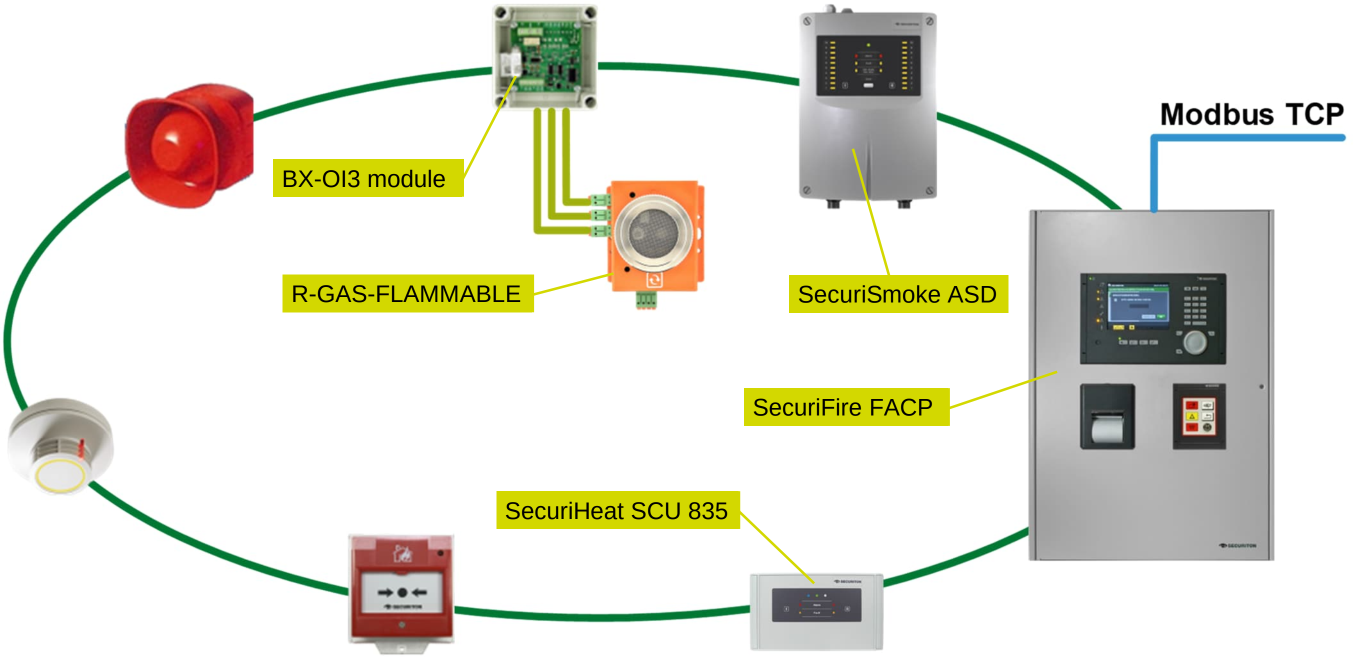
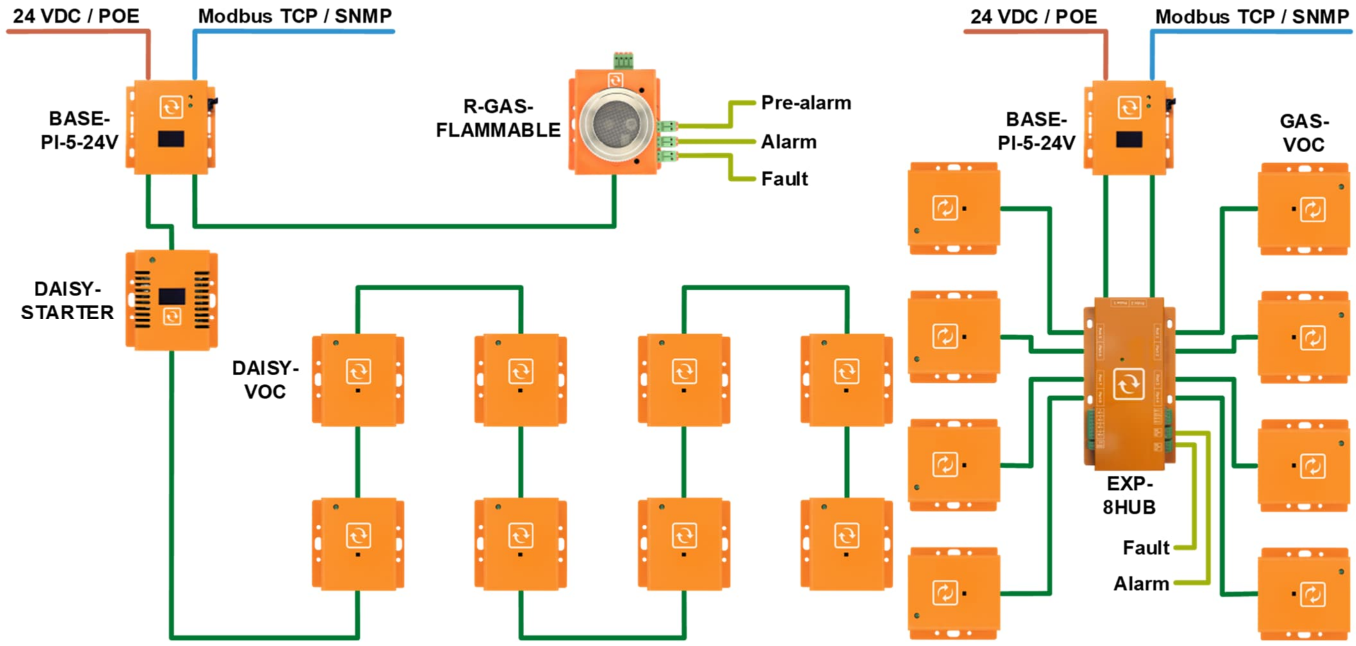


Figure 16 Integration over the loop of a SecuriFire FACP

Depending on the application of the BESS, the gas detection can be integrated in two ways either in a daisy chain or in a star configuration, as illustrated in Figure 17. Both configurations offer an integration to building management systems (BMS) via Modbus TCP or SNMP[11], which is often used in data centres. If the gas detection is to be integrated in a FACP, the daisy chain configuration is preferred as it offers 3 signals (Pre-alarm, Alarm, and Fault). Both configurations for powering the sensors from a 24 VDC power source, or over the ethernet (POE).



(a) Daisy chain

(b) Star

Figure 17 Gas detection configurations

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[11] SNMP: Simple Network Management Protocol

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