Hazard Mitigation Analysis of Energy Storage Systems

PROCESS SAFETY CONGRESS DORDRECHT | 15 MAY 2024

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Source photo: Google search for Tesla Megapack ESS station fire in Victoria, Australia

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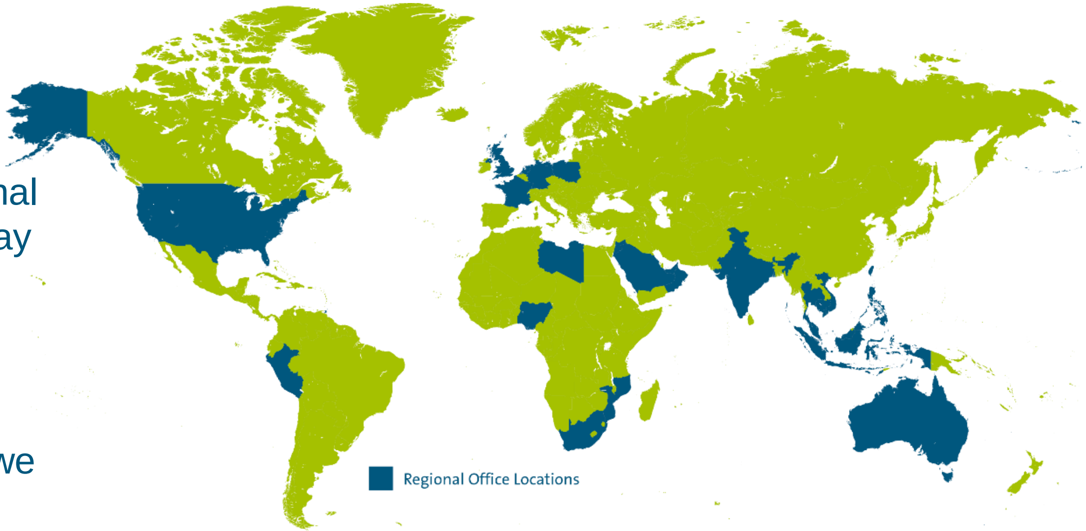

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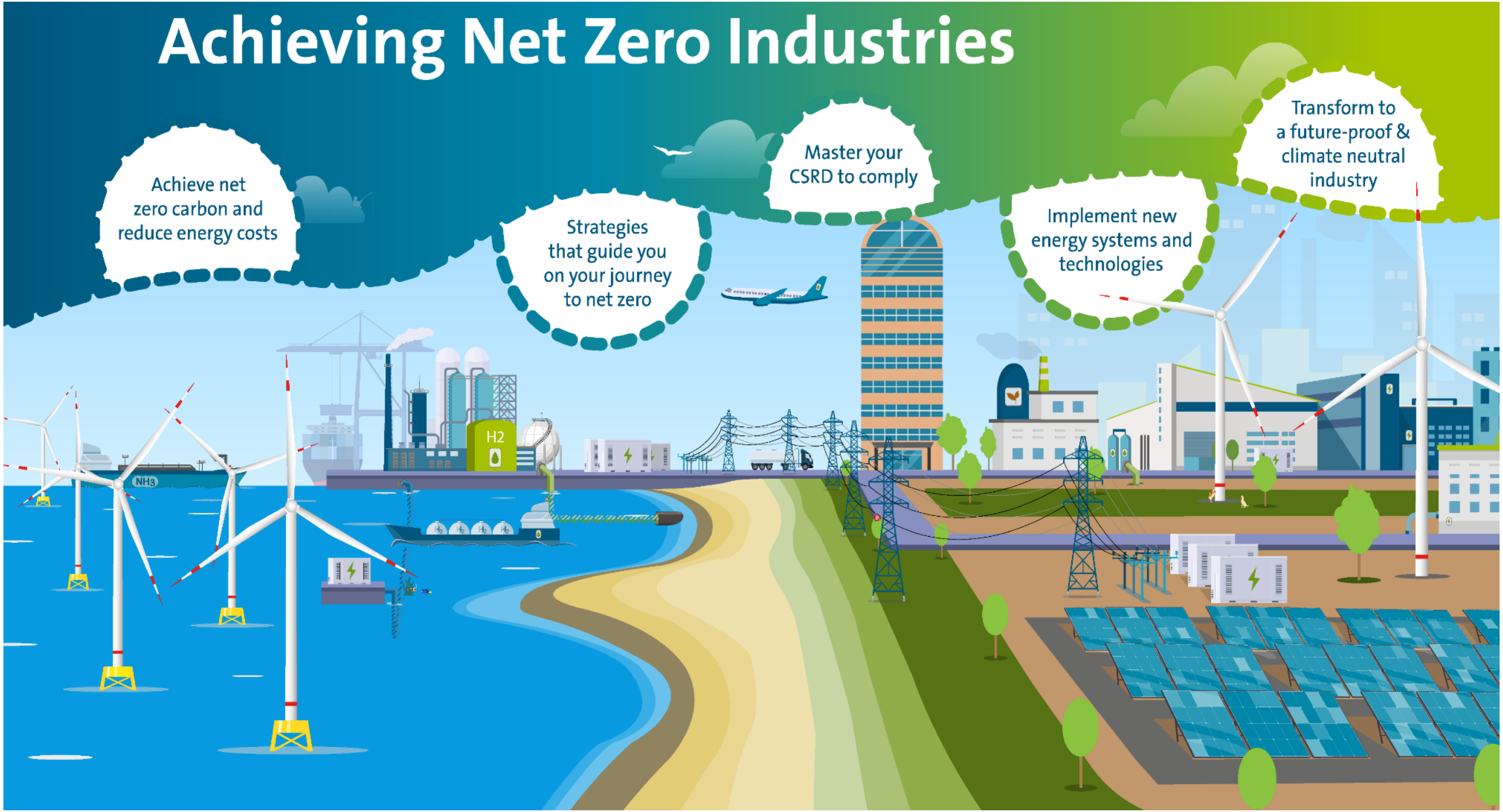
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BESS* is quite a "hot topic" in the energy transition

Outline of this presentation

- Results from our study on ESS technologies
- Structure of a BESS Station
- EU Regulation Concerning BESS
- Hazard Identification & Mitigation Analysis
- Safety Barriers for BESS
- Key Takeaways
- Q&A

***BESS: Battery Energy Storage System**

Source: *Orchid Power Plant energy storage battery short circuit fire | Joint AV (udn.com)*

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Results from our study on ESS technologies

Project by RHDHV for NL ministry I&W

Analysis I: Technique	Feasibility of various (developing) BESS technologies for the Netherlands
Analysis II: Safety	Applicable safety studies and identification of relevant hazards and safety barriers
Analysis III: Relevant regulation	Overview of the governing regulations for BESS in NL & EU

Longlist of ESS Technologies Currently in Development

- Li-ion LPF
- Li-ion NMC
- Solid state Li-ion
- Solid state Na-ion
- Vanadium redox flow
- Zn-Br redox flow
- Molten sodium
- Na-ion
- Al-ion
- Iron oxide
- Ni-Cd
- Ni-MH
- Hydrogen
- Compressed Air (CAES)
- Liquid Air (LAES)
- Flywheel
- Saltwater
- etc.

Report is available at kamerbrief "Voortgang strategische aanpak batterijen 2023"

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ESS Techniques having High Technical Feasibility

BESS technology	BESS type	Application*	Development Phase
Li-ion	Cell based	1,2,3,4,5	Commercially dominant
Molten sodium	Cell based	1,2,3,4	Commercial pilots available
Na-ion	Cell based	1,2,3	Commercial pilots available
Hydrogen	Electrolysis	1,2,3	Commercial pilots available
Vanadium Redox	Redox flow	1,2,3	Commercial pilots available
Zi-Br Redox	Redox flow	1,2,3	Commercial pilots available
Solid state	Cell based	1,2,3,4,5	Research & laboratory scale
Iron oxide	Redox flow	1	Research & laboratory scale

** Feasibility based on technical analysis:*

1. *Solar & wind parks*
2. *(Existing) Industrial terrain*
3. *Terminal Port*
4. *Residential*
5. *Residential in-building*

Report is available at kamerbrief "Voortgang strategische aanpak batterijen 2023"

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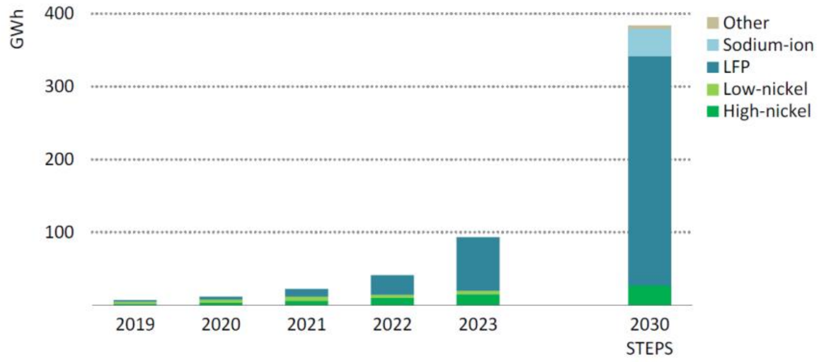
The outlook for battery chemistries

- Lithium-iron phosphate (LFP) has become the technology of choice
- Significant growth is expected for LFP batteries due to advantages over other technologies:
  - Higher thermal stability
  - Lower costs
  - Higher cycle lives
- Sodium-ion is the second choice, and shares many similarities with Li-ion

Figure 2.17 ▹ **Battery storage capacity additions in GWh by cathode chemistry, 2019-2023, and 2030 in the STEPS**



LFP is set to continue to dominate the battery storage market, with sodium-ion starting to make inroads towards 2030

Note: LFP = lithium-iron phosphate.

Source: IEA report "Batteries and Secure Energy Transitions"

Other: redox flow, iron air, etc.

BESS Stations – what they can look like in practice

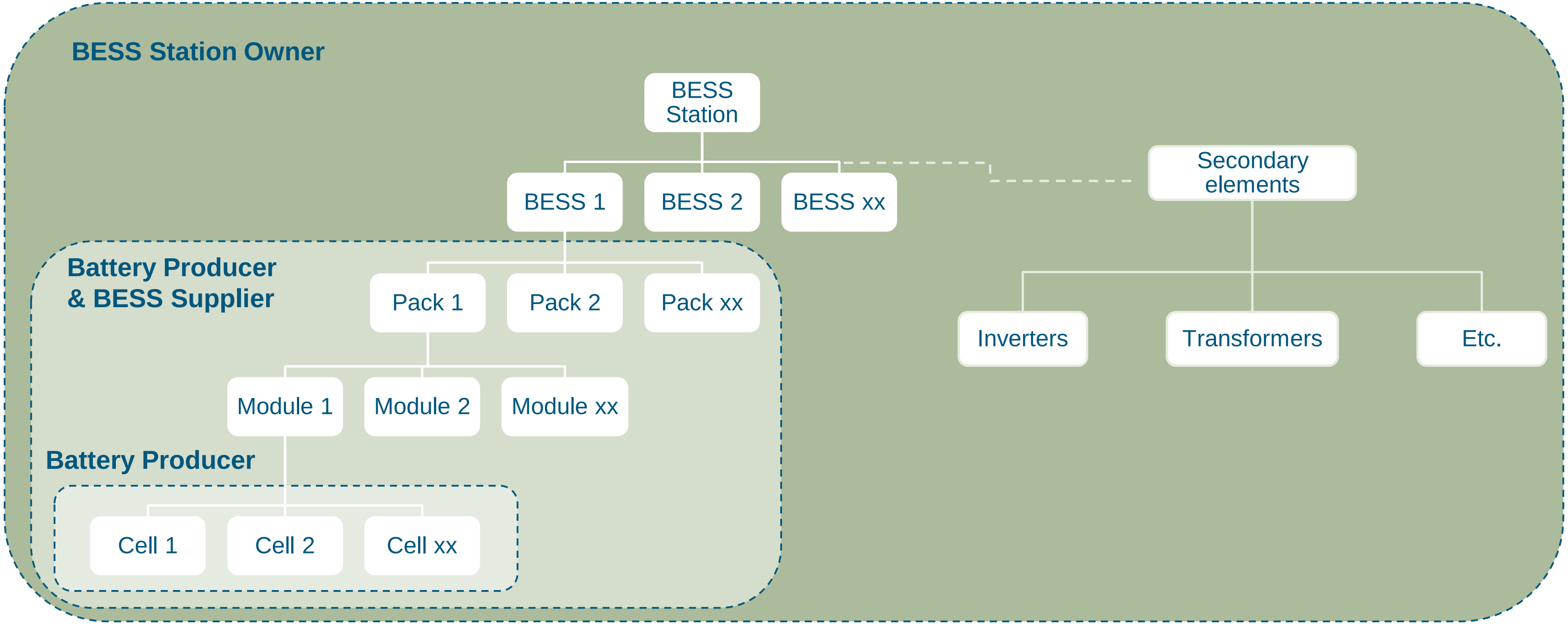
- Capacities ranging from kWh to MWh
- Mostly modular set-up
- For large capacities standard commercial container footprints are mostly used

Battery Pack

Battery Module

Source(s): Google search results on Moss landing energy storage

BESS Station – its functional structure and ownership



Examples of BESS incidents

Source: [“Tesla battery on fire at Bouldercombe energy storage site, Genex confirms”]

Source: ["Crews battle Tesla battery fire at Moorabool, near Geelong"]

Source: [Carnegie road energy storage system failure response, recovery, and rebuild lessons learned, EPRI White Paper]

European Battery Regulation (EU) 2023/1542

“Stationary battery energy storage systems placed on the market or put into service shall be safe during their normal operation and use.”

A technical documentation shall be developed for BESS:

I. Demonstration of **compliance** via successful testing for specified **safety parameters** (incl. possible extra).

II. Include evidence of **successful mitigation and testing** of such hazards.

III. Include **mitigation instructions** in case of such hazards (e.g. fire or explosion).

Examples of specified Safety Parameters:

- External/ internal short circuit protection
- Over-(dis)charge protection
- Thermal propagation protection
- Mechanical damage
- Thermal abuse
- Fire test
- Emission of gases

Currently, not a single standard covers all the safety tests

Source: REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023

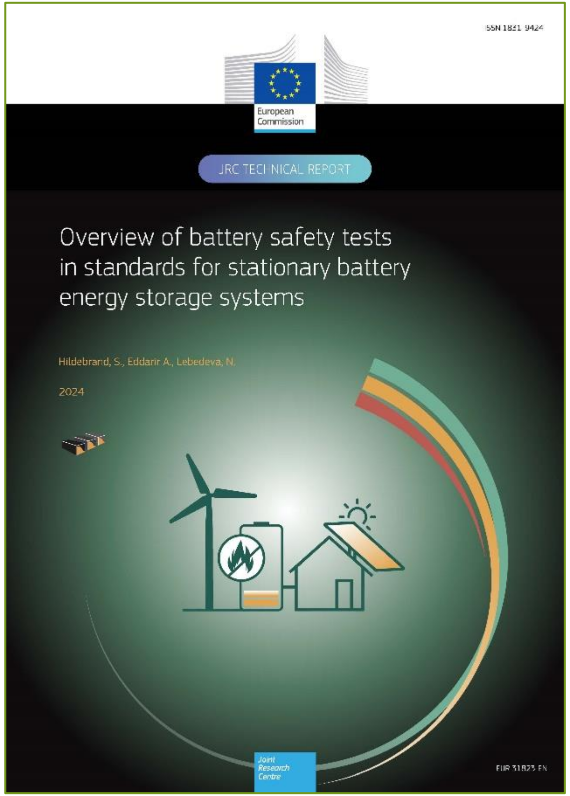
Safety Standards Currently Available for BESS

Examples of existing standards (applicable for Lithium-ion BESS):

- IEC 62619
- IEC 63056
- UL 9540A
- UL 1973
- UL 1642
- GB 40165
- GB 40165
- VDE-AR-E 2510-50

Standards exist for every test, required in the EU Battery Regulation 2023/1542, but they have significant differences.

These differences can have an **impact on the outcome of the test** when following different standards.



Source: Overview of battery safety tests in standards for stationary battery energy storage systems

"The process safety problem"

There has been progress in achieving inherently safer processes, based on the experience with existing materials, equipment, and processes over the past years.

But with new concepts, designs, and materials, building-up experience may have to start all over.

Source: Pasman, H., Sripaul, E., Khan, F., & Fabiano, B. (2023). Energy transition technology comes with new process safety challenges and risks. Process Safety and Environmental Protection, 177, 765-794.

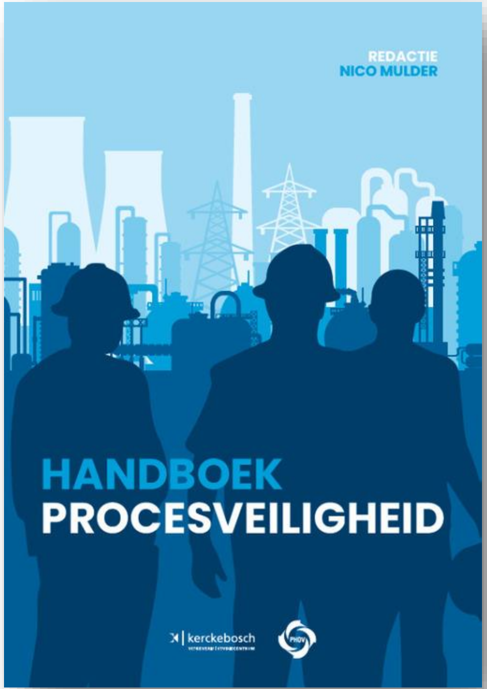
Which existing analysis methods can be suitable for BESS?

The process safety toolbox contains numerous techniques.
Common examples:

Qualitative	Semi-Qualitative	Quantitative
HAZID SWIFT HAZOP FMEA Bowtie FEHA Event tree Fault tree	LOPA SIL	QRA Event tree Fault tree

Factors that influence the choice of suitable methods:

- Type & contents of the system
- Complexity of the system & processes
- Existing regulatory frameworks & prescriptive requirements

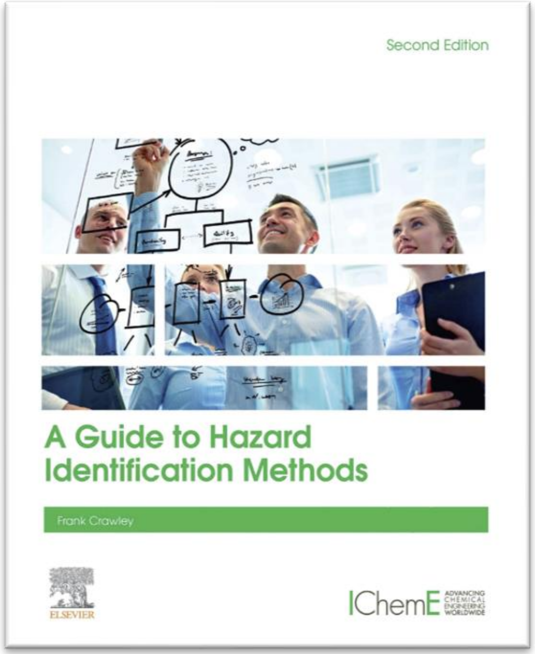


Source: Mulder, Nico, et al., eds. Hanboek Procesveiligheid. Kerkebosch, 2022.

Hazard Mitigation Analysis Methods

- As process safety professionals, we should not only look at the batteries, but at the whole installation. The suitable analysis techniques are:

Method	Applicability as described in guidance books
FEHA	Useful to determine “the location, size, and duration of potential fires [and explosions], and is based upon the fire protection philosophy/strategy, preliminary plot plan”, etc.
Fault tree	"useful in identifying **root causes of a major hazard that has already been identified** and which would occur under quite complex conditions"
Event tree	"is well suited to the analysis of complex processes having **several layers of safety systems in places** to respond to a specific initiating event”
BowTie	"are a visual representation for a hazardous event of the **sequence form initiating causes to a range of consequences"**



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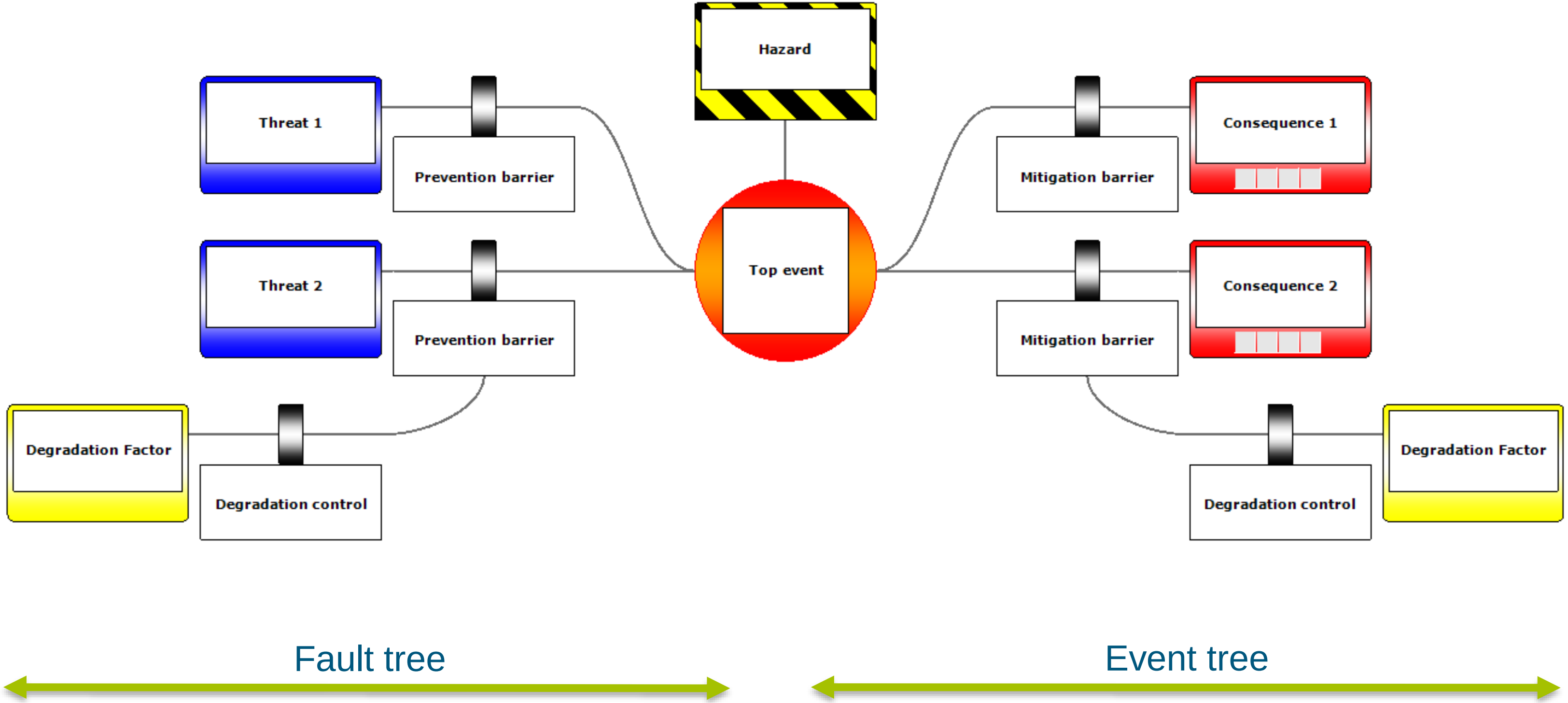
BowTie Diagram - Generic Set-up



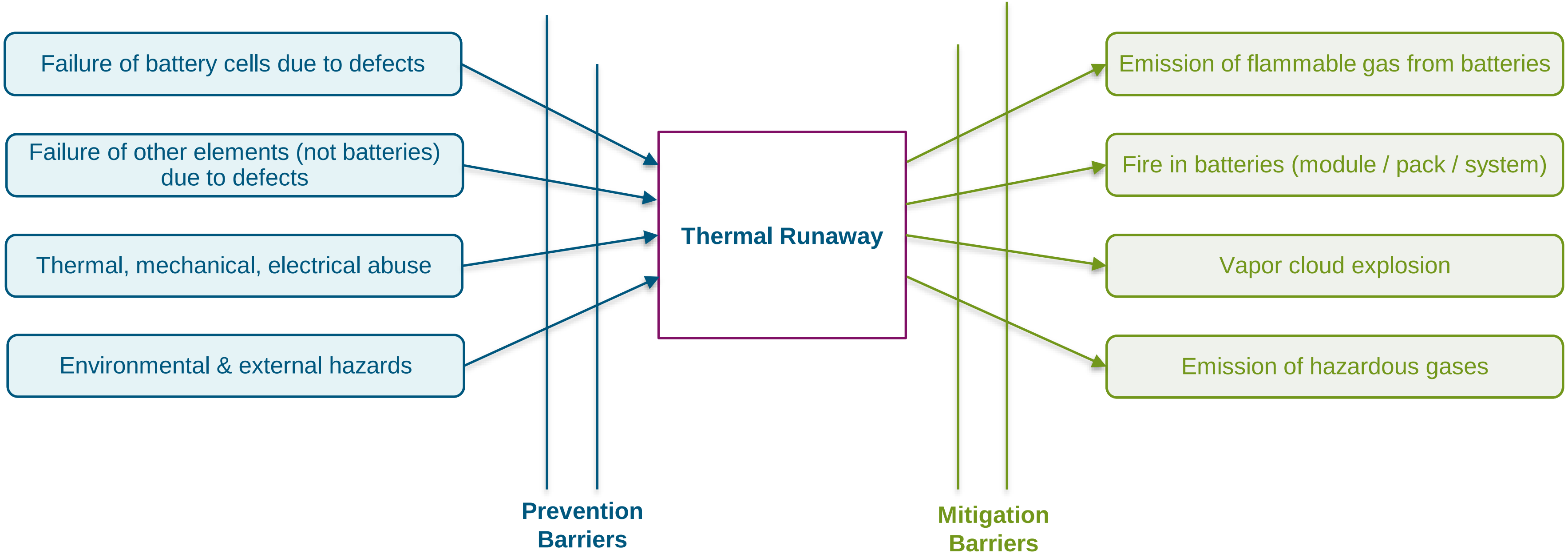
Thermal Runaway vs. Fire

Thermal Runaway off-gas from a battery module

Fire in a battery module

Source(s): Videos from battery fire test at RISE research institute

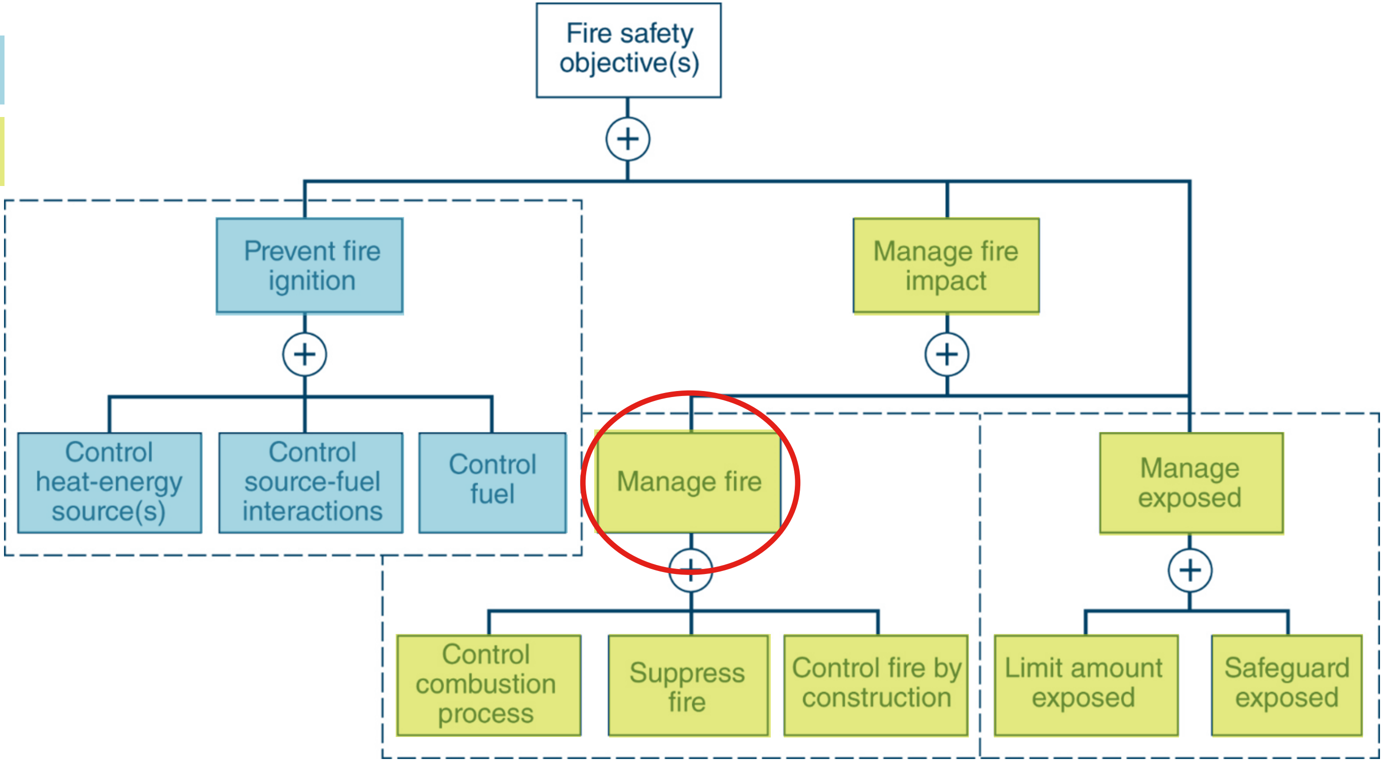
Primary LOC, threats and consequences for Li-ion BESS



Fire Safety Objectives Flowchart

Prevention barriers

Mitigation barriers

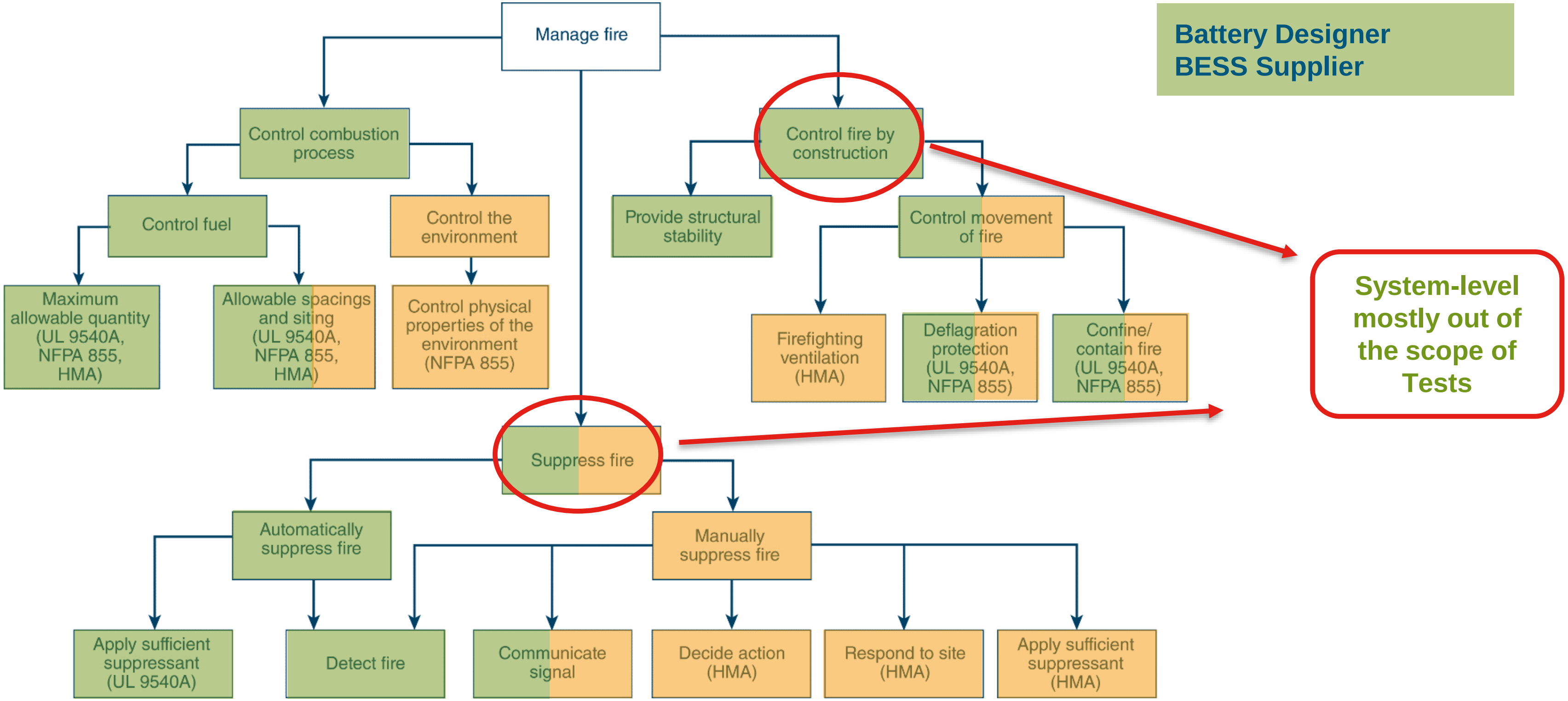


Source: NFPA 550 Guide to the Fire Safety Concepts Tree

BESS Fire Management Flowchart

BESS Owner
Emergency Response Organisation

Battery Designer
BESS Supplier



Source: NFPA 855 Standard for the Installation of Stationary Energy Storage Systems

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Key Takeaways

- BESS are here to stay, but pose inherent risks of fire incidents
- Need for adopting a system approach for assessment of BESS settings
- Current test standards mostly do not address the whole BESS, but rather stop at battery module or battery pack level
- Current test standards mostly do not include system level barriers such as a fire suppression or ventilation system
- Hazard Identification and Mitigation Analysis should not only be based on BESS parameters, but should consider the whole installation
- Need for uniformity in methods for analysis and assessment
- FEHA, Bowtie, Fault-tree & Event-tree as suitable methods
- Managing a potential BESS fire is not entirely up to the BESS designer/ supplier or BESS owner

Q&A

Thank you for your attention!

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