

Battery Energy Storage Systems (BESS)

Technology, set-up and risk-appropriate protection concepts

Stephan Dorner | CEO risk on mind GmbH | 23.09.26

Independent risk
management for the
industrial sector.



www.riskonmind.eu

Agenda

01 – About us

02 – Introduction

03 – BESS Technology

04 – Fire and explosion risks

05 – Protection concepts

06 – Project presentation Indoor BESS

About us

Independent risk management for the industrial sector.

- Operational risk management
- Risk engineering and loss prevention
- Business Continuity Management
- Academy and digital solutions

About risk on mind

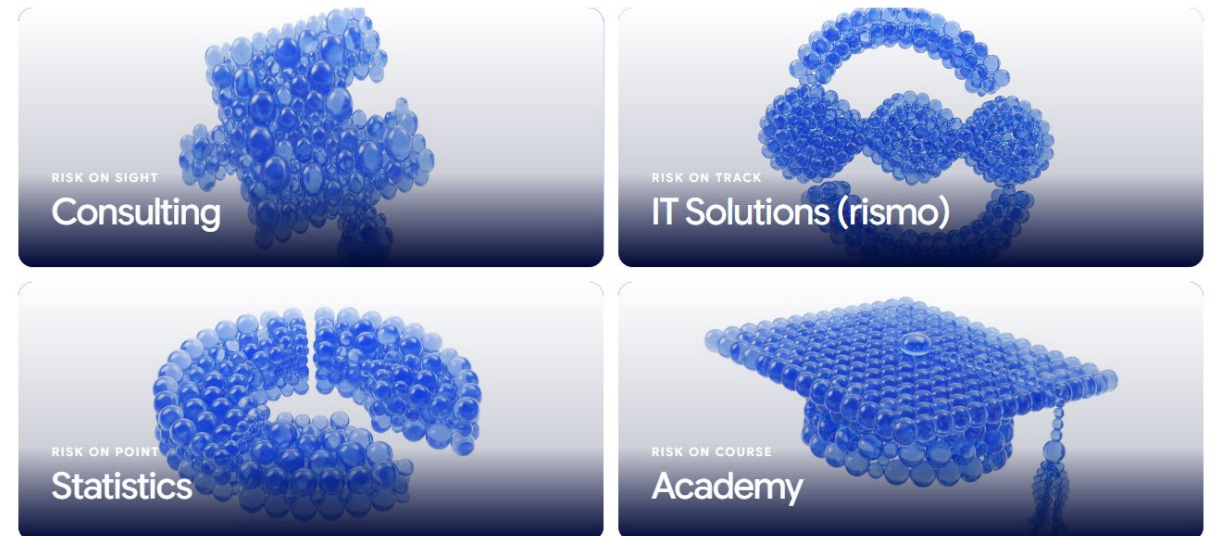
Your **independent** partner for holistic, data-based risk management.

risk on mind supports industrial companies in making risks transparent, making well-founded decisions and managing them economically – through the combination of consulting, data analysis and the rismo® software solution

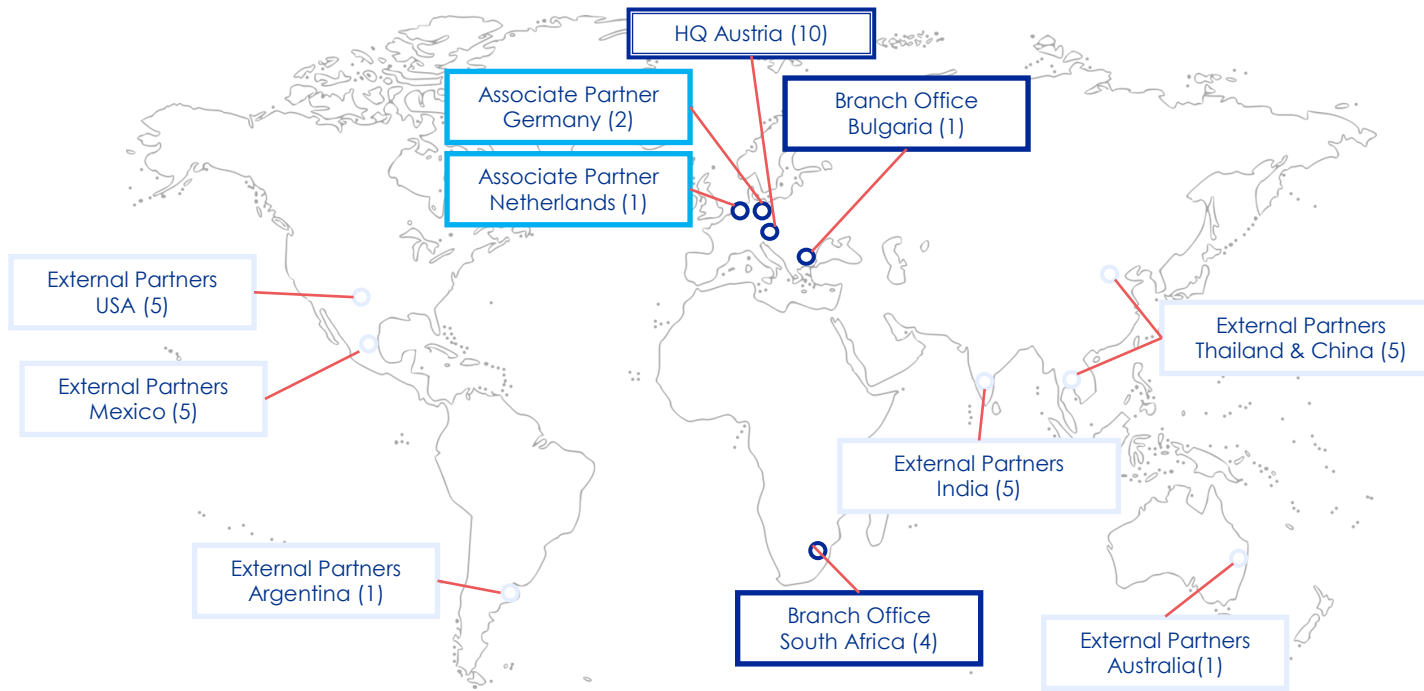
- ➔ Over **25 years of experience**
- ➔ More than **4.000 locations** on 5 continents analyzed
- ➔ **Well-coordinated team** of risk engineers, managers, statisticians and IT experts

4 areas. 1 goal.

Strategic advantage through sustainable risk management



Our network



Our partners

risk on mind is represented worldwide by a strong network of partners and local experts and can therefore react quickly and specifically on site. At the same time, its own risk management standard in combination with an integrated software solution ensures a consistent, objective assessment.

02 Introduction

Why BESS will continue to play an increasingly important role

- Facts and figures
- Main arguments for setting up a BESS
- Costs
- Factors for a successful project

BESS – Key Technology for the Future

Evidence of the current boom in battery storage systems:

610 GWh

Globally installed BESS capacity at the end of 2025

Mathematically, this corresponds to around 10 hours of total German electricity consumption.

7.3 TWh

Projected capacity until 2035

Enough energy to supply Germany with electricity for around five days.

+33%

Expected global market growth in 2026

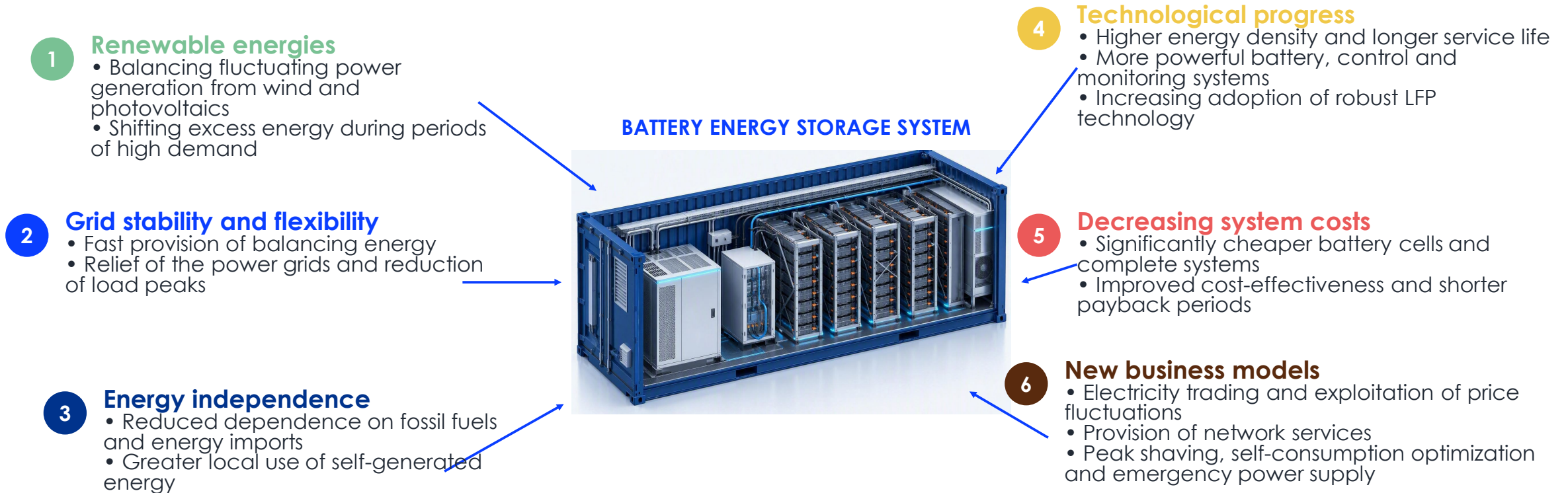
The BESS expansion forecast for 2026 corresponds to a global investment volume of around USD 40 to 42 billion.

The global BESS expansion is accelerating significantly: Within the next ten years, the installed storage capacity could increase about twelvefold.

Sources: Volta Foundation, Battery Report 2025; IEA, Global Energy Review 2026; BloombergNEF, 2H 2025 Energy Storage Market Outlook.

Why battery storage systems are booming worldwide

Energy transition, security of supply and technical progress are driving the expansion



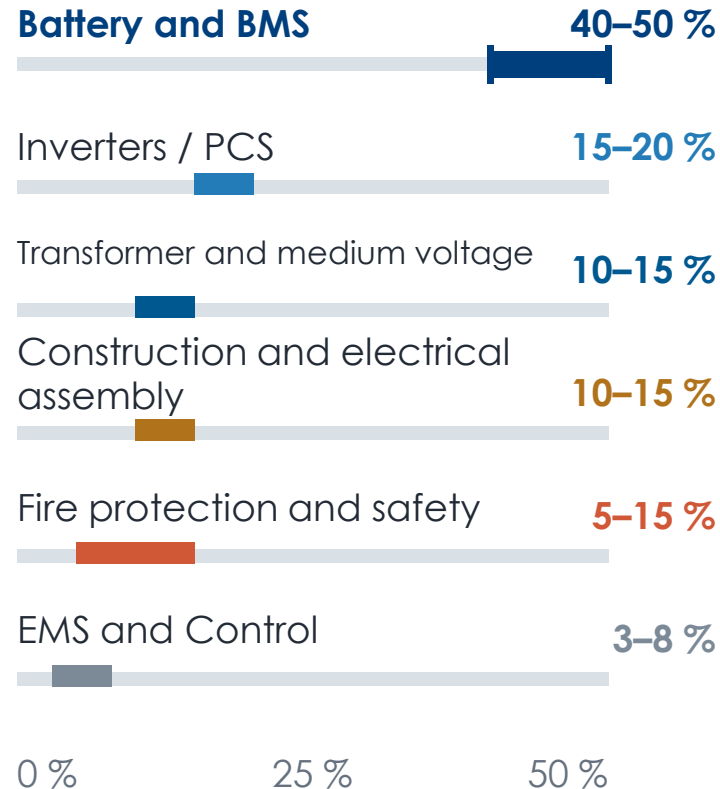
BUT: Growth alone is not enough

As capacity and energy density increase, so does the potential extent of damage. Safety must therefore play a central role from planning to operation.

How much does a BESS cost?

Typical investment ranges and key cost drivers

Typical distribution of the total investment



5 MWh BESS Container



OUTDOOR

Total cost	€1.3–2.5 million
Container + Battery	€0.8–1.3 million
PCS / Transformer / MS	€0.3–0.7 million
Construction / Infra.	€0.05–0.2 million
Fire protection	€0.05–0.15 million
Planning / Approval.	€0.05–0.1 million



INDOOR

Total cost	€1.8–3.8 million
Container + Battery	€0.8–1.3 million
PCS / Transformer / MS	€0.3–0.7 million
Construction / Infra.	€0.3–0.8 million
Fire protection	€0.3–0.8 million
Planning / Approval.	€0.05–0.15 million

10 × 250 kWh All-in-One BESS



OUTDOOR

Total cost	€1.1–2.1 million
10 × All-in-One	€0.8–1.4 million
Electrical / Grid	€0.1–0.3 million
Construction / Infra.	€0.05–0.2 million
Fire protection	€0.05–0.15 million
Planning / Approval.	€0.05–0.1 million



INDOOR

Total cost	€1.4–3.2 million
10 × All-in-One	€0.8–1.4 million
Electrical / Grid	€0.1–0.3 million
Construction / Infra.	€0.2–0.6 million
Fire protection	€0.2–0.7 million
Planning / Approval.	€0.05–0.15 million

Total capacity: 2.5 MWh

It is not only the battery that determines the investment: the type of installation, infrastructure and, in particular, protective measures can have a significant impact on the overall costs.

Cost-effectiveness of a BESS: Example calculation

How electricity trading and peak shaving affect the payback period

 5 MWh Storage Capacity	 2.5 MW Power	 1.8 million € Investment	 90 % Efficiency	 1 full cycle per day Usage	 80–180 Euro/MWh Price difference purchase/sale
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Electricity trading: Three possible market scenarios

Conservative	Realistic	Good market conditions
Simple payback period 13.7 years	Simple payback period 9.1 years	Simple payback period 6.1 years
Price difference: 80 euros per MWh	Price difference: 120 euros per MWh	Price difference: 180 euros per MWh
Usable amount of energy: 4.5 MWh	Usable amount of energy: 4.5 MWh	Usable amount of energy: 4.5 MWh
Revenue per cycle: 360 Euro	Revenue per cycle: 540 Euro	Revenue per cycle: 810 Euro
Annual revenue · 365 cycles: 131 thousand euros	Annual revenue · 365 cycles: 197 thousand euros	Annual revenue · 365 cycles: 296 thousand euros

$5 \text{ MWh} \times 90\% = 4.5 \text{ MWh of usable energy}$; Annual revenue = usable energy × price difference × 365 cycles.

Additional benefits of peak shaving

-  Reduce load peaks
-  Reduce power prices
-  Avoid expanding the grid connection
-  Optimising PV self-consumption
-  Support resilience and backup power

Typical additional savings: **50-150 thousand euros per year**

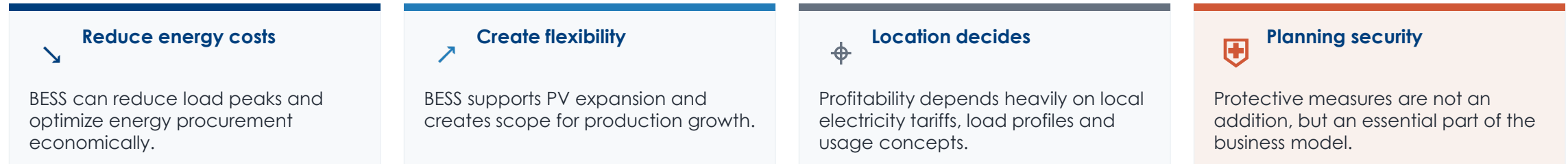
Combined business case

$$\begin{array}{ccccc} 197 & + & 100 & = & 297 \\ \text{Thousand Euro Arbitrage} & & \text{Thousand Euro Peak Shaving} & & \text{Thousand euros per year} \end{array}$$

Simple payback period: **approx. 6-10 years**

The economic benefit of a BESS often only arises through the combination of several applications.

What companies should know about BESS



Protective measures are not a minor matter. They are crucial for the successful implementation of a BESS project.



From technology to safe implementation

DISCLAIMER

The recommendations presented correspond to general best practice approaches. Before setting up a BESS, local conditions as well as current legal, regulatory, normative and insurance requirements must be taken into account. Early coordination with specialist planners, authorities, emergency services and the insurer is required. Due to the dynamic development of technology and limited experience and test data, the current state of the art and regulations must be reviewed on an ongoing basis.

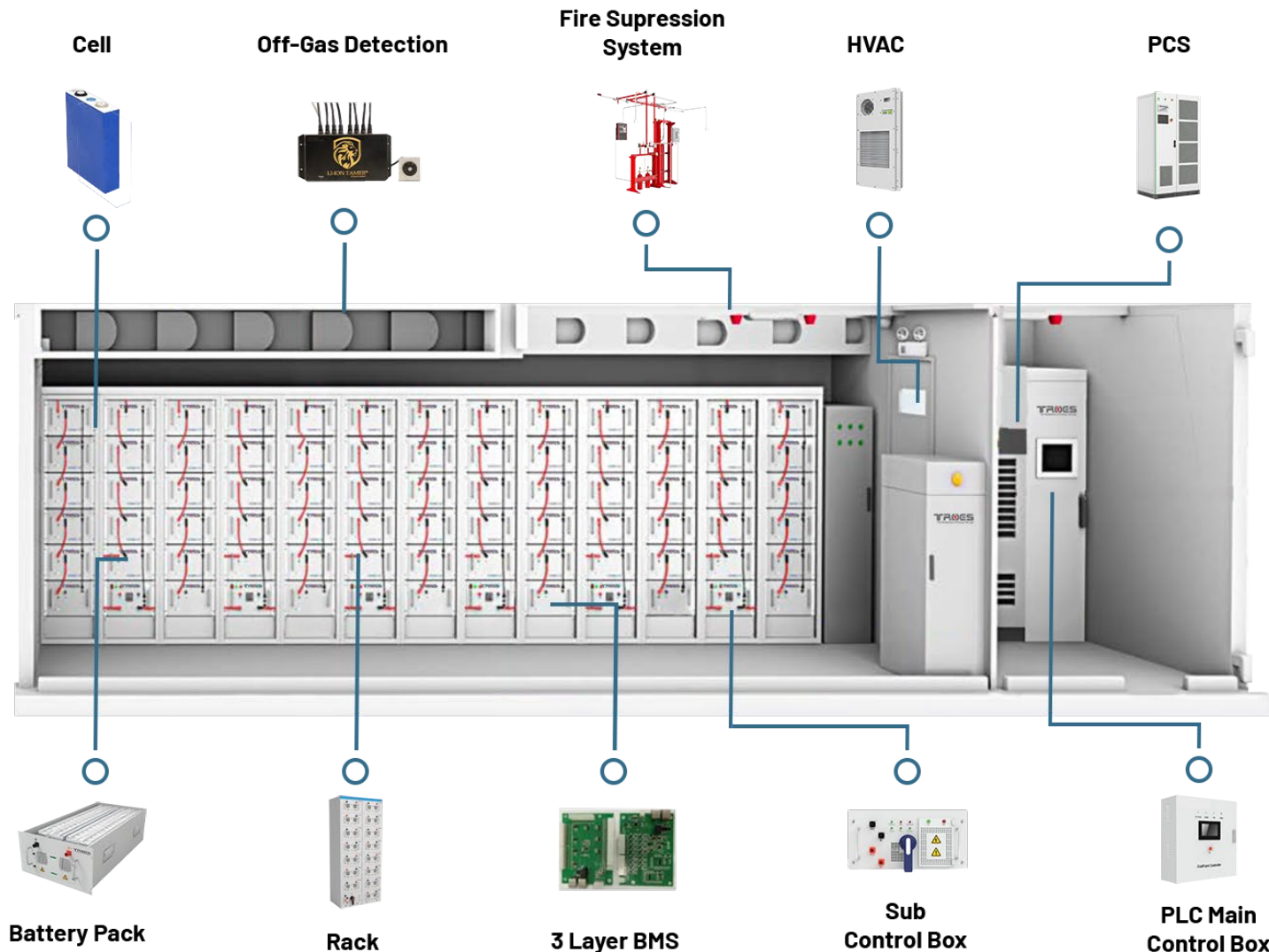
risk on mind follows current developments and keeps you up-to-date on request.

The content does not replace a project-specific risk assessment, specialist planning or official approval.

03 **BESS Technology**

Battery chemistry, system architecture and safety basics

Structure of a BESS



- Battery cells form the smallest storage unit
- Cells are combined into battery packs and racks
- The battery management system (BMS) monitors condition, temperature and voltage
- The cooling system ensures safe operating temperatures
- The inverter (PCS) converts direct current into alternating current and vice versa
- Transformer and switchgear enable connection to the power grid

Pros

- **Capacity:** High gravimetric and volumetric **energy density**
- **Build space:** Compact design with small footprint
- **Operation:** High power output and good dynamic properties
- **Market-ready:** Proven technology with extensive operating experience
- **Flexibility:** Wide range of cell and system sizes

Cons

- **Safety:** higher probability of fire and thermal instability than LFP; violent thermal runaway with high heat release
- **Gases & Propagation:** flammable/toxic decomposition gases; increased cell-to-cell risk
- **Protection:** high costs for early detection, cooling and structural fire protection
- **Service life:** often lower cycle stability than LFP in regular operation
- **Commodities:** nickel/cobalt, higher costs and critical supply chains
- **Stationary:** Space and weight advantages usually of little relevance

Conclusion: Generally not recommended for industrial BESS.

The energy density is rarely decisive in stationary technology, other technologies are clearly preferable because of higher thermal stability, longer service life and lower fire risk.

Pros

- **Safety:** thermally very stable, significantly lower fire risk than NMC
- **Service life:** high cycle stability, less wear during high and deep discharge
- **Cost:** cheaper, without nickel/cobalt
- **Market readiness:** proven and widely available
- **Performance:** high performance and robust dynamics

Cons

- **Gas release:** Thermal runaway produces explosive, toxic and corrosive fluorine-containing decomposition products
 - **Risk of explosion and poisoning**
- **Energy density:** gravimetrically and volumetrically lower than NMC
- **Installation space & weight:** usually larger and heavier systems for the same capacity
- **Cold behavior:** Low temperatures temporarily reduce power and usable capacity, charging power limitations may be required when charging

Conclusion: Clearly preferable for industrial BESS.

LFP is thermally more stable, more cycle-resistant and usually cheaper than NMC, but requires more space for the same storage capacity.

04 Fire and explosion risks

From cell error to possible system escalation

What is a Thermal Runaway?

TRIGGER



Thermal stress

Overheating, external burning,
Failure of the cooling system



Electrical stress

Overcharge, short circuit,
Faulty protection functions

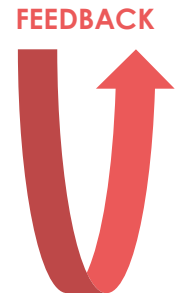
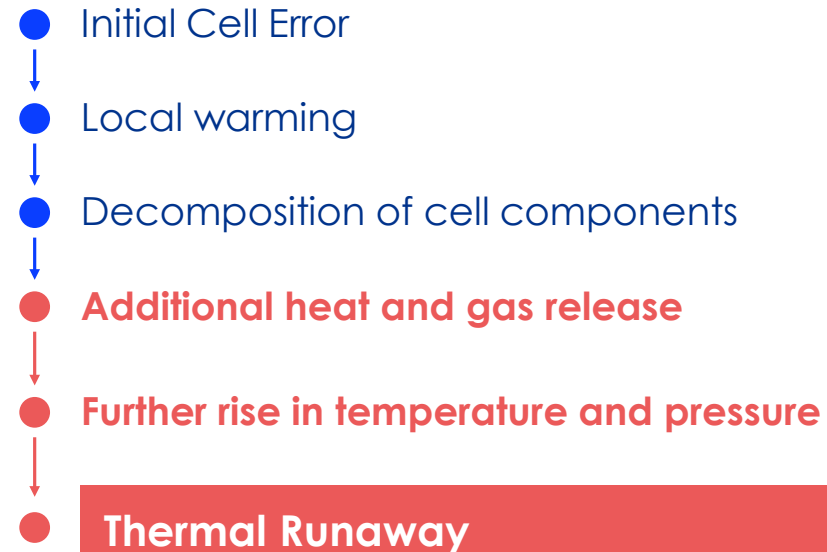


Mechanical stress

Shock, Squeezing, Penetration

Other causes: internal cell defects, aging or production defects

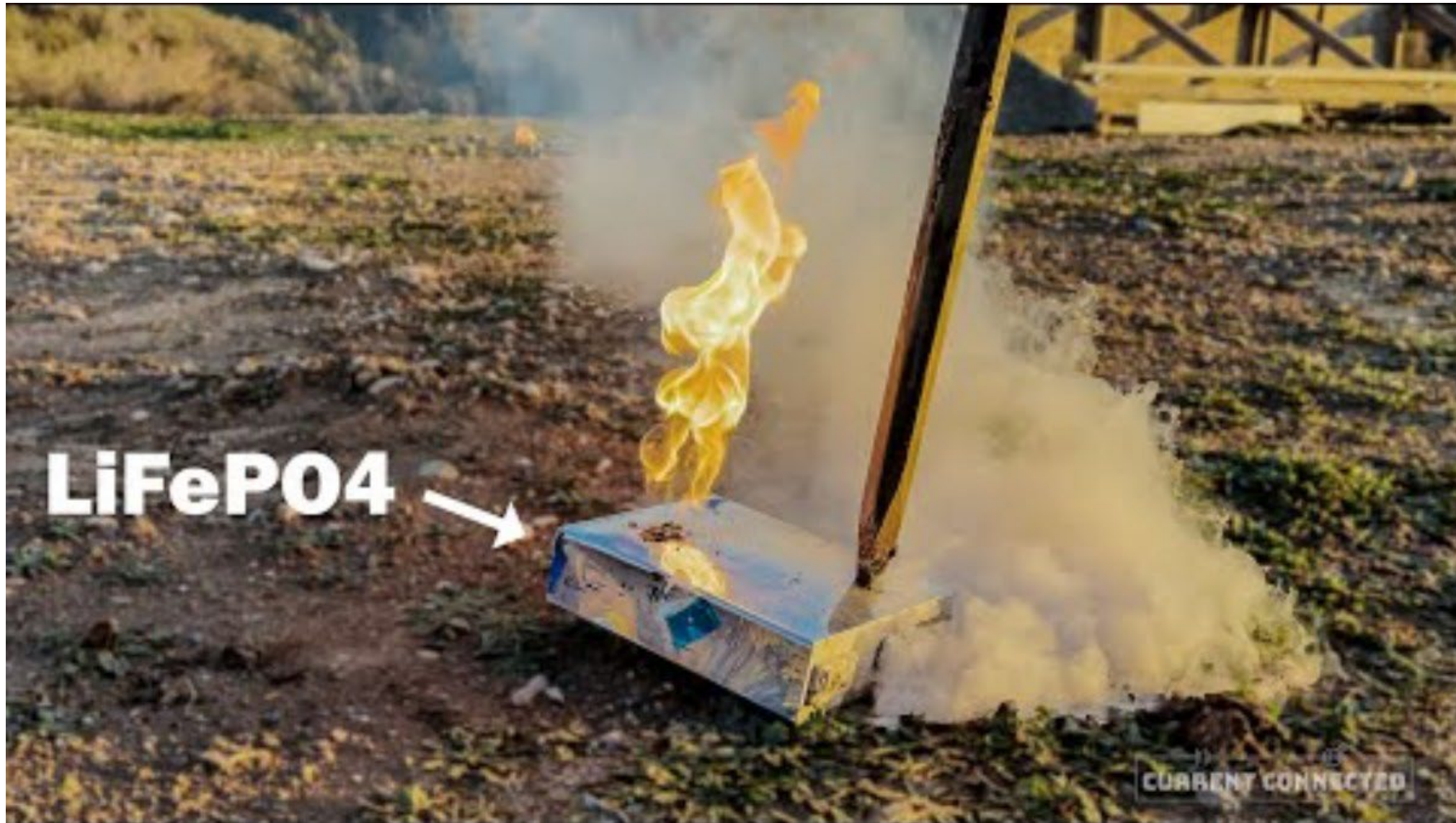
SELF-REINFORCING PROCESS



Conclusion: A thermal runaway can hardly be stopped, as the reaction within the cell generates heat independently and takes place largely independently of the ambient oxygen.

The focus is therefore on early detection, cooling and propagation limitation.

Thermal Runaway LFP Battery



What are the consequences of a thermal runaway?

INITIAL EVENT

Thermal Runaway a battery cell

- Sharp rise in temperature and pressure
- Decomposition of electrolyte and cell components
- **Release of hot decomposition gases**
- Possible opening or bursting of the cell

THREE DANGER ZONES

1 FIRE DANGER

- Decomposing gases ignite
- Flames + strong heat
- Adjacent components ignite
- Heat transfer to other cells
- Cascade propagation

2 GAS DANGER

- Combustible decomposition products
- Toxic + corrosive gases
- Danger to persons / emergency services
- Accumulation in containers / battery rooms
- Spread to adjacent areas

3 EXPLOSION DANGER

- Explosive gas-air mixture
- Ignition by heat, sparks or flames
- Rapid pressure increase in confined areas
- Damage to containers or buildings
- Shock wave + flying components

CRITICAL DIFFERENCE

IMMEDIATE INFLAMMATION

Escaping gases burn immediately – flames and high heat radiation.

DELAYED INFLAMMATION

Unignited gases accumulate and can later ignite explosively.

Even without visible flames, a BESS can be acutely dangerous.

Factors influencing the extent of damage

INITIAL EVENT

**Thermal Runaway
a battery cell**

CRUCIAL QUESTION

**Does the event remain
localized or does it
spread to the entire
system?**

The same cell defect can
lead to completely
different damage patterns.

FOUR SPHERES OF INFLUENCE

1	Energy Content & Cell state	- Cell chemistry & thermal stability - State of charge - Amount of energy from affected cells	- Aging & Technical Condition - Cells involved at the same time
2	System Structure & Propagation	- Spacing: Cells, Modules & Racks - Thermal Barriers & Segments - Cell & module package quality	- Heat transfer to neighbors - Limit propagation in the overall system
3	Location & Surroundings	- Indoor or outdoor installation - Proximity to buildings & infrastructure - Ambient fire loads	- Room or container size - Ventilation & Pressure Relief
4	Effectiveness of the Protective measures	- Early detection via BMS, gas & temperature - Fast electrical shutdown - Cooling & Extinguishing	- Controlled gas discharge - Alerting & Intervention

POSSIBLE DEVELOPMENT

FAVORABLE COURSE	Early detection → rapid shutdown → local limitation → minor property damage
UNFAVORABLE COURSE	Delayed detection → cell and module propagation → the effects of fire or explosion → major damage

05 Protection concepts

Best Practices for Early Detection,
Organizational Fire Protection and Defensive Action

- General protective measures
- Outdoor applications
- Indoor applications

General protective measures for BESS

Overview

01 Thermal Runaway Prevention

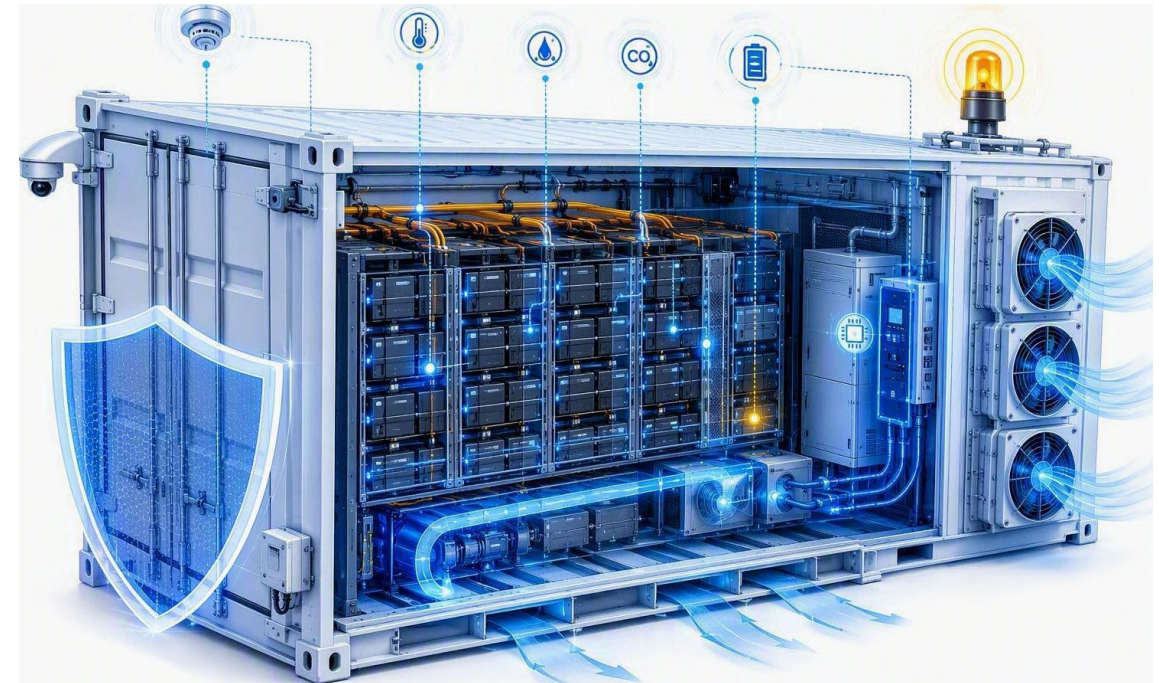
02 Cooling systems

03 Early detection & BMS

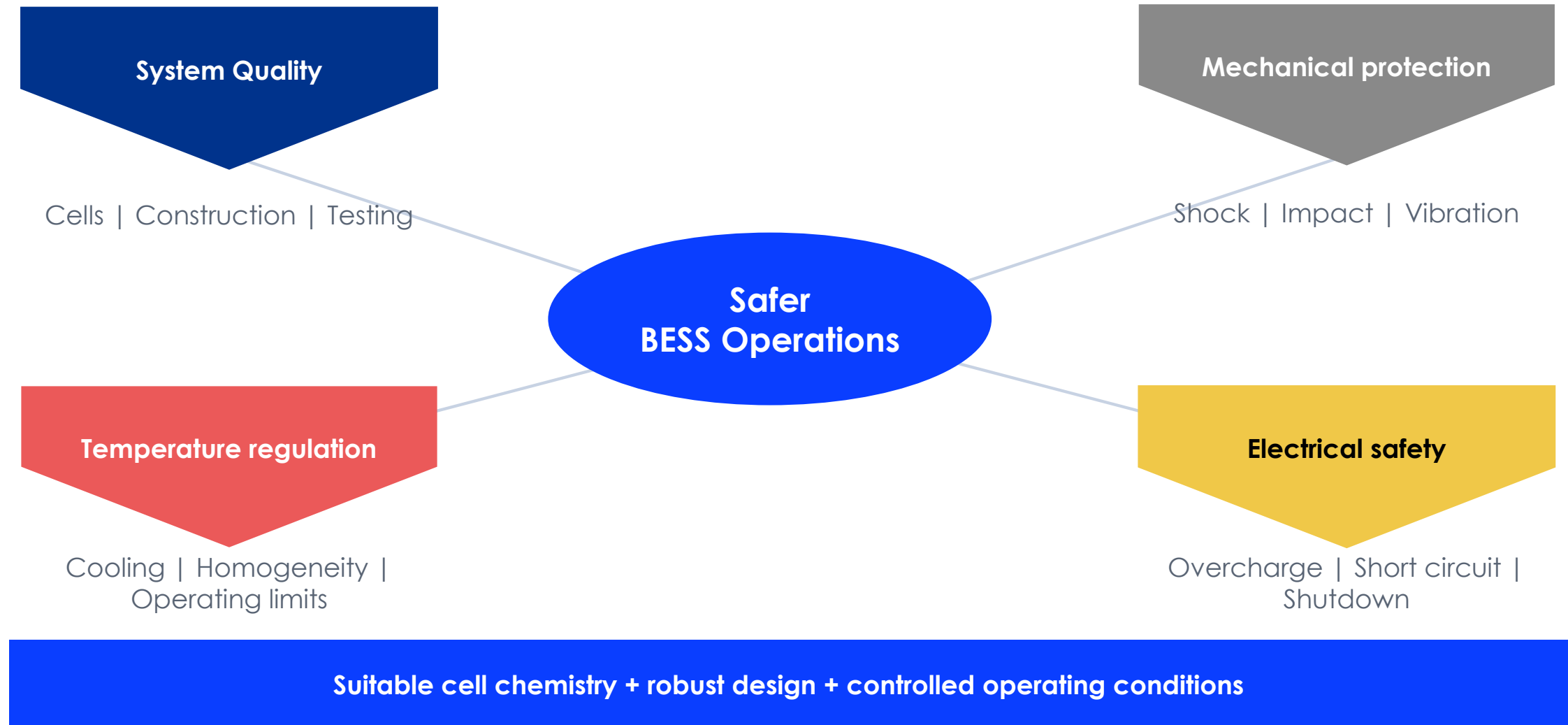
04 Extinguishing systems

05 Reaction chain in the event of an anomaly

06 Container design

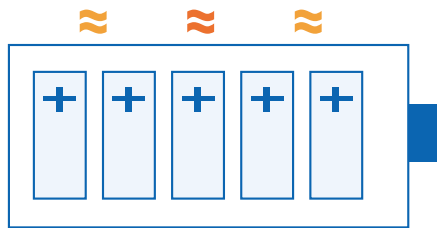


Prevent thermal runaway



Why do BESS need cooling?

Charging and discharging generate heat



Heat generated during operation

Electrical resistance

Current flow through cells, contacts and wires generates heat loss.

Other system components

Inverters, BMS components and electrical equipment also emit heat.

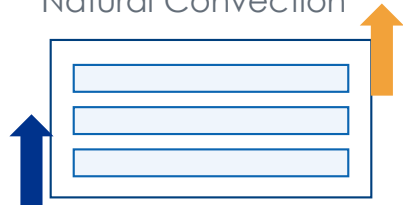
Electrochemical processes

During charging and discharging, reaction and polarization heat is generated in the battery cells.

Cooling keeps the battery cells within the intended temperature range and reduces critical temperature differences between the cells.

Passive air cooling

Natural Convection



Heat dissipation through natural air movement without targeted air delivery.

PROS

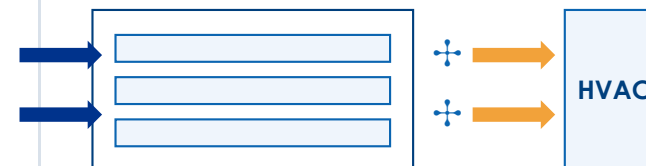
- Easy to set up
- Low energy consumption
- Few moving components
- Low maintenance

LIMITATIONS

- Limited heat dissipation
- Depends on ambient temperature and air flow
- Risk of uneven temperatures
- Only suitable for low thermal loads

Active air cooling

Forced Convection



Fans or HVAC systems guide air through the battery racks in a targeted manner.

PROS

- Higher heat dissipation
- Targeted air flow
- Better temperature control
- Proven and comparatively simple technology

LIMITATIONS

- Additional energy requirements
- Maintenance of fans and filters
- Uneven air flow possible
- May not be sufficient in case of high energy density

Passive air movement → controlled air flow

Liquid and refrigerant systems for higher thermal loads

Increasing thermal stress requires more efficient heat transfer

Air cooling can reach its limits in:

- Consistently high charge/discharge rates ($\approx 1C$ or more)
- Outdoor temperatures above about 30–35 °C
- High energy and power density in a confined space
- frequent cycles and continuous high-performance operation
- Uneven cell or module temperatures
- unfavorable air flow, dust or direct sunlight

Cold-plate liquid cooling

INDIRECT CONTACT



PRINCIPLE OF OPERATION

A coolant flows through channels in a cold plate. The heat is transferred through the cell or module housing to the plate and then to the fluid circuit.

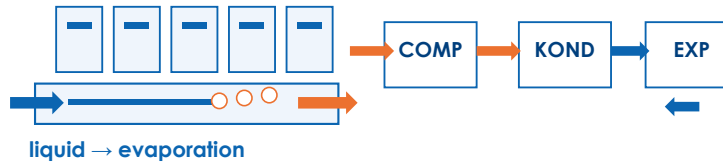
STRENGTH Easily controllable heat dissipation

CHALLENGE

Thermal contact and additional fluid circuit

Direct Refrigerant Cooling

INDIRECT CONTACT WITH DIRECT EVAPORATION



PRINCIPLE OF OPERATION

Refrigerant evaporates in a cooling plate directly on the battery module and absorbs heat in the process. This eliminates the need for a separate water-glycol cycle.

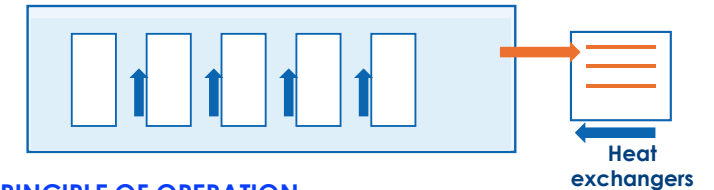
STRENGTH High heat absorption due to phase change

CHALLENGE

Sophisticated control, tightness and refrigeration technology

Immersion cooling

DIRECT CONTACT



PRINCIPLE OF OPERATION

Battery cells or modules are located directly in a dielectric coolant. The liquid absorbs heat directly at the cell surfaces and transports it to a heat exchanger.

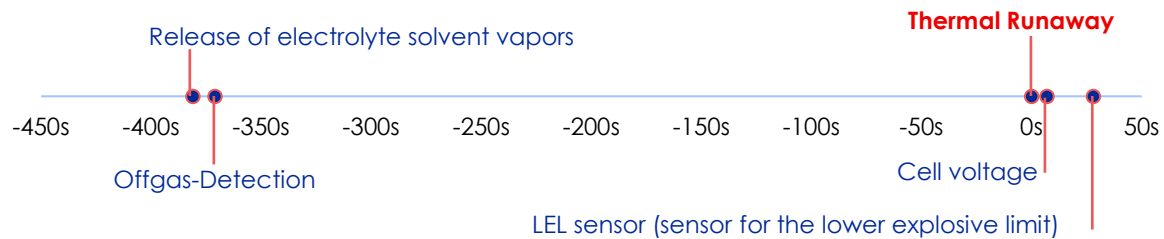
STRENGTH Direct heat absorption at the cell surface

CHALLENGE

Cooling medium, material compatibility and system sealing

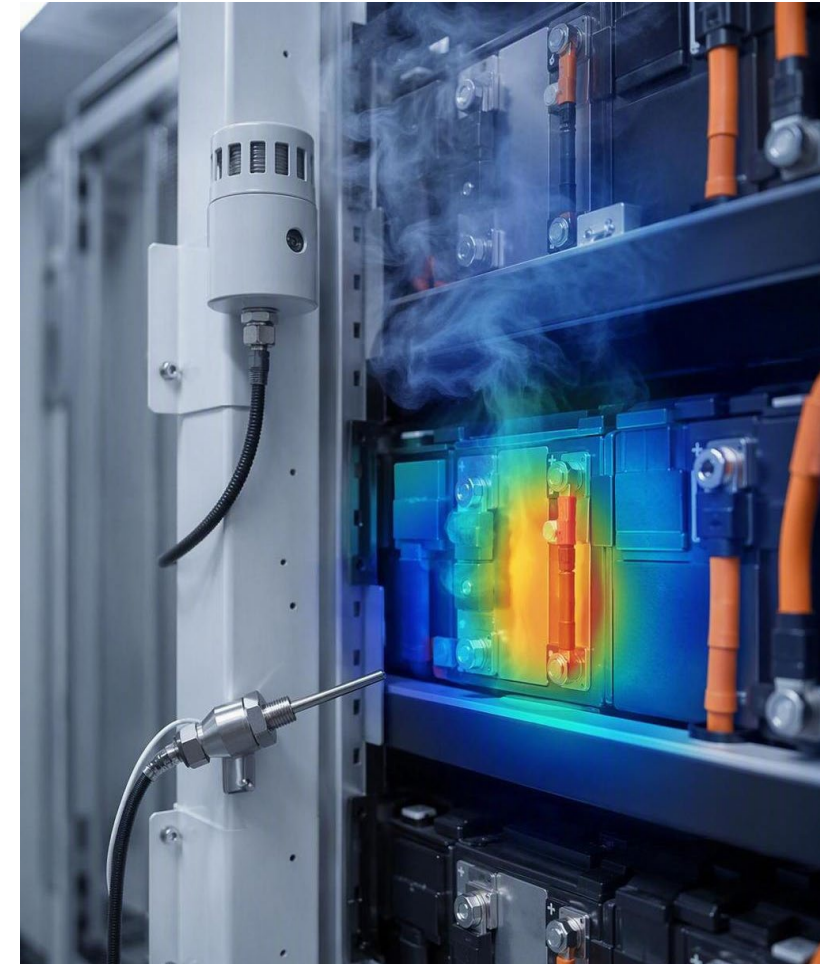
Off-gas/gas detection

- Detects vent gases before visible smoke, flame or explosion
- Earliest physically detectable indicator of an impending thermal runaway



Thermal early detection

- Detects slow or local temperature deviations before BMS limits are reached
- Good for trend and hotspot detection; not enough on its own



CENTRAL MONITORING

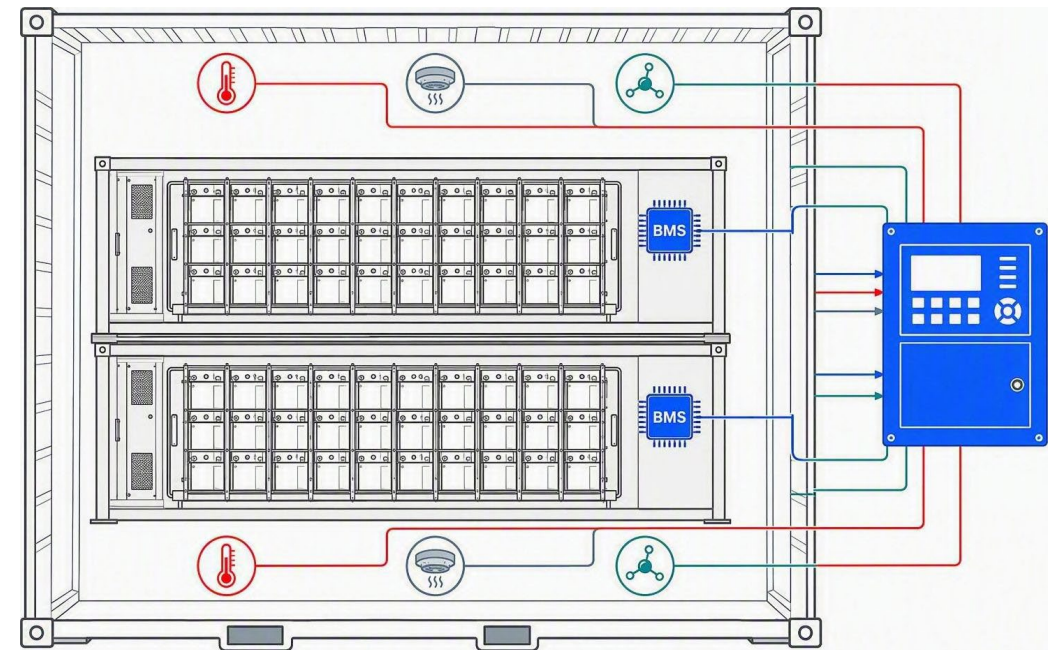
The BMS safely controls and monitors battery operation:

- Cell voltage
- State of Charge (SoC)
- Depth of Discharge (DoD)
- Charge and discharge currents
- Cell and module temperatures
- Cell balancing
- Communication and system errors

AUTOMATIC PROTECTIVE MEASURES

If the BMS detects electrical or thermal anomalies, it can automatically:

- Switch off individual modules
- Disconnect the system from the inverter
- Limit charging or discharging currents
- Activate alarms
- Suspend continued operation

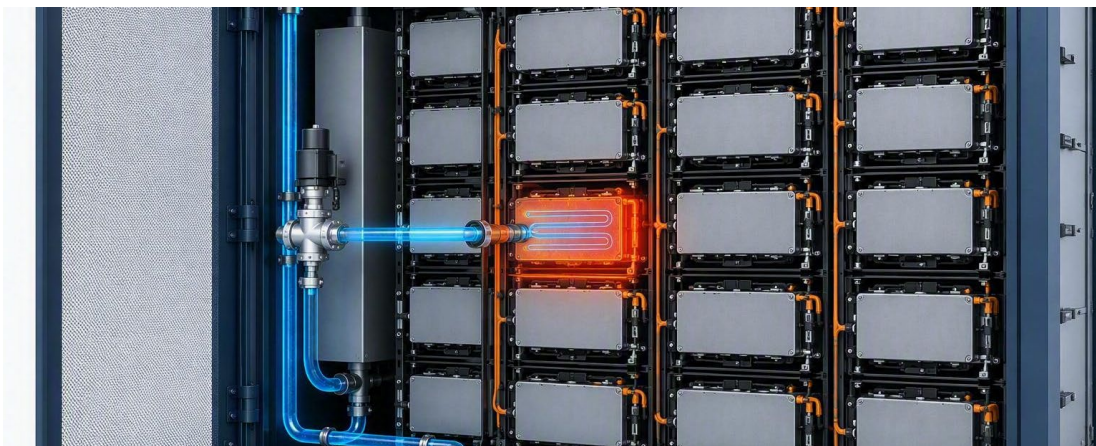


Extinguishing strategies for battery fires

01 Targeted cooling on the battery pack



02 Comprehensive extinguishing operation with water



AUTOMATIC ACTIVATION

- **Solenoid valve channel opens automatically** from defined threshold value for temperature or gas concentration.
- **Direct heat dissipation** at the affected pack limits the spread.
- **Selective effect:** Only affected cell or pack is affected – the rest of the battery remains intact.



PROS

- High heat absorption
- Cooling of adjacent cells and packs
- Limitation of thermal propagation
- Reduction of the risk of re-ignition
- Protection of adjacent racks or containers

USE ONLY AT THE HIGHEST ALERT LEVEL

Massive use of water can cause considerable BESS damage. Only use if targeted cooling does not stabilize the incident and limiting the spread of fire has priority.

Aerosol extinguishing system

- Interrupts the chemical flame reaction by inhibiting free radicals
 - Can reduce open flames inside the container
 - Compact design and small footprint
 - No cooling effect on cells and modules
 - Does not stop a running thermal runaway
- Only suitable as a supplementary measure for damage limitation

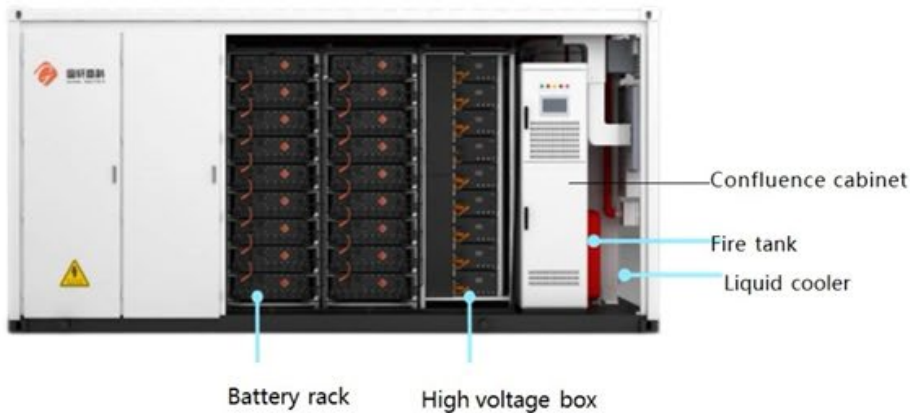
Sprinkler or deluge system

- Cools affected and neighboring battery units with water
 - Delays propagation to additional modules or racks
 - Limits open flames and potential secondary fires
 - Effectiveness of water-based systems proven in large-scale fire tests
 - Water causes damage to battery cells and electrics
- Recommended only in combination with multi-criteria detection
- Preferred measure for cooling and damage limitation



Video Extinguishing System - Coolant

Gotion High Safety Liquid Cooled Energy Storage System Solution



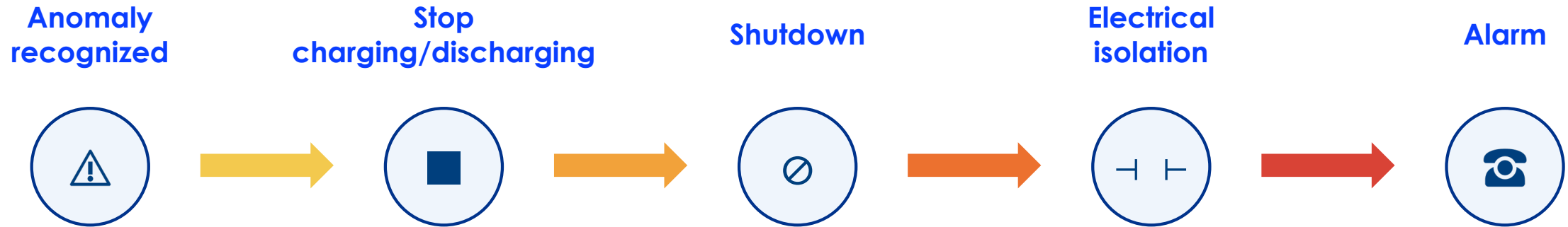
High Security: Ventilation, explosion-proof and pressure relief, Lion tamer combustible gas detector, fire protection, etc



High Security: Back-to-back design, independent fire zone, and cabinet meets a fire resistance limit of 1.5 hours

The "Pack-level liquid-cooled submersion extinguishing integration technology" independently developed by Gotion has the characteristics of accurate positioning, efficient suppression, and never reignition, ensuring the safety and reliability of the system and constantly creating value for customers!

Reaction chain in the event of an anomaly



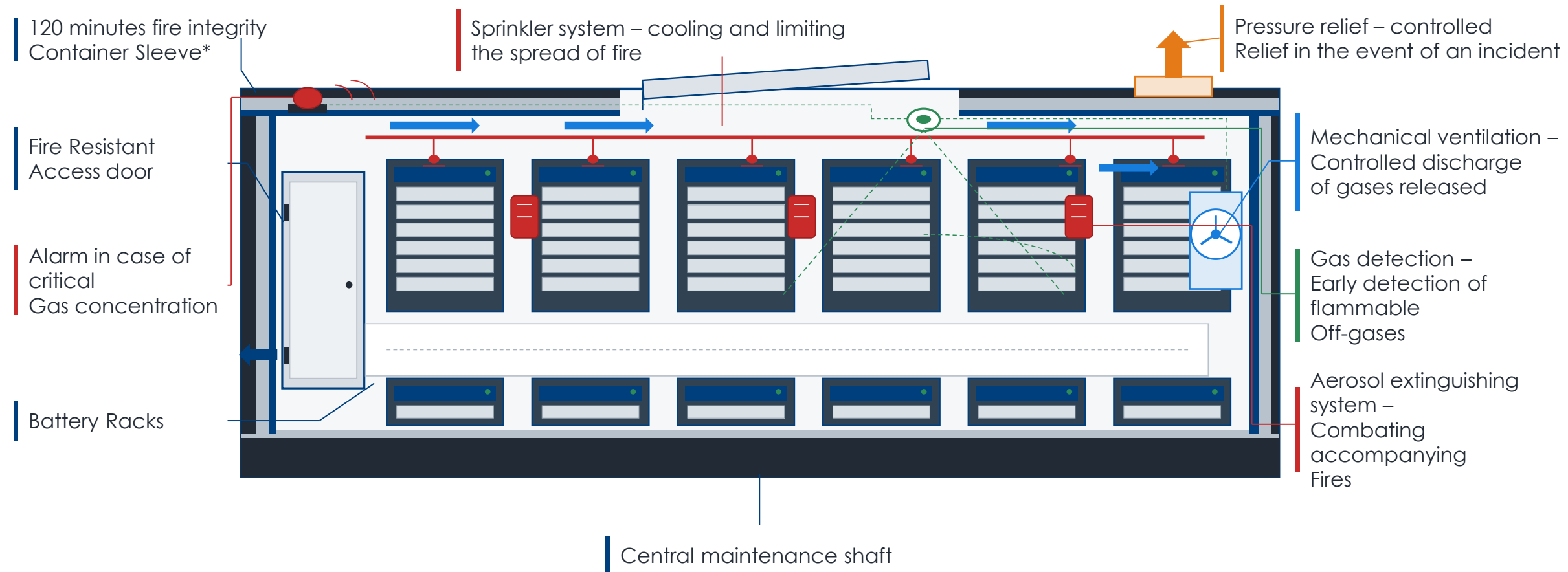
MORE REACTIONS

- Mechanical ventilation / Activate emergency vent
- Cooling capacity Increase
- Preparing for firefighting operations
- Danger zone Lock
- Collect data for future incidents

BMS PROTECTION LOGIC

The BMS detects electrical and thermal anomalies, switches off modules, disconnects the system from the inverter, limits currents, triggers alarms and blocks further operation.

Ideal BESS container design



* Target value; project-specific proof in accordance with fire protection concept, approval and approval required.

Protective measures Outdoor applications



Basically, the following applies:

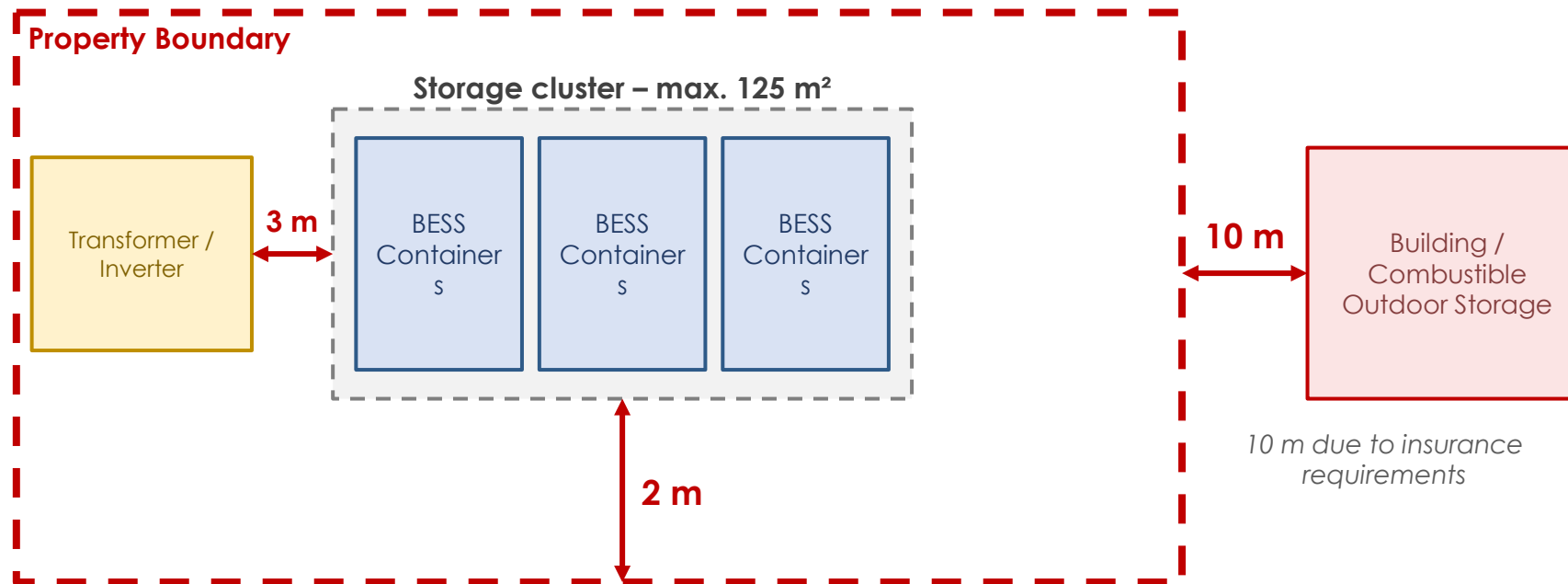
The minimum distance can be determined by a real fire test
according to UL 9540A

Attention: Take other influencing factors into account (e.g. wind).

Minimum requirements despite real fire test:

- 3 m distance to transformer and inverter
- 2 m distance to property line
- Max. 125 m² cluster area
- Distances between containers, other storage clusters and neighboring systems can be significantly reduced or eliminated
- A distance of 10 m from combustible external warehouses and buildings is required due to insurance requirements

Minimum distances with UL 9540A test at a glance

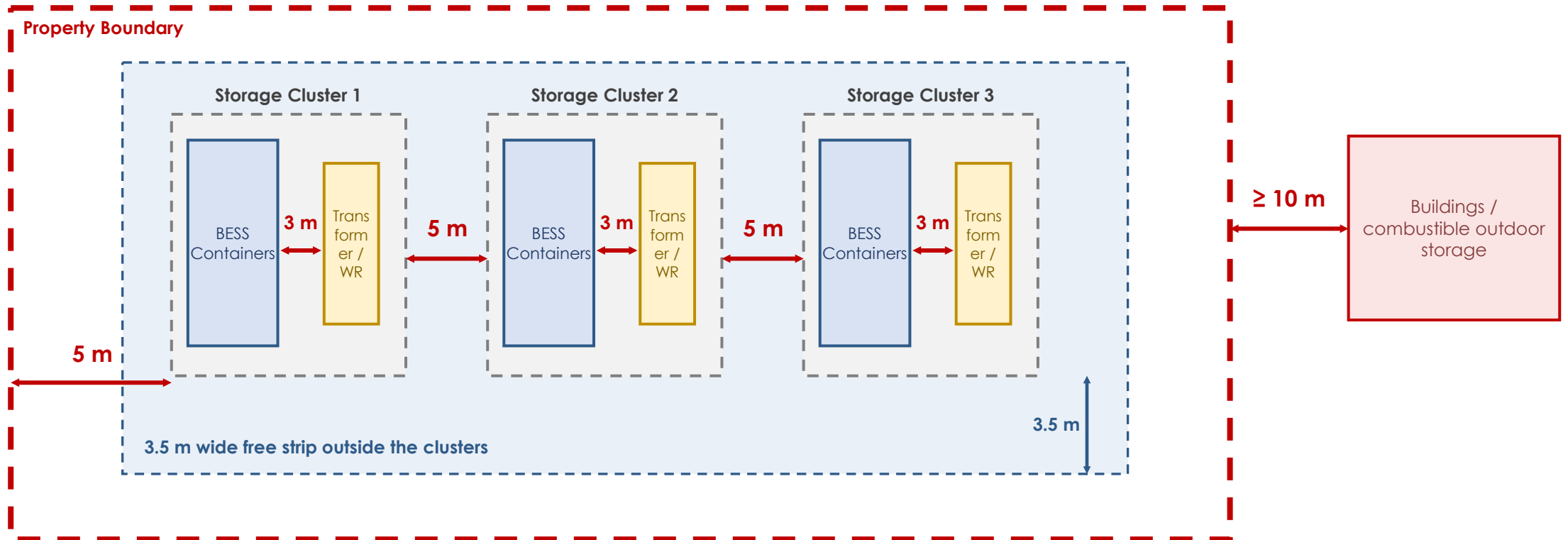


Minimum requirements

- 3 m to transformer and inverter
- 2 m to the property line
- max. 125 m² cluster area
- 10 m to combustible outdoor warehouses and buildings (insurance)

Distances between containers, other storage clusters and neighboring systems can be significantly reduced or eliminated.

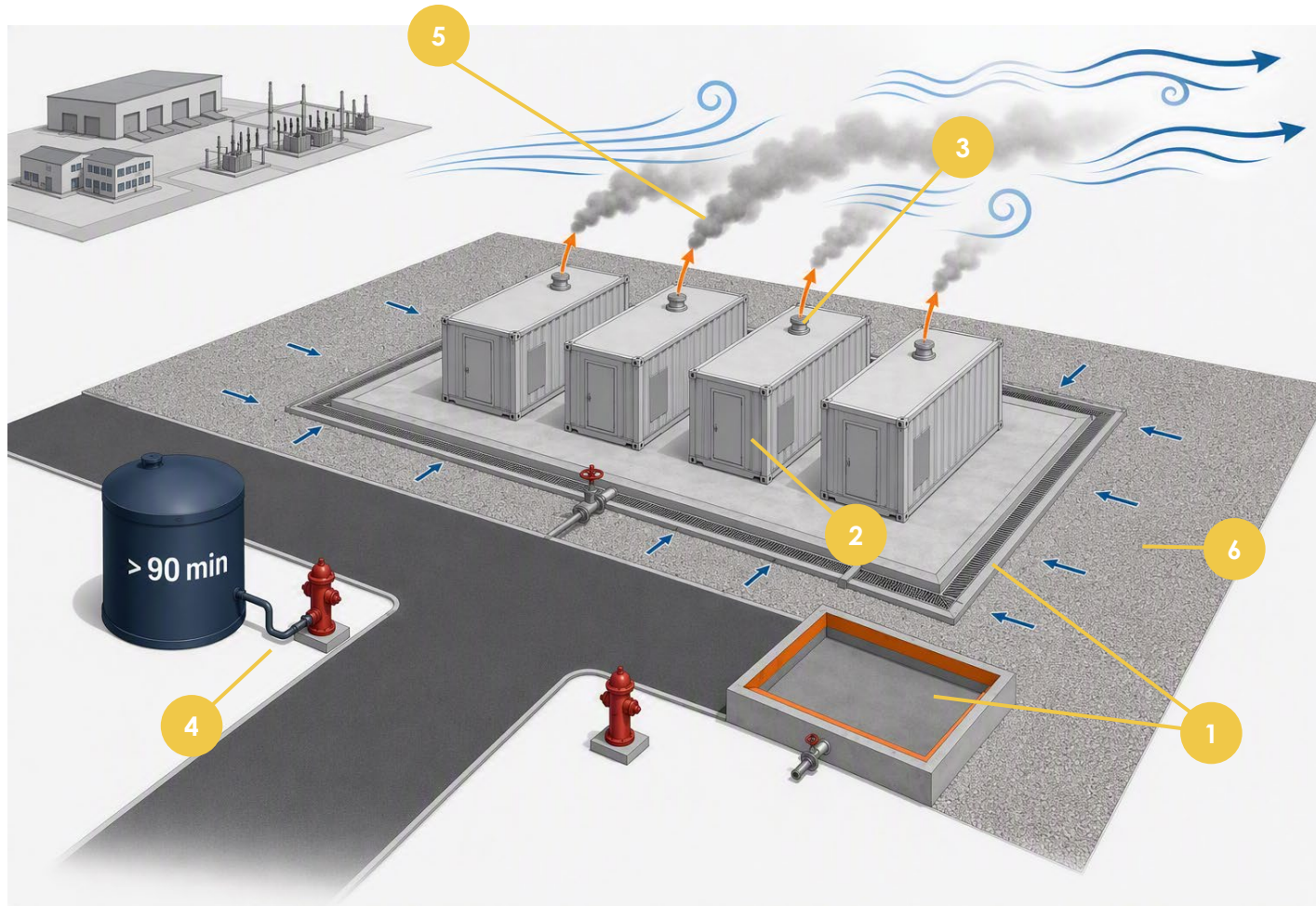
Outdoor installation plan – without fire test



Minimum distances

- 5 m to the property line
- 5 m between clusters
- ≥ 10 m to building / external storage
- **3.5 m wide free strip**
- 3 m to transformer / inverter

Other aspects of BESS outdoor applications



6 OUTDOOR PROTECTIVE MEASURES

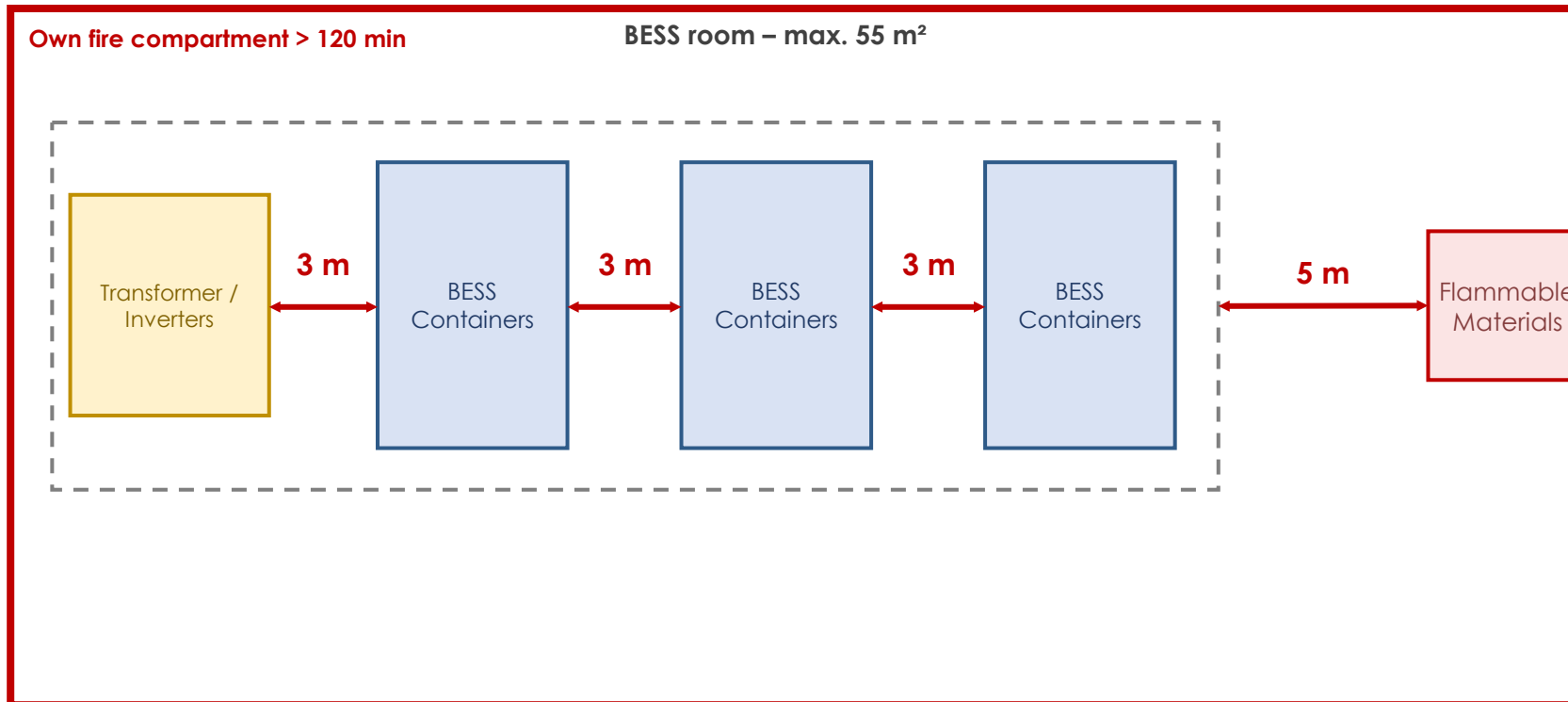
- 1 Extinguishing water retention**
 - Environmental threat from toxic decomposing agents
 - Extinguishing water must drain into gutters in a controlled manner and be collected in basins
- 2 Non-combustible container construction**
 - Shell, roof, doors and supporting structure non-combustible
 - No combustible panels or facades
- 3 Emergency ventilation & pressure relief**
 - Discharge into free, non-hazardous areas
 - Not on technology, buildings or routes
- 4 Fire brigade access & extinguishing water**
 - Free access as well as installation and attack surfaces
 - Supply ≥ 90 min, out of exposure
- 5 Location & Environmental Risks**
 - Assess and take appropriate account of natural hazards at the site
 - Avoid the spread of toxic fire gases into manned areas
- 6 Vegetation & Exposure Protection**
 - Avoid combustible vegetation around the plant
 - Regular maintenance of the plant environment

Orange = protective measure / defined danger zone | Red = inadmissible orientation / exposure

Protective measures Indoor applications



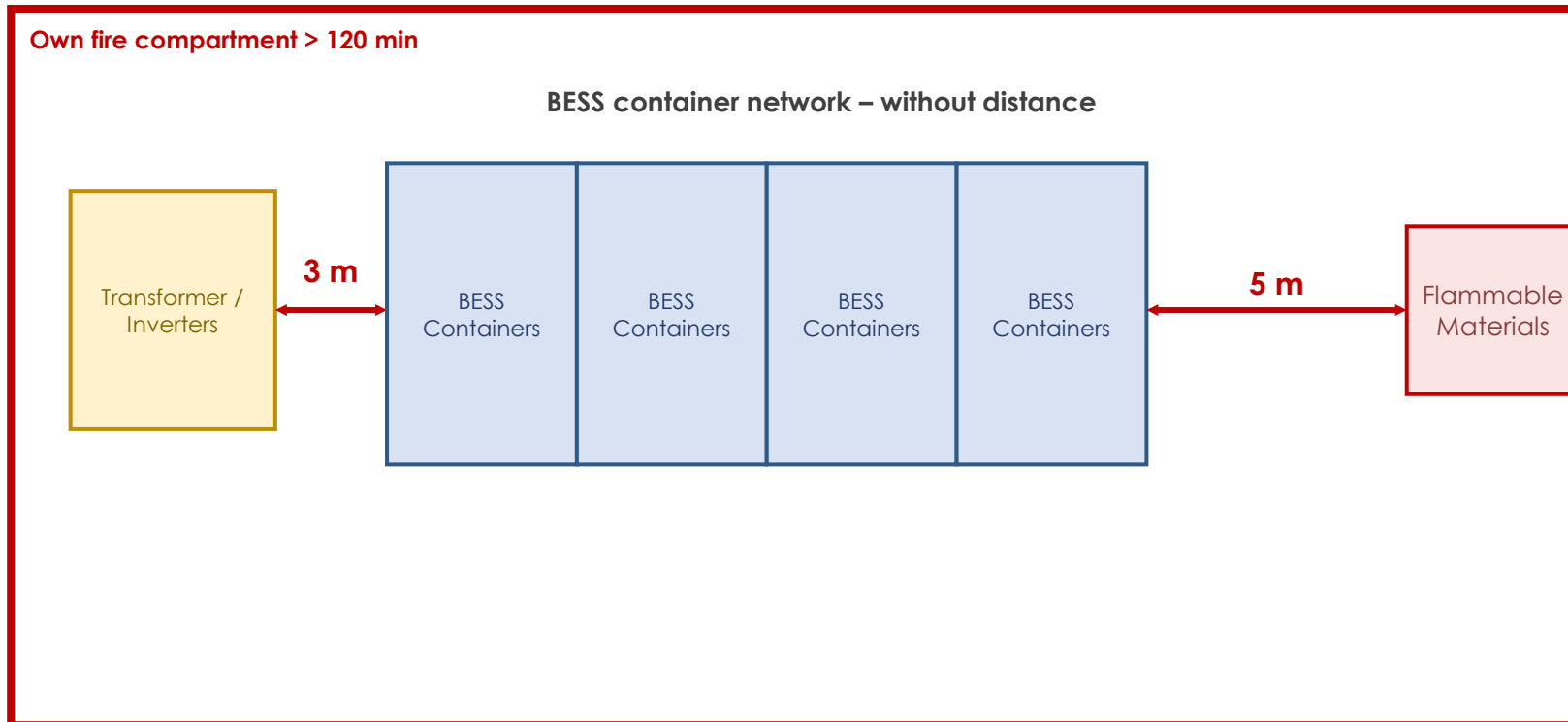
Minimum distances without UL 9540 A test at a glance **riskmind**



Minimum requirements

- 3 m between containers
- 3 m to transformer / inverter
- 5 m to combustible materials
- max. 55 m² room area
- **Own fire compartment > 120 min**

Minimum distances with UL 9540 A test



Minimum requirements

- Containers lined up directly next to each other
- 3 m to transformer / inverter
- 5 m to combustible materials
- **Own fire compartment > 120 min**

Again, the following applies:

If it can be proven by a real fire test according to UL 9540A that the fire does not spread to neighboring systems, distances can be selected as desired.

Restrictions:

- 3 m distance to transformer and inverter
- Installation must be in a suitable separate room
- Insurance companies recommend a maximum room area of 55 m² (unrealistic replacement measures required)
- Distances between containers or neighboring racks can be eliminated

Other aspects

- Set up BESS in a separate, exclusively dedicated room or fire compartment
- Provide fire-resistant walls, ceilings and doors as well as professionally sealed cable and wire penetrations
- Lead emergency ventilation and pressure relief outside in a controlled manner without endangering escape routes, intake openings or manned areas
- Ensure sufficient escape and rescue routes, doors must open in the direction of escape and be able to be opened from the inside at any time
- Restrict access to authorised persons and do not allow additional fire loads or third-party storage in the battery compartment
- Collecting contaminated extinguishing water through dense soils, thresholds and suitable retention facilities
- Enable safe fire brigade access and provide shutdown, system and hazard information at the entrance
- Prevent fire and smoke from being transmitted via ventilation ducts, cable trays or common areas of the building



06 Project presentation

BESS Indoor Protection Concept created by risk on mind

- Project details
- Installation incl. distances
- Protective measures

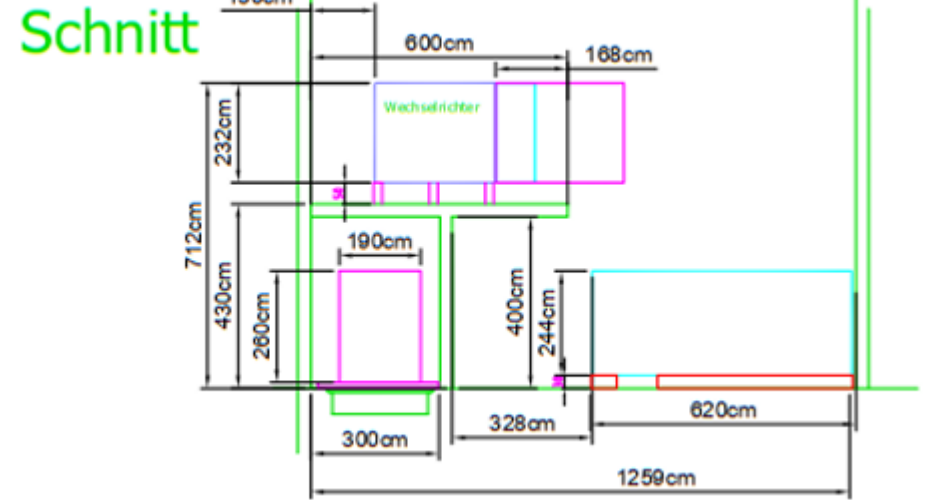
Wood industry - Austria

System used: Gotion GRID 5015

- Lithium Iron Phosphate Technology (LFP / LiFePO_4)
- Prismatic battery cells with a capacity of 314 Ah
- 6 BESS containers
- Storage capacity of approx. 5.015 MWh per container, a total of approx. 30.09 MWh
- Installation within specially designed, continuously monitored technical buildings

Details

- Battery containers and medium- and low-voltage switchgear on the ground floor
- 3 transformers of 5,100 kVA each on the ground floor
- Inverter upstairs
- Distance between transformers and battery containers: 3.6 m
- Room area: approx. 300 m²



Clear roles, resilient alarm channels and prepared intervention

01



Responsibilities

- Fire protection officer and deputy
- Clear responsibilities
- Documented controls

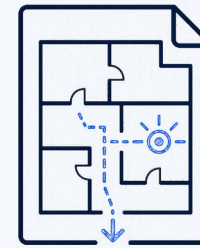
02



Readiness and alerting

- 24/7 technical on-call service
- Defined escalation paths
- Direct alarm transmission

03



Contingency planning

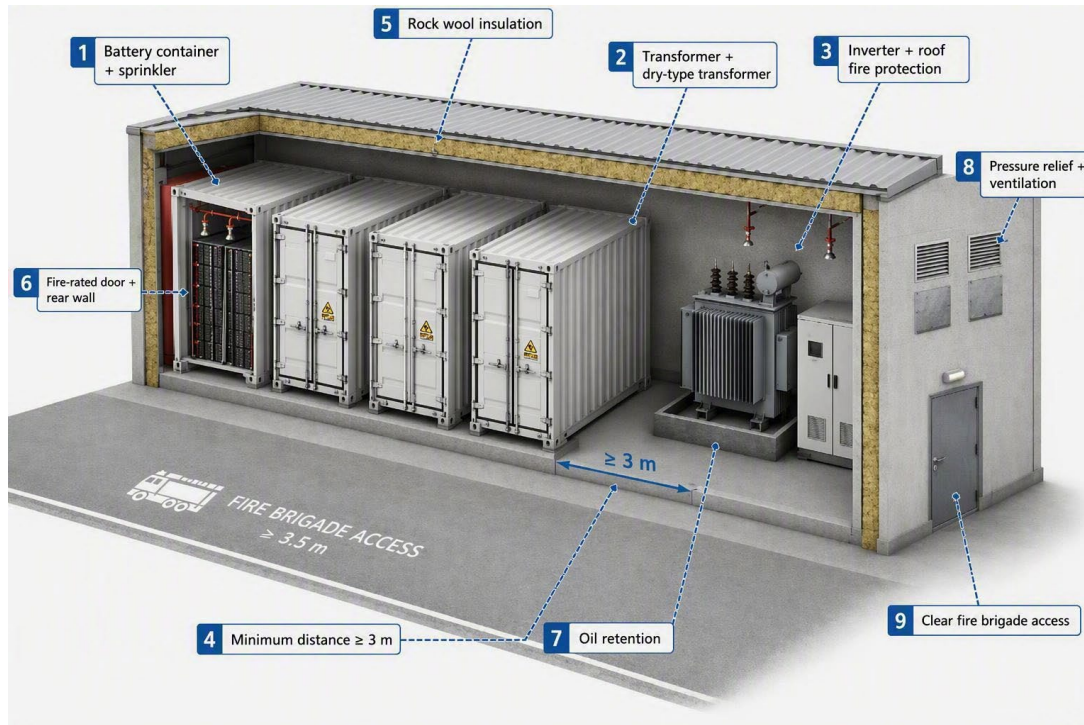
- Fire protection and emergency plans
- Shutdown and isolation points
- Evacuation and access restriction

04



Fire brigade coordination

- Coordination before commissioning
- Site inspections and exercises
- Safe access and intervention areas



Structural protective measures

- Dedicated technical building
- Rock wool insulation
- Tested doors and rear walls > 2 h
- Functional separation of the plant components
- Minimum distance to transformers ≥ 3 m
- Oil and extinguishing water retention

Deviations from the recommended room size (55m²) are compensated by:

- Fully enclosed, factory-built containers as separately monitored and independently controlled units
- Container-specific detection, electrical isolation, pack cooling, aerosol suppression and controlled ventilation
- Separate technical building without external production or storage of flammable materials
- Additional building protection measures such as fire detection, sprinkler protection, emergency ventilation, direct alarm transmission and fire brigade access

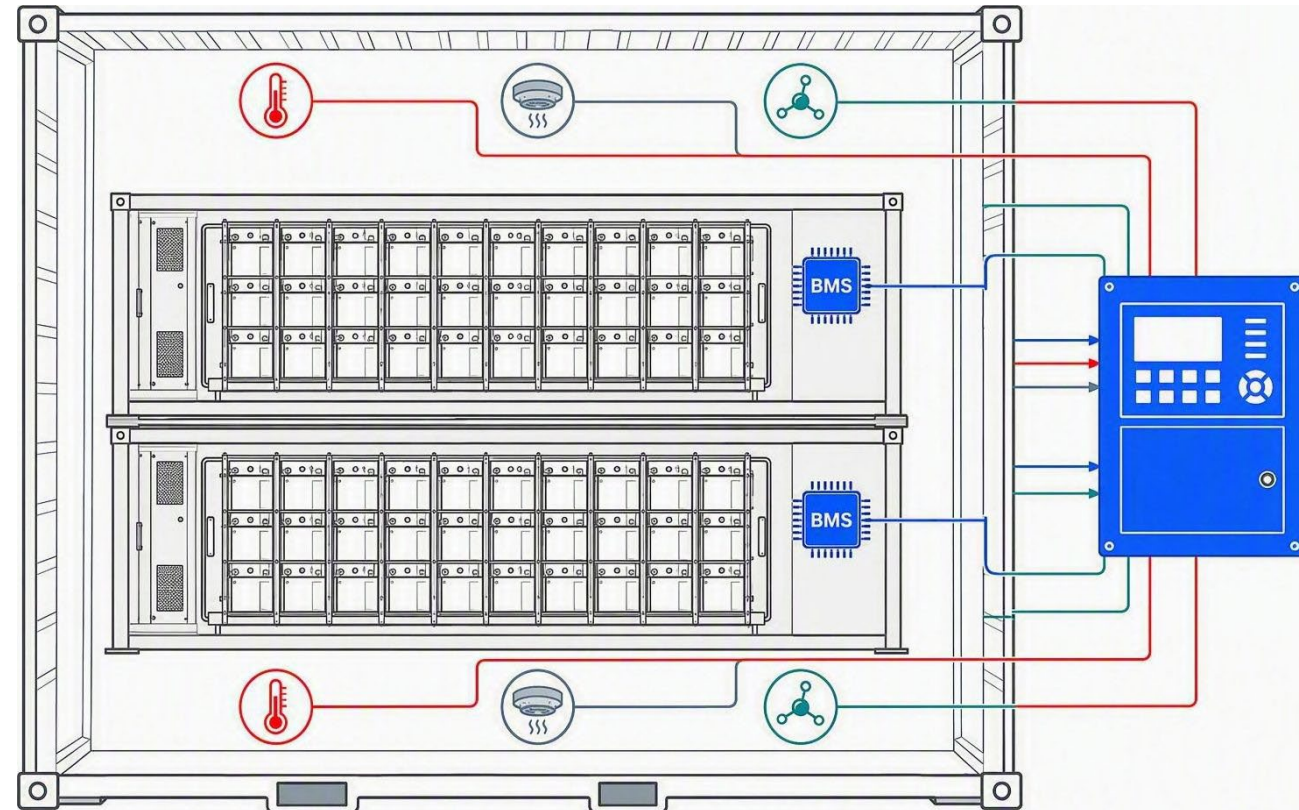
Early detection and alerting

Built-in detection systems

- 2 temperature detectors per battery container
- 2 smoke detectors per battery container
- 2 Li-ion Tamer off-gas detectors per battery container
- Additional temperature monitoring at cell, pack and rack level by the BMS
- Local visual and audible alarms
- Transmission of alarm and fault messages to fire detection and monitoring systems

Multi-level evaluation logic

- One detector: first alert level
- Two different types of detectors: confirmed second alarm level
- Off-gas detection enables a warning even before conventional smoke detection
- Depending on the scenario, confirmed events lead to shutdown, isolation and activation of further protection systems
- Faults in detectors, communication or power supply are also monitored and reported



Ventilation, smoke and explosion protection

Container ventilation

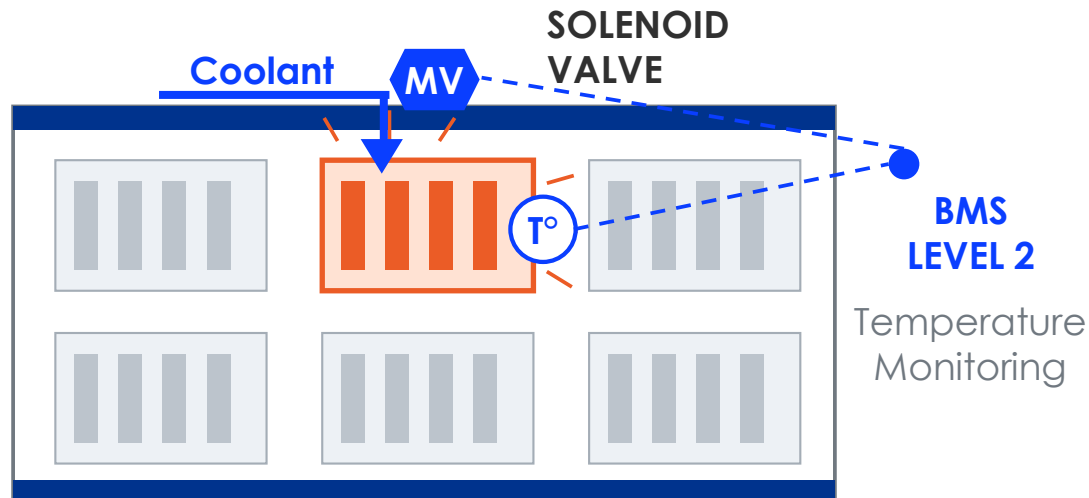
- Separate ventilation for each battery container, independent of the building
- Motorized supply and exhaust air flaps
- Explosion-proof exhaust fan with a maximum of 820 CFM
- Automatic activation after off-gas detection; pressure relief limits critical overpressure

Building and emergency ventilation

- Fresh air supply at low level and exhaust air ducting via high openings
- Directed air flow from bottom to top to dissipate heat, smoke and gases
- Automatic emergency ventilation at 10% LEL or at 80°C after activating pack cooling
- At least 30 air changes per hour, projected are about 57 to 60 air changes per hour
- Two redundant fresh air fans with five hours of backup power
- Automatic fault notification and electrical isolation in the event of emergency ventilation failure during an off-gas event

Pack Direct Cooling

DIRECT COOLING ON THE AFFECTED PACK



SYSTEM PARAMETERS

7.3–7.5 l

Coolant
per pack

50/50

Glycol Water
Mixture

15 min

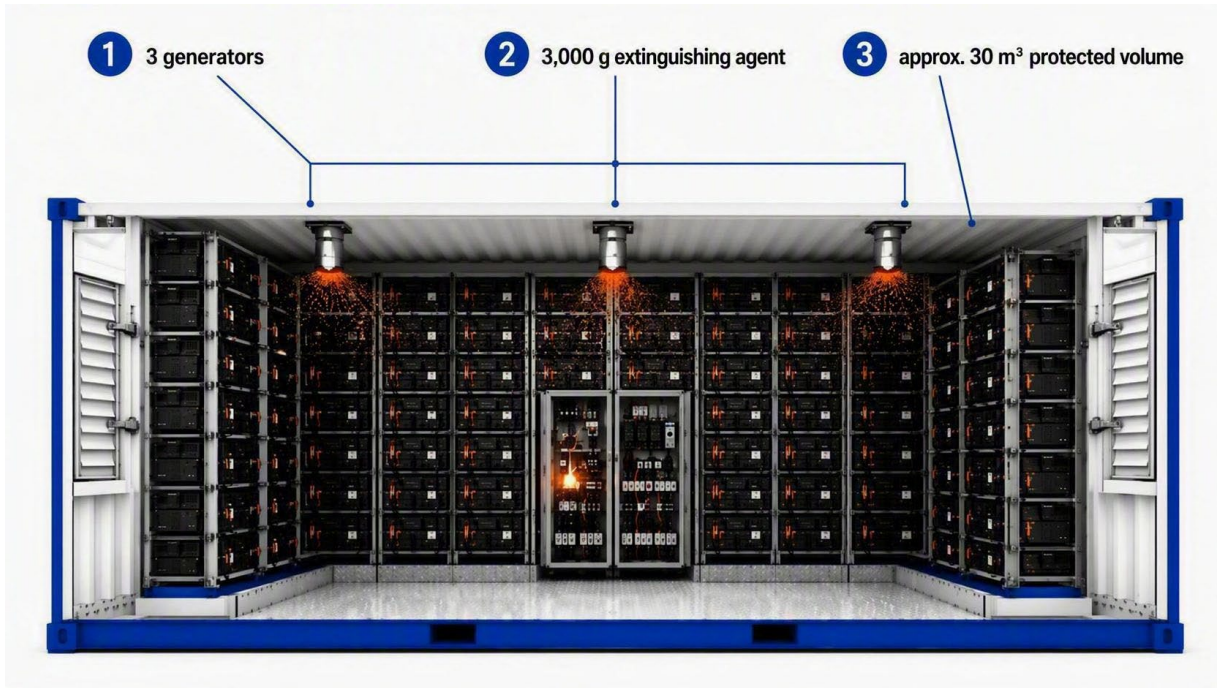
Valve
opening duration

PROTECTIVE EFFECT

- Targeted cooling at the point of origin
- Delay of thermal escalation
- Limitation of possible cell propagation
- **In the absence of stabilization: escalation to further protective measures**

- 1 Thermal Runaway Criteria recognized**
- 2 Level 2 BMS opens Solenoid valve**
- 3 Coolant is injected into the affected pack**
- 4 Direct heat extraction and further monitoring**

Aerosol extinguishing system



1. Confirm fire

- Defined fire criteria met
- Alarm is transmitted

2. Secure the system

- Shutdown and electrical isolation
- Stop ventilation and close flaps

3. Release aerosol

- Triggering after defined delay
- Fast distribution in the container

4. Follow up on the event

- Container access remains blocked
- Atmospheric testing and controlled post-aeration
- Replacement of the triggered generators

Water spray deluge system



PRINCIPLE OF ACTION

Water is primarily used for external cooling and limitation of thermal propagation.

Not a stand-alone measure for stopping thermal runaway.

Execution

- Standalone pre-action water protection system for each battery container
- 12 water spray nozzles per container
- Design volume flow of 81 l/min per nozzle
- Total water capacity of 972 l/min per activated container
- Manual triggering also possible from a safe location

Activation logic

- The water is only released after the event has been confirmed by the defined multi-criteria logic:
 - Smoke detection
 - Battery cell temperature above 80 °C
 - Container temperature of 93 °C

Early warning	TRIGGER RESPONSE	Rack temperature 45 °C for 3 seconds Alarm level 3, operator is notified immediately.
Protection Shutdown	TRIGGER REACTION	Rack temperature 55 °C for 3 seconds Loading/unloading is blocked; PCS shutdown via potential-free contact.
Critical Isolation	TRIGGER REACTION	Rack temperature 60 °C for 3 seconds Alarm level 1, loading/unloading is blocked; PCS shutdown; Open the main switch and rack contactors.
Temperature rise	TRIGGER REACTION	Cell temperature rises by ≥ 1 °C within 1 second BMS temperature rise alarm and escalation logic.
Thermal Runaway Detection	TRIGGER REACTION	Rack High Temperature Alarm + ≥ 2 Sensors in a Pack $> 80^{\circ}\text{C}$ + Temperature Rise Alarm Coolant valve of the affected pack opens for 15 minutes, automatic system isolation.
A single fire alarm	TRIGGER REACTION	Smoke, temperature or off-gas detectors Fire alarm level 1, off-gas detection also activates ventilation.
Any two detector types	TRIGGER REACTION	Two different types of detectors Confirmed fire alarm level 2, immediate electrical isolation, container ventilation stops, dampers close, aerosol extinguishing after 30 seconds, building ventilation switches to released fire mode.
Leakage or major fire signal	TRIGGER REACTION	Leakage signal or potential-free contact "major fire" Automatic shut-off and electrical isolation.
Confirmed transformer or inverter fire	TRIGGER REACTION	Smoke detector alarm + confirmed heat detection in the affected area Temperature rise to $> 93^{\circ}\text{C}$ Immediate shutdown and isolation of the affected areas; alarm transmission; deluge system activation with a maximum delay of 30 s.

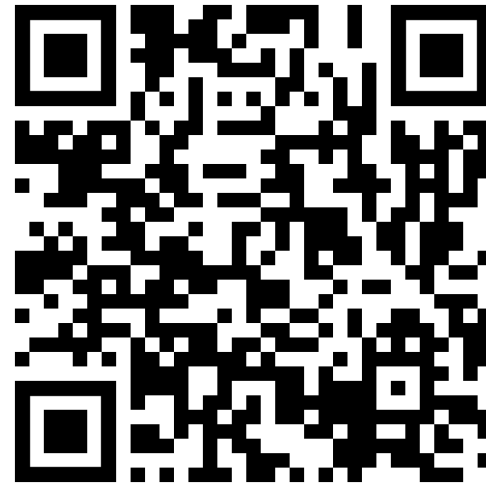


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