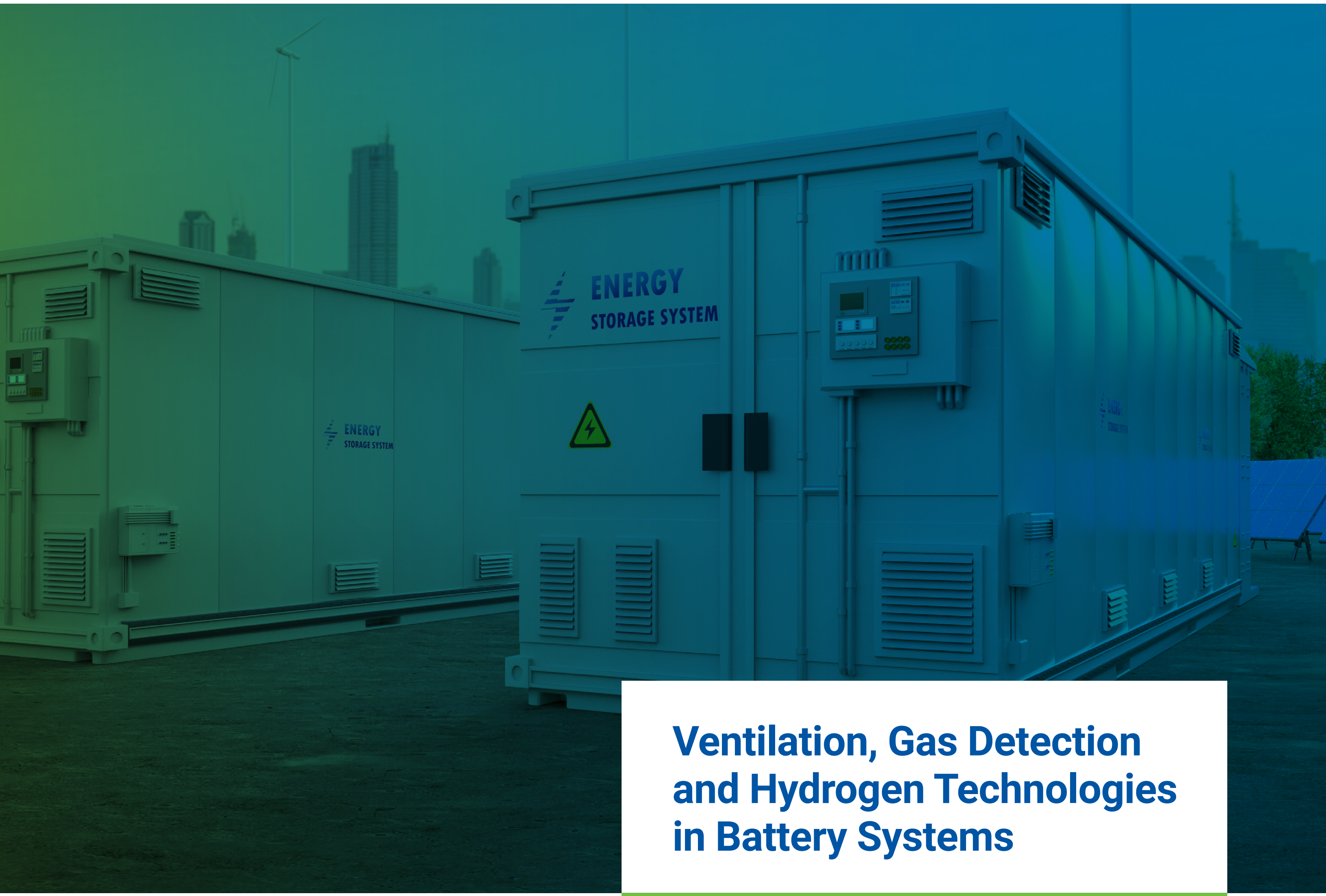
H2scan
Advanced Hydrogen Sensing



Ventilation, Gas Detection and Hydrogen Technologies in Battery Systems

WHITE PAPER

This paper was first presented at the NiBS Battery Conference 2025

Jeff Donato
Director – Safety Products, H2scan

Valencia, California, USA

Overview

This overview introduces key standards and technologies related to ventilation and gas detection in battery systems used for standby power and large-scale energy storage. We will explore essential tools and methods for air exchange to maintain safe environments and meet regulatory requirements. Additionally, the discussion covers various hydrogen technologies available today, including their operational principles, application methods and respective advantages and disadvantages. You'll learn how to effectively implement hydrogen sensing technologies into your facility's hazard mitigation and emergency response plans. Finally, the review includes relevant IEC standards on hydrogen monitoring, focusing on sensor types, installation practices, calibration and maintenance protocols to ensure comprehensive safety measures.

IEC/EN Safety Standards (EN IEC / IEC 62485, EN 50272-2, etc.)

IEC 62485-2 (Part 2: Stationary Batteries – Safety Requirements) sets the safety requirements for stationary secondary batteries and battery installations, such as those used in energy storage, telecommunications, UPS and standby power. Its goal is to minimize risks to people, property and the environment during installation, operation, and maintenance. The standard covers protection against electric shock, short circuits, fire, explosion, electrolyte leakage and harmful gas emissions. Correctly sized ventilation, as per industry standards, is essential in preventing the accumulation of hydrogen gas. The system owner or facility management must clearly define maintenance and emergency procedures to ensure long-term safety.

EN 50272-2

"Safety requirements for secondary batteries and battery installations – Part 2: Stationary batteries."

EN 50272-2 (VDE 0510 Part 2) is a standard established in December 2001 that sets safety and performance criteria for batteries and rechargeable energy storage systems. The standard ensures compliance and proper design, installation and operation of stationary battery systems, primarily in large UPS systems.

The standard addresses items that comply with European regulations. These items include installation, ventilation and protection against electric shocks, fires and explosions to protect personnel and equipment.

The design of rooms and enclosures must provide calculated ventilation to prevent the buildup of explosive gases such as hydrogen for batteries like lead-acid types that emit hydrogen during charging. Proper airflow is essential to keep hydrogen concentrations below hazardous levels, typically under 4%, which can be achieved through forced or natural ventilation systems. EN 50272-2 Annex C provides formulas to determine the necessary airflow based on factors such as battery type, number of cells, charging current and room volume.

1. **Batteries (esp. lead-acid) emit hydrogen during charging.**
2. **The standard defines airflow calculations to keep H_2 <4%.**
3. **Forced or natural ventilation is required.**
4. **EN 50272-2 Annex C formulas consider:**
   - **Battery type & number of cells**
   - **Charging current**
   - **Room volume**

EN 50272-2 is not just a recommendation—it's a mandatory safety standard for any significant stationary battery installation in the EU. In large UPS systems, it ensures the safe integration of batteries into the electrical infrastructure, mitigating risks such as fire, explosion and electric shock.

National/Local Building Codes & Fire Safety, Explosion Safety Regulations

Individual EU Member States implement standards via local building, fire safety and electrical installation codes. Additionally, ATEX (for areas with an explosion risk) may apply if there is a risk of an explosive atmosphere.

Requirements: May require gas detection, forced ventilation in certain battery charging areas, positioning of inlets/exhausts, ventilation rates and combining ventilation with alarms/interlocks, as well as proper dispersal of gases to the outside, etc. The standards above often serve as a reference.

Details of Ventilation Requirements (Typical/Established Practice)

Below are commonly used or required in many battery installation projects in Europe, especially for lead-acid or VRLA battery systems.

1. **Hydrogen threshold:** Aim to keep the atmospheric hydrogen concentration below 4% by volume. That is the LEL (lower explosive limit) for hydrogen/air mixtures in many standards.
2. **Safety / Dilution / Safety Factor:** Standards assume overcharge/end-of-charge gas emission currents (I_gas), number of cells and battery capacity, then include safety factors (often five times) in ventilation calculations.
3. **Natural ventilation:** Openable vents (inlets and outlets) are designed to allow airflow, facilitating the dilution of gases. Openings should be located on opposite walls or spatially separated to avoid dead zones. Air velocity through vent openings may be specified (e.g., ~0.1 m/s for natural ventilation in some Italian guidance).
4. **Forced (mechanical) ventilation:** Required when natural ventilation isn't enough to keep hydrogen below threshold, or for high-capacity installations. Often includes exhaust fans, possibly interlocked with charging systems or with gas detection/triggers. Exhaust air to be vented outside. Ventilation system design following a calculated required flow (based on hydrogen generation, etc).

Natural Ventilation

Hydrogen is a very small molecule and escapes quickly with proper ventilation. Natural ventilation is acceptable if enough vents are installed. Below are considerations for natural ventilation.

1. **Low:** Air intakes should be placed low
2. **High:** Place outtake vents high to facilitate hydrogen escape, as hydrogen is lighter than air and will rise to the top of the room or container
3. **Forced ventilation is required if:**
   a) Natural flow is insufficient
   b) Battery capacity or charging current is high enough to produce more hydrogen than natural ventilation can safely vent
   c) The battery is enclosed in a cabinet or small room: IEC 62485-2 does not explicitly mandate hydrogen sensors, but: Hydrogen detectors can be integrated into the ventilation control strategy, especially when ventilation is demand-controlled rather than continuous, natural ventilation is limited, batteries are placed in unusual or confined locations such as underground or enclosed cabinets, or in higher-risk setups like those with large ampere-hour capacity or mission-critical systems.

If Sensors Are Used:

- They should trigger alarms and/or forced ventilation if hydrogen reaches predefined levels (typically 1% H_2 in air)
- They must be placed at the highest point of the room or enclosure where hydrogen accumulates

The system should be fail-safe — meaning it defaults to maximum ventilation or shutdown if the sensor or controller fails. Alarms should be sent to a monitored fire or building management system that aligns with the Hazard Management Plan (HMP).

Practical Applications for Battery Room Design

Putting together what is in 62933-5-2 plus its references, here is what a compliant design will need to include (or ensure):

1. A gas detector system that can detect flammable gases (hydrogen, etc.), with audible/visual alarms, tested per accepted standards (IEC 60079-29, etc.)
2. Interlock/automation: Gas detection must be able to trigger ventilation (if forced ventilation is provided) so that ventilation activates when the gas concentration reaches a hazardous level
3. Ventilation systems must be type-tested and tested on site (SAT) under simulated gas detection signals to ensure they work as intended
4. For VRLA batteries, during both normal and boost charging, the ventilation must meet whatever is required in IEC 62485-2 (which specifies ventilation and safety distance requirements)
5. The layout must consider the safety distance between vent openings and potential ignition sources
6. The ventilation may be both internal to the BESS enclosure and/or external to the room around it (depending on the category)

Examples of Local Laws/Directives

European countries and regions have regulations that address building, fire safety, explosion safety and environmental/industrial safety, including the monitoring and control of hydrogen in battery rooms, charging rooms and battery installations. These regulations illustrate how national and local regulations can complement international standards, such as IEC 62485, EN 50272-2 and ATEX, among others.

Germany

Directive/Regulation/Rule Abbreviation Key Requirements

- ATEX Directive 2014/34/EU requires employers/operators to assess explosion risk, define zones and use explosion-protected equipment; mandates certification/ATEX rating for equipment used in potentially explosive atmospheres (e.g., lighting, fans, detectors)
- Betriebssicherheitsverordnung BetrSichV Implements the ATEX Directive (2014/34/EU)
- German Technical Rules for Industrial Safety TRBS 2152 Addresses hazardous explosive atmospheres, including their assessment and protective measures (design, detection, ventilation)
- German Technical Rules for Industrial Safety TRGS 751 address the handling of hydrogen, particularly in fuel stations; safety practices (sensors, ventilation, zoning) are relevant by analogy

Netherlands

Document/Regulation Scope/Context Threshold/Applicability Key Requirements

- PGS-37 (and PGS-37-1) Lithium Energy Storage Systems (ESS) safety. Larger than ≈20 kWh. Requirements for fire safety, ventilation (including measurement of gases like CO and H2), escape routes and emergency shutdowns.
- Dutch Activities Decree / Activities Regulation Categorization and external safety of lithium-ion batteries (hazardous substances). When certain thresholds for large quantities are exceeded. Requirements for distance/zoning, reporting and mitigation.

France

Rule/Document Applicable Battery Type Power Threshold Key Requirements/Focus

- Arrêté du 29 mai 2000 Lead-acid >50 kW DC (Charger Power) Dedicated charging room is necessary
- Decree No. 2019-1096 Lithium-ion >600 kW DC (Charger Power) Mechanical ventilation must keep hydrogen levels below ≈1% of room volume; Chargers must automatically shut off if ventilation fails; Hydrogen detection is essential for monitoring and triggering safety protocols
- Good Practices (INRS technical memoranda) N/A (General Safety) N/A Sensor placement (high), addressing roof shapes/gas pockets, interlocking alarms (e.g., at 10% and 25% of LEL), with ventilation speeds

United Kingdom

Document/Regulation | Scope/Context | Key Safety Requirements | Specific Ventilation/Detection Mandates

- MGN 550 (Marine Guidance Note) (UK) Safe design, installation and operation of lithium-ion batteries in a marine context. Guidance on safe design, installation and operation. Active ventilation with a minimum of 6 air changes per hour. Includes detection and shutdown systems in the event of ventilation failure or hazardous levels being detected.
- PAS 63100:2024 Protection Against Fire of Battery Energy Storage Systems for use in dwellings. Batteries must be separated from escape routes and habitable rooms, equipped with fire detection systems and have adequate ventilation—addresses venting and location. Ventilation is required. Hydrogen sensing is less explicitly required, but detection is addressed.
- Building Regulations / Fire Safety (England, Wales) General fire safety (e.g., in buildings). Enforce requirements on fire compartmentation, means of escape and detection systems. Requirements are general and not battery-specific.

Key Regulatory Themes & Common Requirements

The standards are increasingly becoming common across different regions worldwide, reflecting a global trend toward harmonization in various industries and practices. The table below shows the standard European requirements:

Requirement Purpose / Regulatory Driver

1. Hydrogen concentration thresholds (e.g., 1 vol%, or 25% of LEL) are used to trigger alarms/safety actions. To ensure a safety margin well below the lower explosive limit (~4%). Many regulations require hydrogen <1% by volume.
2. Ventilation (mechanical or natural) with a sufficient rate to dilute hydrogen, automatically controlled, especially in high-power/large battery or high charger power scenarios. To prevent accumulation, especially at high points (since H_2 is lighter than air).
3. Hydrogen/gas detectors are installed in battery rooms (usually positioned at or near the ceiling) to sense accumulation before dangerous levels are reached, interlocking with ventilation/charger shutdown.
4. Explosion-protected/ATEX-rated electrical equipment must be used in rooms that may generate explosive atmospheres; lighting, fans, and sensors must be suitable for this purpose to avoid ignition sources.
5. Automatic shutdown/interlocking if ventilation fails or gas concentration rises above safe limits. To prevent worsening of the situation.
6. Fire detection & suppression, compartmentation of rooms, safe means of escape, because fire risk is elevated and hydrogen explosion risks are similar to fire risks.
7. Environmental/industrial safety regulations for the storage/handling of gases/chemicals/acids and other hazardous substances. To ensure not just fire risk but chemical/explosion/toxicity risks are managed.

Examples of Local Laws/Directives

What IEC 62933-5-2 says (or requires) is as follows, based on available previews/clauses of IEC 62933-5-2:2020/ the draft ED2 (2025). The relevant parts regarding ventilation and detection are presented in Figure 1.

Topic	Key Requirement/Detail	Specific Application/Context
Scope and Relevant Batteries	Covers grid-integrated electrochemical energy storage (EES) systems	Explicitly acknowledges that VRLA batteries emit hydrogen under normal conditions, with significantly higher emission (factor of ≈50) under abnormal/overcharge conditions
Ventilation Testing and Automatic Operation	Ventilation systems (site or BESS internal) require type testing (components) and site acceptance testing (SAT). System must operate automatically	For BESS categories V-H/S-O/C-A, C-B, C-D and C-Z with forced ventilation, SAT must include simulation of gas detection signals to ensure automatic ventilation response (8.2.3.3)
Gas Detectors and Alarm Signals	Flammable gas detection systems are required. All functions (audible and visual signals) must be tested upon installation to ensure response when gas concentration exceeds the manufacturer's limit	Refers to IEC 60079-29 (all parts)for guidance on the use of flammable gas detectors
Ventilation of Battery Compartments	Ventilation amounts and safety distances are not fully detailed inside 62933-5-2	Specific requirements detailed in the annex for VRLA batteries (B.5.2.3)

Figure 1.

NFPA 855

NFPA 855 requires you to treat combustible-gas (including H_2) hazards as part of an ESS fire/explosion strategy — with options that include ventilation, gas detection tied to emergency ventilation or other mitigations and explosion-control measures (deflagration vents or explosion-prevention systems). It also makes gas detection an accepted component of a mitigation scheme in specific, tested/approved configurations and it ties into NFPA 68/NFPA 69 and UL 9540A testing requirements.

Below is a concise breakdown of the NFPA 855 requirements and their practical implications for controlling hydrogen in battery systems.

1. **Recognize combustible-gas hazards and evaluate them.**
   NFPA 855 requires a hazard evaluation for ESS installations that include flammable-gas generation and accumulation, as a potential hazard that must be mitigated. Designers must identify credible gas generation scenarios and select mitigations.

2. **Ventilation/exhaust is a prescriptive mitigation.**
   The standard includes requirements for exhaust/ventilation to prevent the accumulation of flammable gas. NFPA 855 (and jurisdictional guidance based on it) requires mechanical or natural ventilation to be sized and arranged to avoid hazardous concentrations.

3. **Gas detection is an accepted mitigation element (and can be required)**
   NFPA 855 explicitly recognizes gas detection systems (combustible-gas detectors) as part of the protection approach. Gas detectors are commonly required to provide early warning and to actuate controls (alarms, emergency ventilation, shutdowns) and are referenced in guidance and annex material.

4. **Gas detection + emergency ventilation can be used as a performance-based option (with caveats)**
   NFPA 855 allows a mitigation strategy that uses gas detection to trigger emergency ventilation or other automatic actions, but this is subject to testing, validation, AHJ approval and/or adherence to explosion-mitigation standards (NFPA 69 for prevention or NFPA 68 for venting). In short, gas detection and emergency ventilation are accepted strategies when demonstrated to be effective (often through testing or analysis).

5. **Explosion control/prevention is required where applicable**
   Where an explosive atmosphere could form, NFPA 855 requires explosion-control measures (for example, deflagration venting per NFPA 68 or explosion-prevention systems per NFPA 69) or design choices that prevent the formation of explosive atmospheres. NFPA-69's performance criterion (keep global concentration <25% LFL for an explosion-prevention approach) is often referenced when designing explosion-prevention systems.

6. **Integration with thermal runaway/fire testing requirements**
   NFPA 855 requires or references testing (UL-9540A) for evaluating fire and explosion hazards of representative ESS installations. The gas/venting/detection strategy must be compatible with these test outcomes and with the required suppression or mitigation schemes.

7. **AHJ / engineering judgment and documentation matter**
   NFPA 855 is performance-based in many areas, including the use of gas detection as a primary mitigant or substitute. Using ventilation as a control requires engineering justification, written procedures, declared alarm/interlock setpoints and approval by the authority having jurisdiction (AHJ). Many jurisdictions also require documented SAT/VAT (site acceptance/verification testing).

IEC 60079-29/UL 2075

When applying IEC 60079-29 and UL 2075, both standards are related to safety and performance in the field of electrical equipment. IEC 60079-29 provides guidelines for the design, testing and certification of gas detection equipment used in hazardous areas, ensuring that devices operate safely and reliably in explosive atmospheres. Similarly, UL 2075 establishes requirements for gas detectors to ensure they meet safety and performance standards, including reliability and accuracy. Both standards aim to ensure the safety of personnel and property by setting rigorous criteria for gas detection devices, making them comparable in their purpose of safeguarding hazardous environments. To battery rooms (where hydrogen may be generated or accumulate), the following design and specification considerations should be satisfied:

1. Use hydrogen gas detectors that comply (or claim compliance) with IEC 60079-29-1 or UL 2075 (including metrological performance, response, diagnostics, failure modes)
2. Place the detectors high in the room (or at locations where hydrogen would naturally accumulate), with good airflow and minimal stagnant zones
3. Ensure the detectors have appropriate ingress protection and are suitable for the classified hazardous environment (certified to EX standards)
4. Integrate the detectors with the ventilation/safety system so that alarms or threshold exceedances can initiate ventilation or other protective action
5. Perform maintenance procedures, if required. This includes periodic calibration, bump testing, maintenance, and diagnostics to ensure continued reliability
6. Utilize robust software, communications, and diagnostics if detectors are integrated into a larger monitoring/control system
7. Alarm thresholds should annunciate to a system or person that can activate the emergency response plan. Ensure that alarm thresholds, ranges and interfacing with safety logic are appropriately documented, thoroughly tested and fully validated.

Selecting a Hydrogen Monitor

High-temperature environments can cause hydrogen molecules to dissociate, leading to inaccurate sensor readings. Similarly, high hydrogen concentrations may cause sensor saturation, which also impacts measurement accuracy. Additionally, hydrogen sensors can be cross-sensitive to gases like methane and ethane, which can be mistaken for hydrogen, further compromising the readings. Standards and regulations specify requirements for hydrogen measurement, but these can vary depending on the application, making it difficult to ensure compliance with all necessary regulations. There are also various sensor types available on the market, each with distinct characteristics, maintenance requirements and specific applications. Selecting an appropriate sensor type based on the conditions and requirements is crucial for accurate and reliable hydrogen measurement.
See Figure 2 for the explanation of the most popular hydrogen sensors on the market.

Sensor Type	Operating Principle	Maintenance Requirements
Thermal Conductivity Detector (TCD)	Measures the thermal conductivity of the gas mixture. Different gases have different thermal conductivities, and the sensor measures the weighted average.	Requires regular calibration. The TCD filament should be cleaned or replaced regularly to prevent contamination.
Catalytic Bead	Measures the heat generated when hydrogen reacts with a catalyst (typically a metal oxide).	Requires regular calibration. The catalytic bead should be cleaned or replaced regularly to prevent contamination.
Solid State Precious Metal	Uses the catalytic properties of precious metals to detect hydrogen gas. Very sensitive (can detect concentrations as low as 1 ppm). Fast responding (typically detects H_2 within a few seconds).	Compared to TCD and catalytic bead sensors, Solid State Precious Metal sensors require less maintenance. Older-generation sensors necessitate regular calibration to maintain accuracy, while newer styles automatically calibrate during operation.

Figure 2.

Practical Recommendation (What to Put in a Spec/Design)

If you need a single, conservative approach that satisfies both NFPA and IEC expectations:

1. Design ventilation to meet IEC 62485 calculations: documented engineering demonstrating dilution capacity relative to expected gassing rates from the batteries. IEEE 1635/ASHRAE 21 is a suitable tool for determining battery gassing rates.
2. Adopt the NFPA 1% operational limit as your alarm/activation setpoint: Install hydrogen detectors according to IEC and program them to activate ventilation and alarms before reaching 1% H_2. This makes the system compliant with NFPA 855 and provides a safety margin well below the LFL.
3. Integrate the detector and ventilation interlocks and conduct the Site Acceptance Test (SAT) and Factory Acceptance Test (VAT). Simulate gas at setpoints and demonstrate the ventilation response, as required by IEC 62933-5-2 and recommended by NFPA. Keep documented proof for AHJ.
4. Maintain detectors according to IEC 60079-29 practices, including selection, calibration, bump testing and placement near high points (accounting for buoyancy effects) for hydrogen monitoring.
5. Document procedures & power backup: alarm logic, automatic fan power redundancy and power backup, maintenance/calibration intervals and logged SAT results, so the AHJ/inspectorates can accept detector-triggered ventilation instead of continuous ventilation.

Conclusion

In conclusion, adhering to safety standards like IEC 62485-2 and EN 50272-2 is crucial for the safe installation and operation of stationary battery systems. Proper ventilation is a key aspect of these standards, ensuring the safe reduction of hydrogen, which can accumulate during battery charging and under abnormal battery conditions. Facility managers can effectively mitigate risks by implementing maintenance procedures, integrating sensors with safety systems such as ventilation and utilizing natural and forced ventilation systems based on airflow calculations and hydrogen evolution of the battery. Additionally, compliance with national and local building codes ensures that battery installations align with specific regulatory requirements, further ensuring safety. Ultimately, a proactive approach to these standards and guidelines will protect critical systems, personnel and property.
The appendix provides draft specifications for ventilation and detection systems in accordance with the standards. This may serve as a guide for specifying engineers and facility engineers.

Appendix

Draft Specification – Hydrogen Sensing & Ventilation System (for Stationary Battery Rooms, ≥10-Year Design Life)

1. **Scope**
   This specification defines the requirements for hydrogen detection and ventilation control in stationary battery energy storage system (BESS) rooms. The system shall prevent hydrogen accumulation above 1% by volume, as per NFPA 855, while ensuring compliance with IEC 62485-2 and IEC 62933-5-2. Equipment shall be designed for a minimum 10-year service life, requiring neither calibration nor replacement parts.

2. **Hydrogen Sensors**
   Standard Compliance
   1. Sensors shall meet IEC 60079-29-1 (performance requirements for flammable gas detectors)

   Measurement Range
   1. 0–4% H_2 by volume (minimum)
   2. 5% H_2 Survivability

3. **Communications**
   1. Dry Contacts (1% and 2% H_2 setpoints)
   2. 4-20 mA Analogue
   3. Modbus RTU

4. **Accuracy**
   1. ±0.2% H_2 or better in the 0–2% range
   2. Dry Contact Setpoints:
      1. Alarm/ventilation activation: 1.0% H_2 (pre-alarm)
      2. High alarm/charger shutdown: 2.0% H_2

5. **Mounting**
   1. Sensors shall be installed at the highest practical points of the room, near expected sources of gassing, with airflow considerations
   2. Longevity
      1. Use solid-state H2 sensors rated for an operational life of ≥10 years with factory-calibrated stability
      2. Provide automatic self-diagnostics (fault relay on drift or failure)
   3. Maintenance
      1. Support bump testing at customer-defined intervals
      2. No calibration is required throughout the sensor's life
      3. No replacement parts required throughout the sensor's life

Draft Specification – Ventilation System

Design Basis

1. Sized per IEC 62485-2 ventilation calculations to maintain H_2 < 4% under worst-case charging, plus NFPA 855 limit of <1% with sensor-triggered demand control
2. Operation
   - Normally off or low speed; automatically triggered to the whole duty when sensor ≥0.8% H_2
   - Shall activate before 1% concentration
3. Reliability
   - Fans rated for continuous duty, L10 life ≥100,000 hours
   - Bearings: sealed, maintenance-free
   - Motors: inverter-duty, thermally protected, designed for a minimum of 10 years
4. Redundancy
   - N+1 fan configuration or equivalent fail-safe strategy, ensuring airflow if a single unit fails
5. Power Supply
   - Fans and sensors shall be backed by UPS or ESS auxiliary power, so hydrogen control is active during outages

Draft Specification – Control & Integration

1. Logic
   - Sensor alarm ≥0.8% → ventilation ON
   - Sensor ≥1.0% → high alarm + charger shutoff / BMS inhibit
   - Sensor fault → fail-safe ventilation ON and alarm

Testing

1. In accordance with IEC 62933-5-2 the complete detection-ventilation system shall undergo:
   - Type test (factory acceptance)
   - Site acceptance test (SAT/VAT): simulated gas inputs shall verify alarms, interlocks, and ventilation response
2. Data & Monitoring
   - 4–20 mA analogue, Modbus, and dry-contact outputs for BMS/SCADA integration
     Dry contacts shall be set at 1% and 2% alarm thresholds
   - Fault indicator communicated through data integration
   - Optional local display with concentration readout and alarm indicators

Draft Specification – Documentation & Maintenance

1. The manufacturer shall provide:
   - 10-year MTBF/MTTF reliability data for detectors and fans
   - Recommended spares and calibration gas kit, if required
   - Bump test procedure
2. The system design shall support at least 10 years of operation without calibration or part replacements