AUTRONICA

DET-TRONICS

BATTERY STORAGE

Safety solutions are available at cell, pack, rack and container level, however a comprehensive and integrated safety solution for complete BESS plant is the need of the hour.

INTRODUCTION

Battery energy storage systems (BESS) are pivotal in the global shift towards clean energy. Over the past decade, the BESS sector has witnessed remarkable growth, expanding from less than a GW to over 55 GW. This exceptional increase of around 60% year-on-year—underscores the sector's rapid development. Key drivers include grid stability, seamless integration of renewable energy sources, and energy arbitrage. Policy incentives and technological advancements have further propelled BESS adoption.

Safety Challenges and Concerns

Despite this growth, BESS faces safety challenges, particularly related to fire incidents. While comprehensive data remains scarce due to limited public disclosure, agencies have identified over 85 static BESS fire incidents occurring in last decade. Some of these incidents have been catastrophic, resulting in significant damage and loss of life.

Notably, a recent fire incident in east Asia claimed many lives and caused extensive harm to the facility and its surroundings. Such events underscore the urgent need for robust safety measures within the BESS industry. Safety solutions are available at cell, pack, rack and container level, however a comprehensive and integrated safety solution for complete BESS plant is the need of the hour.

AUTRONICA IN BESS

In the current market, existing solutions lack comprehensive end-to-end safety for Battery Energy Storage Systems (BESS). Autronica takes an integrated approach to BESS fire safety, covering 360 degree approach including prevention, detection, and suppression phases. Additionally, Autronica integrates an advanced monitoring and supervisory safety layer, offering real-time visibility into potential internal and external statuses, alarms, and faults of BESS.

AUTRONICA'S STRENGTHS

Global Recognition
Autronica's has global presence and support across the continents. Our commitment to excellence has earned us recognition from industry leaders and clients alike.

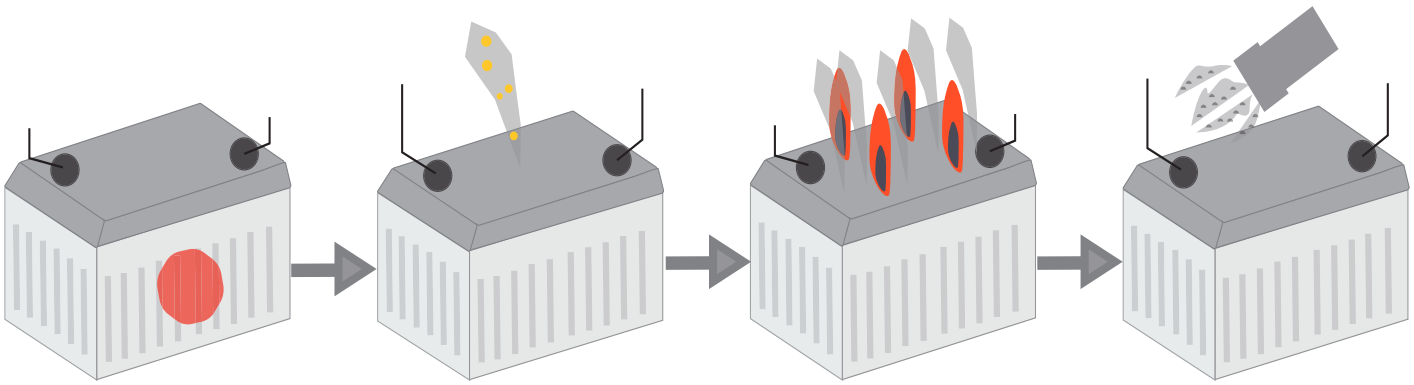
End-to-End Solutions
Autronica provides turnkey solutions, from manufacturing to life-cycle support. Our holistic approach ensures seamless integration and optimal performance.

Personalized Service
Dedicated technical and commercial support staff forge lasting relationships with clients. We understand your unique needs and tailor solutions accordingly.

Performance and Reliability
Autronica's solutions sets industry benchmarks for performance and dependability. Our track record speaks volumes about our unwavering commitment to quality.

Scalability
Whether you're a small business or a global enterprise, Autronica's solutions adapt to your requirements. Our flexibility ensures that your investment grows with your business.

Certified Expertise
Autronica's in-house capabilities are backed by global certifications and demonstrated expertise. You can trust us to deliver results that exceed expectations.



PHASES IN BESS OPERATION

Lithium-ion energy storage systems (ESS) have become increasingly popular due to their high energy density and extended lifespan. However, these systems carry inherent risks, particularly the potential for thermal runaway and fires. Lithium ion battery safety has 3-major stages as outlined below.

Prevention

The prevention phase marks the initial potential failures in lithium-ion (Li-ion) batteries. These failures can be related to thermal, environmental, power, and mechanical issues. Any of these four anomalies detected & addressed in time prevents further escalation and battery system can be returned to normal operation.

Detection

Detection involves two sub-stages: the off-gas stage and thermal runaway. During specific operating conditions and failure modes, Li-ion batteries release gases. The off-gas primarily consists of hydrogen, electrolyte vapors, and volatile organic compounds. Off-gas serves as an early warning sign of potential thermal runaway. Detecting and promptly addressing off-gas release is crucial to prevent fire hazards from escalating. If gas release remains unaddressed, thermal runaway can occur within seconds to minutes.

The second sub-stage is thermal runaway, which occurs when a system's temperature uncontrollably increases due to an exothermic reaction. In energy storage systems, thermal runaway leads to smoke and fire. Early detection of smoke and flames helps prevent escalation and ensures safety for Battery Energy Storage Systems (BESS).

Supression

The Arrhenius equation explains how the rate of a chemical reaction varies with temperature. In most processes, the reaction rate doubles or triples for every 10°C increase in temperature. Lithium-ion batteries contain metals (such as lithium, cobalt, and nickel) and metal oxides (such as lithium cobalt oxide and lithium iron phosphate). At elevated temperatures, the decomposition of metals and metal oxides releases oxygen gas (O_2). Oxygen acts as a combustion catalyst, facilitating reactions with other materials. Liquids within the battery, including the electrolyte, can vaporize during decomposition. These gases (such as hydrogen and volatile organic compounds) are flammable. The decomposition process generates heat, further accelerating decomposition and leading to a self-sustaining reaction. Thermal runaway, once initiated, can spread to nearby racks and ultimately impact the entire Battery Energy Storage System (BESS) facility. While fire suppression systems are often ineffective against BESS fires, a carefully designed system can both extinguish fires and prevent reflash.

Lithium-ion batteries are extremely responsive to temperature changes.

PREVENTION PHASE

Thermal Risks

Lithium-ion batteries are extremely responsive to temperature changes. Severe heat or cold can affect their performance and safety. Exposure to external heat sources, such as fire and direct sunlight impacts battery safety. Additionally, internal short circuits resulting from contact between the positive and negative electrodes within the battery cell, along with manufacturing defects like electrode misalignment, impurities, or improper cell assembly, contribute to thermal risks associated with Li-ion batteries.

Electrical Risks

Electrical risks includes power fluctuations, over charging caused by failure of BMS to cutoff charging current at rated charging level, over voltage causing lithium plating on the battery's anode, under voltage, over discharge of several cycles, and ground faults, among other factors. If left unidentified, these hazards can lead to excessive heat built up, significant loss of capacity and occasionally result in catastrophic battery failure.

Environmental Risks

Extreme environmental conditions present significant challenges to battery safety. High humidity corrodes battery terminals, degrades insulation, and promotes short circuits. Submersion in water causes irreversible damage, including short circuits and electrolyte leaks. Exposure to acids or alkalis erodes battery components. Excessive vibrations stress battery connections, potentially causing internal damage. Any of these conditions may lead to battery failure and result in significant consequences if not identified early.

Mechanical Risks

Mechanical anomalies such as punctures, dents, or crushing compromises battery integrity. Battery casing Ruptures exposes internal components to external elements. Overpressure, physical stress, or manufacturing defects can cause rupture as well.

DETECTION PHASE OFF GASING

Off-gas release is a critical phenomenon observed in lithium-ion (Li-ion) batteries. It serves as a predictor of potential thermal runaway events, indicating that the battery is not operating within suggested parameters. detecting early offgas release is of vital significance in battery safety.

Off-Gas Release

Off-gas release refers to the emission of gases from battery cells during specific operating conditions or failure modes, primarily generated due to chemical reactions occurring within the battery. Key scenarios include charging, discharging, and, most importantly, thermal runaway events.

During a simulation study, it was observed that lithium-ion batteries undergoing a thermal event typically emit 1-3 liters of gas per ampere-hour (Ah) at 26°C and 3.7 volts (V), depending on the battery's chemistry and state of charge (SOC). The gases released include carbon dioxide, carbon monoxide, combustible hydrocarbon gases, toxic gases, and hydrogen. The significant proportion of flammable gases makes these emissions an explosion hazard. Although batteries with a low state of charge emit less gas than those with a high state of charge, the risk of explosion may be higher for low-charge batteries due to the increased likelihood of delayed ignition.

Technologies of Off-Gas detection

A crucial measure to mitigate the risks associated with venting or fires in lithium-ion batteries is early detection. This is particularly important because thermal runaway occurs much more rapidly compared to a smoldering fire. Existing gas detection technologies provide various options for off-gas detection. These technologies are performance certified for specific gases, come with worldwide certifications, Ex ratings, proven speed of response, and well-maintained maintenance procedures.

hazardous conditions.

One such technology is the Combustible IR detector, which detect select gases in as little as 1.5 seconds. This technology is immune to damage from exposure to constant background gases or high gas concentrations and does not require routine calibration. However, it is effective for detecting hydrocarbon gases but does not respond to hydrogen.

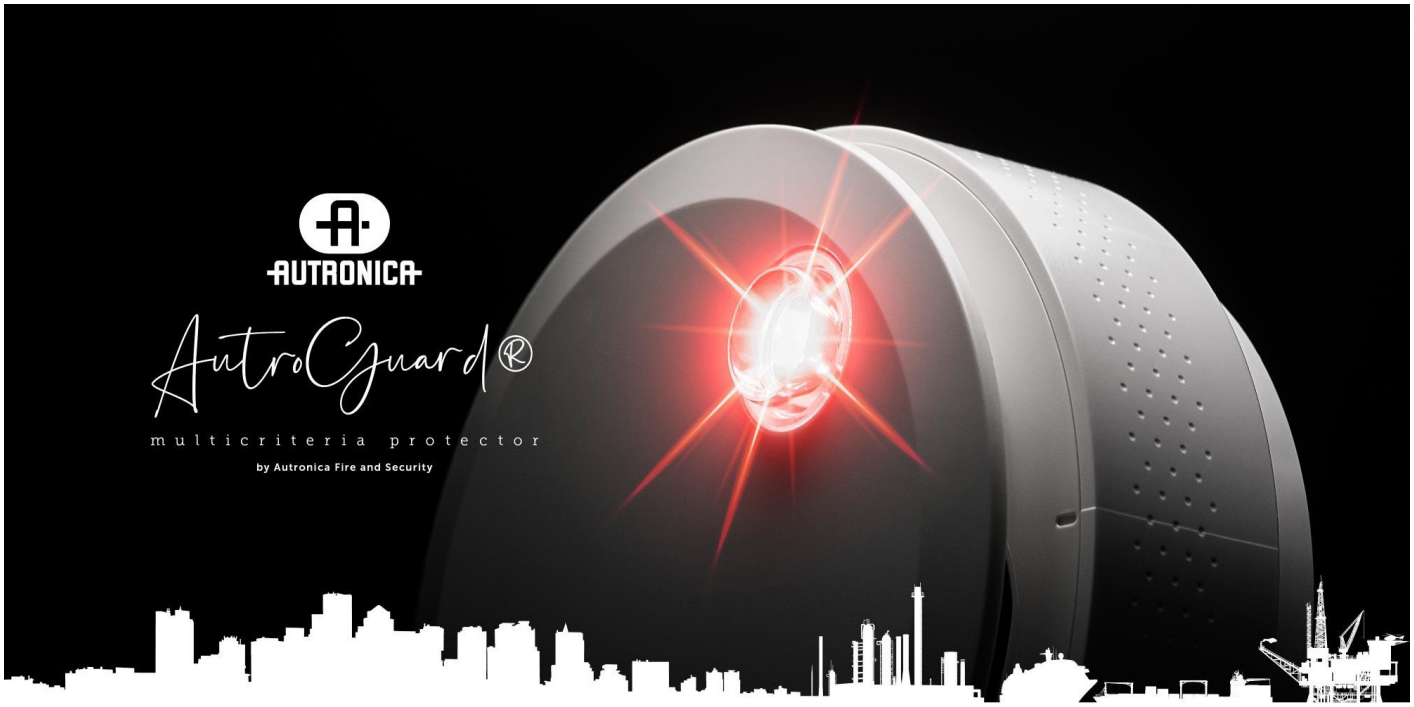
Another technology is the CGS-Catalytic bead detector. Catalytic bead sensors operate by oxidizing the gas on a catalytic surface, generating heat and changing the resistance of the sensor. This change is measured to determine the gas concentration. These sensors can measure 0-100% LEL with response times T50 less than 10 seconds for methane and less than 5 seconds for hydrogen.

For off-gas compositions, including hydrogen (H2), methane (CH4), and other hydrocarbons (HCs), catalytic bead sensors provide the highest detection possibility in terms of composition. These sensors can detect both hydrogen and hydrocarbons, covering a large percentage of the off-gas composition. However, catalytic bead detectors have shortcomings, such as not signaling when they fail and being susceptible to poisoning. Modern BESS facility are water cooled and air ventilation is only turned on when there is offgas , smoke or fire therefore poisioning does not pose any significant challenge. However periodic bump or proof testing with calibration gas is required to ensure proper sensor operation. The sensor life is 3 to 5 years when the environment is free of substances and conditions detrimental to the catalytic sensing element.

CO_2 detectors uses IR technology for detection of CO_2 component of Off-Gas, It provide continuous monitoring of carbon dioxide (CO2) gas concentrations in the range of 0-3%/volume (0-30000 ppm) with a response time T50 of 6 seconds.

Another technology, GT3000/CO detection, focuses on carbon monoxide (CO), one of the primary gases released during off-gassing and remaining present for an extended period. This characteristic makes CO detection particularly significant for early-stage identification of off-gassing and preventing potential thermal runaway. Dettronics electrochemical sensors measure up to 0-1000 PPM within a time period of T50-15 seconds and T90-40 seconds. These detectors have a short sensor shelf life (6 months) and an operating life of 2 years in an open environment.

Off-Gas from lithium ion batteries contains micro size particles which provides possibility of offgas detection with aspiration detectors. Aspirating detectors function by sampling air via a network of pipes, sampled air is passed through a dust filter and into a detector chamber where the air is analysed for traces of Off-Gas. The detectors are capable of detecting the small amounts of Off-Gas that are generated during initial stage, ensuring the earliest possible warning of a potential thermal runaway while distinguishing real Off-Gas from dust and pollutants, reducing unwanted alarms to a minimum.

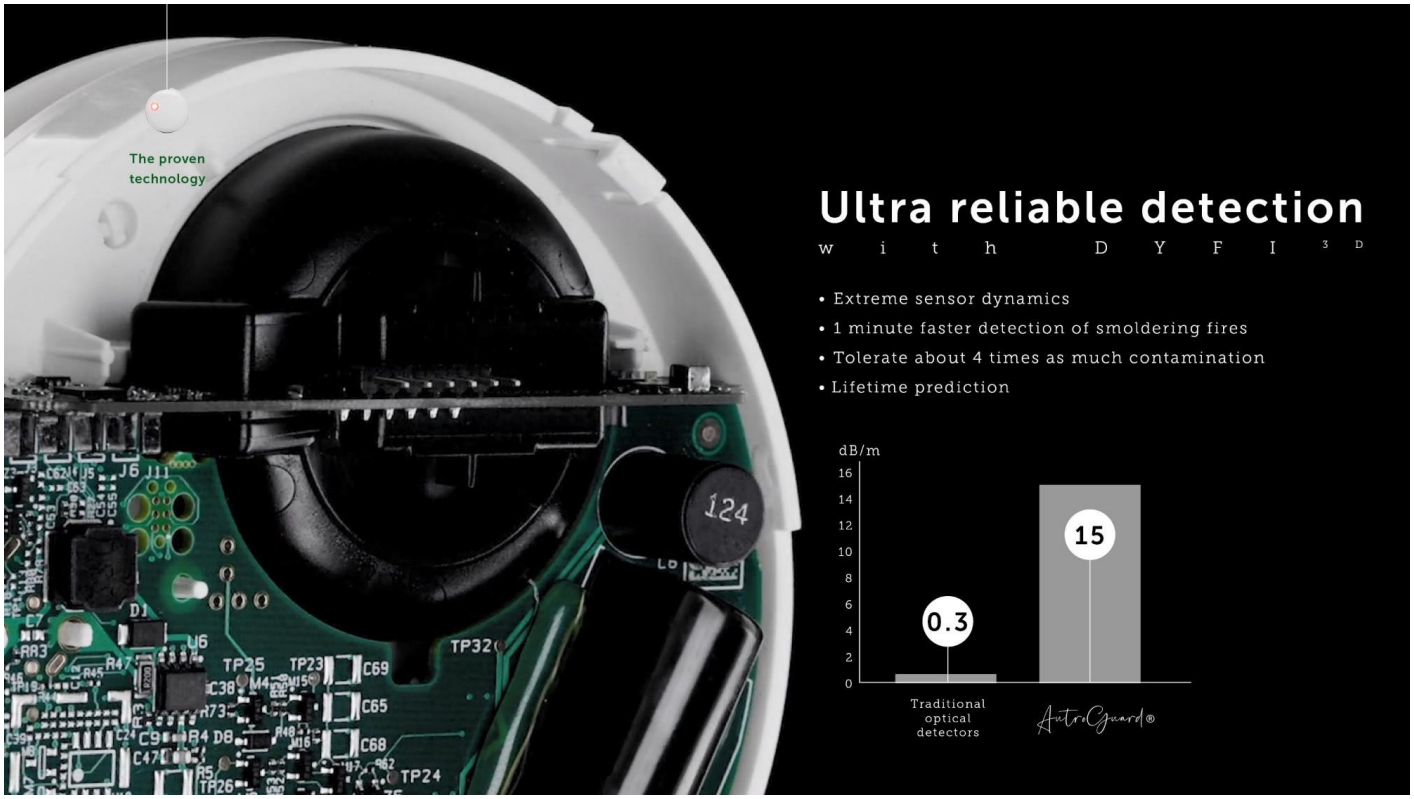


DETECTION PHASE SMOKE & FIRE

BESS are designed to operate continuously, necessitating a safety system that does not require shutdowns during operation. Components of the safety system must function without the need for frequent maintenance. BESS installations may be subjected to challenging environmental conditions, including vibration, high temperatures, subzero temperatures, and high humidity. The safety system must deliver the required protection without any degradation in performance under these conditions. Given that BESS are often managed remotely, the safety system must offer remote connectivity and diagnostic capabilities to ensure effective monitoring and management. Autronica provides a low-maintenance solution tailored for BESS applications, ensuring reliable performance and robust protection in diverse and demanding environments.

When a battery anomaly reaches the offgasing stage, the speed of detection and action becomes critical. If the BESS continues operating, such as supplying power to the load or charging, it will rapidly reach the thermal runaway stage. In this case, the response time of the detector plays a crucial role. Autronica provides detectors for both offgasing and smoke detection with fast response times.

The correct placement of detectors is crucial for the effective application of BESS. A typical BESS design incorporates physical segmentation of the unit, which is essential for preventing the escalation of fires from one part of the system to another. Each segmented section should contain at least one optical smoke detector equipped with integrated heat and carbon monoxide (CO) sensors. Additionally, it is necessary to install optical smoke detectors in utility and control areas to mitigate fire hazards originating from electrical or control circuits. In scenarios where multiple BESS containers operate as cascaded units, flame detectors shall be implemented through area monitoring.



Autronica has developed a specifically structured safety system to address these needs. This system employs a group principle to manage the various stages of BESS safety effectively, ensuring robust protection against potential fire hazards. The safety system operates based on a cause-and-effect matrix, ensuring precise and timely responses to potential hazards. When offgas detection occurs, it triggers an event within the control system to isolate the power supply to the affected rack. This action is crucial in preventing the escalation of issues within the rack. Additionally, ventilation systems are activated to prevent the accumulation of combustible gases inside the container, thereby avoiding the creation of a flammable atmosphere. Downtime in BESS can lead to significant financial losses due to interrupted energy production. False alarms can cause unnecessary shutdowns of BESS. Autronica fire detection system provides the highest level of false alarm immunity.

The safety system must be engineered to endure throughout the operational lifetime of the BESS.

Key features include reliability, long-term support, and seamless compatibility with the overall control system. Autronica fire alarm control panel and detectors are specifically designed to maintain their performance up to 20 years in normal environment without any degradation. New systems come with backward compatibility to facilitate easy upgrade if required. Autronica SIL2 certified system provides a high degree of availability and reliability.

BESS are designed with a modular concept, allowing for further integration to meet future demands. Safety system for BESS must be scalable to accommodate both current and future requirements, offering both upward and downward scalability. The Autronica system provides a high level of scalability, with the capability to connect 64 control panels and up to 15,000 detectors.

SUPPRESSION PHASE

In the context of Li-ion battery fires, there are several unique fire issues that complicate the component interactions in the fire tetrahedron.

Chain Reaction

The "thermal runaway" phenomenon in Li-ion batteries is self-perpetuating when cathode materials are in close proximity to each another and heat is permitted to cascade from cell to cell.

Oxygen

During thermal runaway, oxygen is believed to be self-generated during cathode consumption, which may defeat oxygen-depriving extinguishers.

Heat

Because the thermal runaway reaction is exothermic, removal of heat becomes a challenge because the fire has an internal heat source.

Fuel

A Li-ion battery fire has multiple sources of fuel. The cathode consumed during thermal runaway is the fire ignition source and is consuming metals and is momentarily a Class D fire. The electrolyte and its solvents are typically ethylene carbonates and are therefore highly flammable Class B2 materials (flammable gases and liquids) and potentially Class C (electrical) if voltage remains on unburned batteries. Lastly, the separator and external pouch and casing of the battery may be polymers and are therefore Class A materials. The duration of the fire can be seconds or minutes, and the majority of consumed mass is likely Class A and B materials.

To compound the complexity of the Li-ion battery fire, the materials involved in the ignition and propagation of the fire are tightly integrated into a pouch, cylindrical cell, or prismatic cell, and therefore the fire is a "deep seated" fire. Deep seated fires present extinguishing challenges for all

extinguisher types.

Fire Hazard assessment

A fire hazard assessment of Li-ion Batteries ESS will provide the first step towards developing the technical basis necessary for the safe installation, protection, and emergency response to Li-ion ESS fires: Hazardous Mitigation Plan, Gas Detection/ Venting, Fire Detection and Suppression, Cooling, Post Incident Clean Up.

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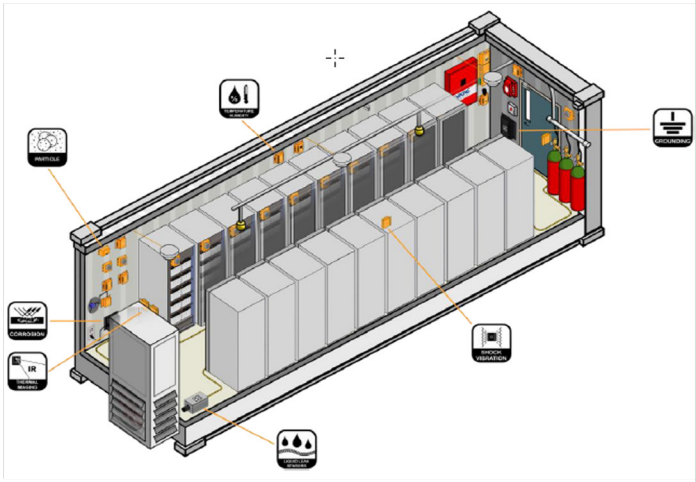
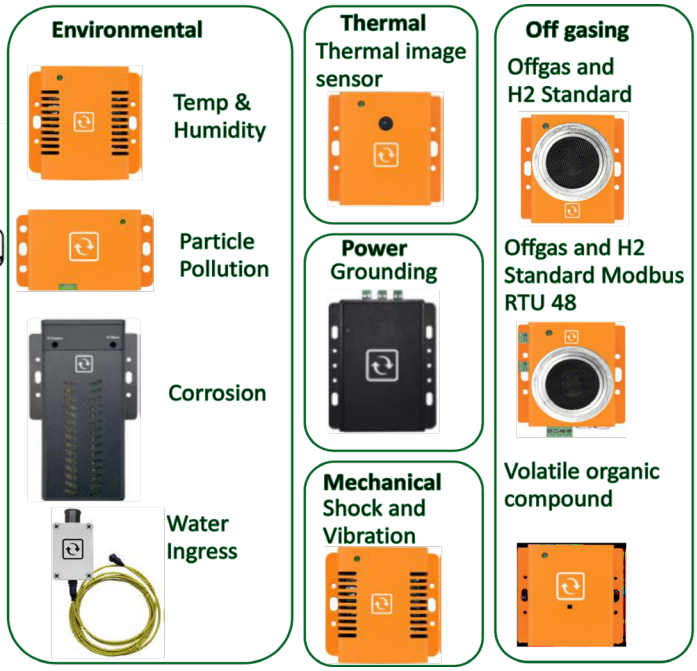




SOLUTION – PREVENTION & OFFGASING

In collaboration with Infrasensing, Autronica offers sensors for detecting anomalies during the prevention phase, as well as solutions for early off-gas detection.

Environmental monitoring

Ambient Temperature & Humidity Sensor monitors the environmental conditions inside the container to ensure that the temperature and humidity stay within the specified operating range set by the manufacturer. The sensor provides an early warning before condensation (dew point temperature).

Particle Sensor (PM1, 2.5, 4, and PM10) detects foreign pollution that may impact the container. Dust particles can affect electrical equipment.

Atmospheric corrosion level sensor provides Real-time monitoring of corrosion levels using standard ANSI/ISA 71.04. Corrosion if present over time can harm electrical systems.

The water ingress sensor detects water inside containers. Combined effect of water and electricity are hazardous for BESS.

Thermal monitoring

Thermal Image Sensor (32x24 pixels):The sensor is mounted inside the control panel (PLC, BMS). It detects thermal anomalies.It complements Panel sensor for detecting cable smoldering.

Power system monitoring

Purpose: Ensures electrical earthing remains connected and undegraded.

Mechanical monitoring

Shock & Vibration Sensor: It monitors vibrations within the container. Vibrations if left unattended can loosen terminal connectors, leading to potential catastrophic failures.

Offgasing

Self-calibrating standalone sensors designed for monitoring off-gas and hydrogen in stationary battery systems. Available either as standard or Modbus RTU RS485 sensors which enables direct integration with PLC or controllers.

SOLUTION – DETECTION

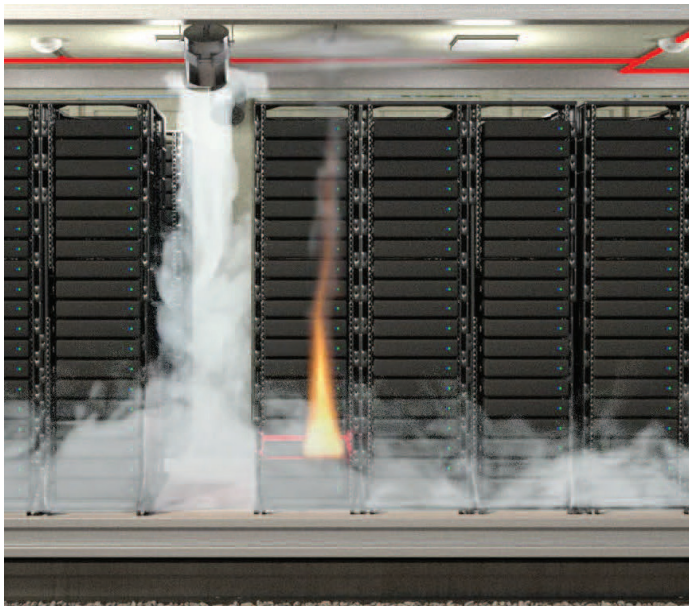
Detecting offgas and smoke in Battery Energy Storage Systems (BESS) is particularly challenging due to the compact nature of BESS containers, which house Battery Modules, Power Electronics, Control Systems, Cooling Systems, and power transformers. The rapid escalation of fires necessitates smoke detectors with high sensitivity and quick response times. Additionally, these energy storage units often operate remotely without manual supervision.

Autronica, in collaboration with its sister company Det-Tronics, offers a comprehensive range of solutions for Battery Energy Storage System (BESS) offgas detection. The GT3000 series CO detector, available in both loop and external configurations, serves as an early warning system for offgas emissions. This series can detect carbon monoxide (CO) in the range of 1-100 parts per million (PPM), with response times of T50 at 15 seconds and T90 at 40 seconds.
Catalytic bead detectors provide an alternative solution by detecting multiple components of

The Autroguard protector operates effectively across a wide temperature range (-30°C to +70°C) and exhibits good resistance to salt, vibration, oil mist, weather, and pollution.

offgas, including hydrogen and hydrocarbons. The CGS can measure gas concentrations from 0-100% of the Lower Explosive Limit (LEL), with response times of T50 less than 10 seconds for methane and less than 5 seconds for hydrogen.
Another option is the Pointwise Eclipse detector for carbon dioxide (CO2), which monitors CO2—a significant component of offgas. This detector provides continuous monitoring of CO2 concentrations in the range of 0-2% by volume (0-20,000 PPM), with a response time of T50 at 6 seconds.
A fourth solution involves combustible gas detectors. The Eclipse detectors for combustible gases offer rapid detection times of approximately 1.5 seconds. These detectors are designed to be immune to damage from constant background gases or high gas concentrations, and they do not require routine calibration.
The Multi-Spectrum IR Flame Detectors X3301 are employed for comprehensive area protection. These flame detectors offer rapid response times and extensive coverage areas, both on-axis and off-axis. They utilize bandpass filters to ensure false alarm immunity and are selective for CO2 and CO spectral emissions.
The Autronica AutroGuard Protector provides capabilities for both early alarm and fire detection. It features high alarm immunity and is certified to Safety Integrity Level 2 (SIL2), ensuring high degree of reliability and availability.

SOLUTION – SUPPRESSION



Stat-X Aerosol fire suppression

To provide superior fire protection for Battery Energy Storage Systems (BESS), a suppression system should:

- Limit the propagation of thermal runaway.
- Suppress any existing fire.
- Provide primary and secondary cooling.
- Minimize damage to components.
- Require minimal infrastructure.

Despite the challenges in meeting these criteria, Autronica offers following fire suppression solution for BESS.

Aerosol systems

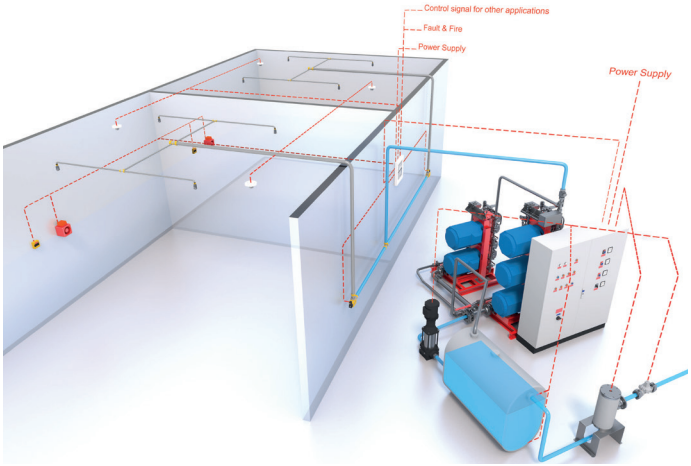
These systems are lightweight, compact, and cost-effective. Each suppression unit features a highly durable, hermetically sealed stainless-steel canister containing a stable, solid compound. These canisters are robust, non-pressurized, and designed to withstand the harsh environments often encountered in BESS applications.

High-pressure water mist systems

These systems combat fire through both primary and secondary mechanisms affecting fuel, oxygen, and heat. The primary mechanisms include cooling gases, displacing oxygen and flammable vapors, and wetting the fuel. The secondary mechanisms involve suppressing heat radiation from the fire and reducing the fire's kinetic energy. When water is fed through HI-FOG sprinklers at high pressure, it produces a fine water mist, offering several benefits.

Clean agent systems

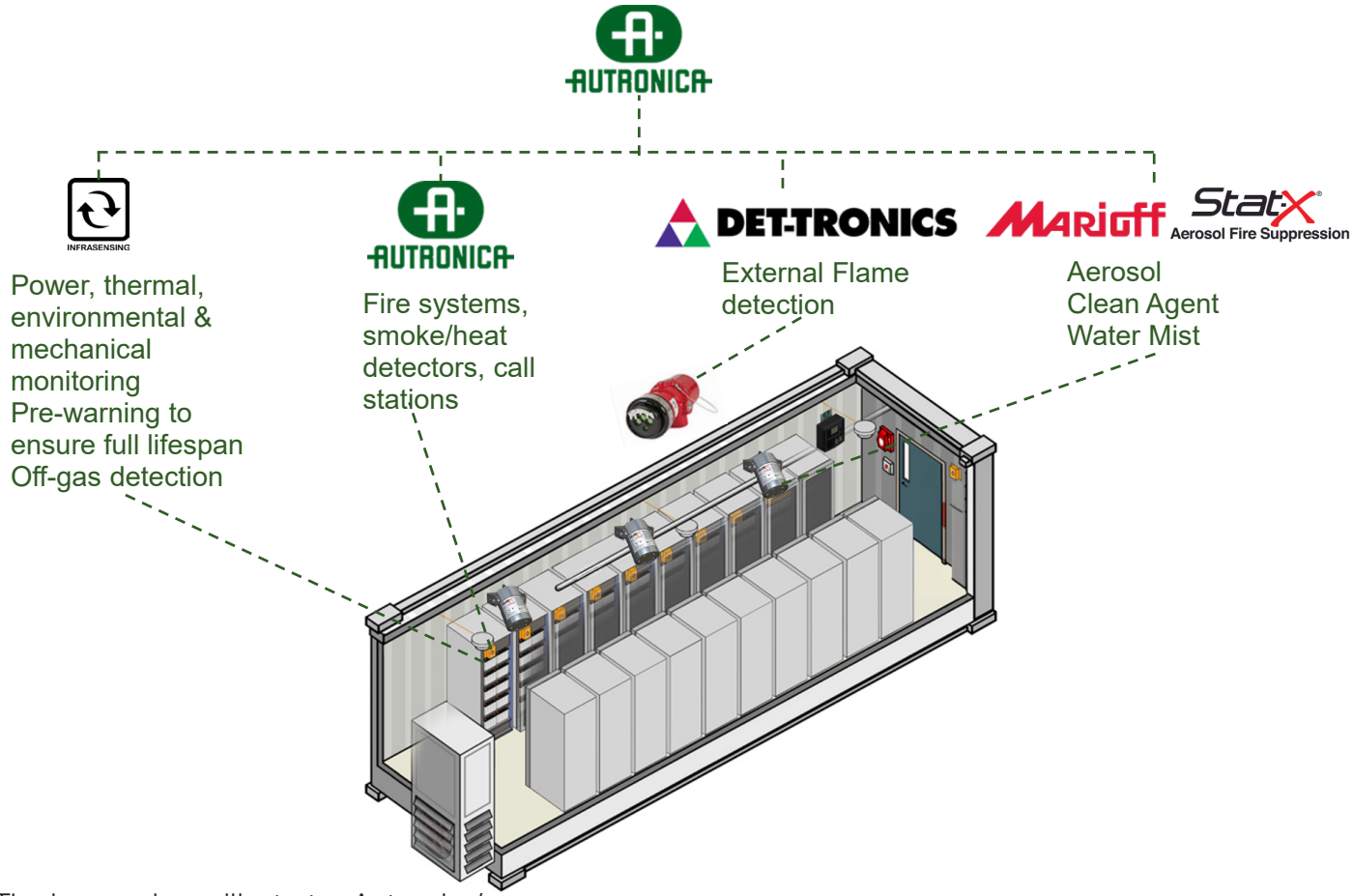
Clean agents, such as nitrogen, are delivered in highly pressurized cylinders with integrated nozzles, restrictors, and deploying mechanisms. They primarily act by reducing the oxygen level, making it insufficient to sustain combustion, while some also act as cooling agents.



Marioff watermist fire suppression

When a fire is detected by the Autronica fire detection system, the suppression units are automatically released based on a cause-and-effect philosophy, effectively extinguishing fires using any of the three methods. The integration of detection and suppression system has been thoroughly tested inhouse with Autronica suppression solution currently operational within multiple installations.

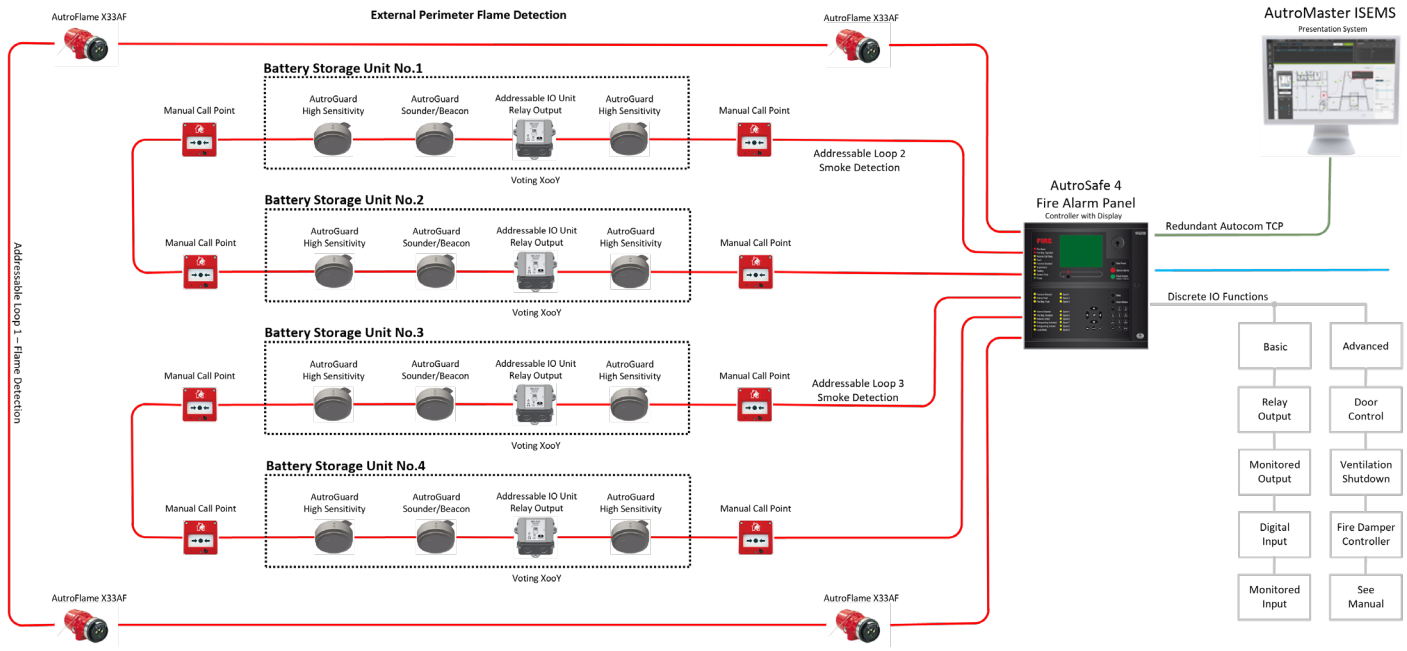
COMPREHENSIVE AND INTEGRATED – BESS SAFETY



The image above illustrates Autronica's comprehensive and integrated solution, which covers prevention through the escalation phases in battery energy storage systems (BESS). Autronica collaborates with Infrasensing, leveraging their expertise in monitoring battery system health and the BESS environment. This monitoring is based on parameters outlined in stage 1 and 2 of the report. Autronica has offgas detection capability through its legacy products as outlined in previous sections.

Should the system enter stage 3, characterized by thermal runaway and the potential onset of smoke or fire, Autronica's proprietary Autroguard platform offers a state-of-the-art detection solution. Additionally, at the large-scale BESS facility level, an integrated suppression system from Stat-X , clean agent or watermist ensures effective fire suppression.

Autronica's unique and holistic approach distinguishes it in the market, making it the preferred choice for BESS OEMs, operators, and insurance companies.



SAFETY OF ENTIRE BESS FACILITY

To ensure safety across an entire Battery Energy Storage System (BESS) facility, the fire loops from the entire facility are integrated into a centralized system. This integration provides comprehensive visibility of warnings, alarms, detection and historised data using Autronica's fire central and Autromaster. Autronica's fire system has high capacity, allowing it to connect up to 15,000 loop units per system and accommodate up to 64 system units. This scalability ensures safety for large scale BESS installations.

The BESS Human-Machine Interface (HMI) provides status updates and alarms related to the battery system across all four stages. These statuses are displayed for each individual BESS system and then aggregated into a combined overview, summarizing the overall facility status. HMI also provides detailed diagnostic information , temperature measurments from each detector.

The Autromaster has capability to provide remote monitoring of facility through a secure remote link. The data from multiple facilities can be combined into one integrated Autromaster system for monitoring and control.

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