Evaluating Hazards and Risk Mitigation for Utility-Scale Lithium-Ion Battery Energy Storage Systems

Karli Steranka

SFPE Foundation Webinar

06/29/26

Outline

- Project overview and scope
- Risk framework
- BESS hazard definition and quantification
- Industrial vs BESS hazard case study
- BESS hazard reduction strategies
- Risk framework application and conclusions

Project Overview and Scope

Project Motivation

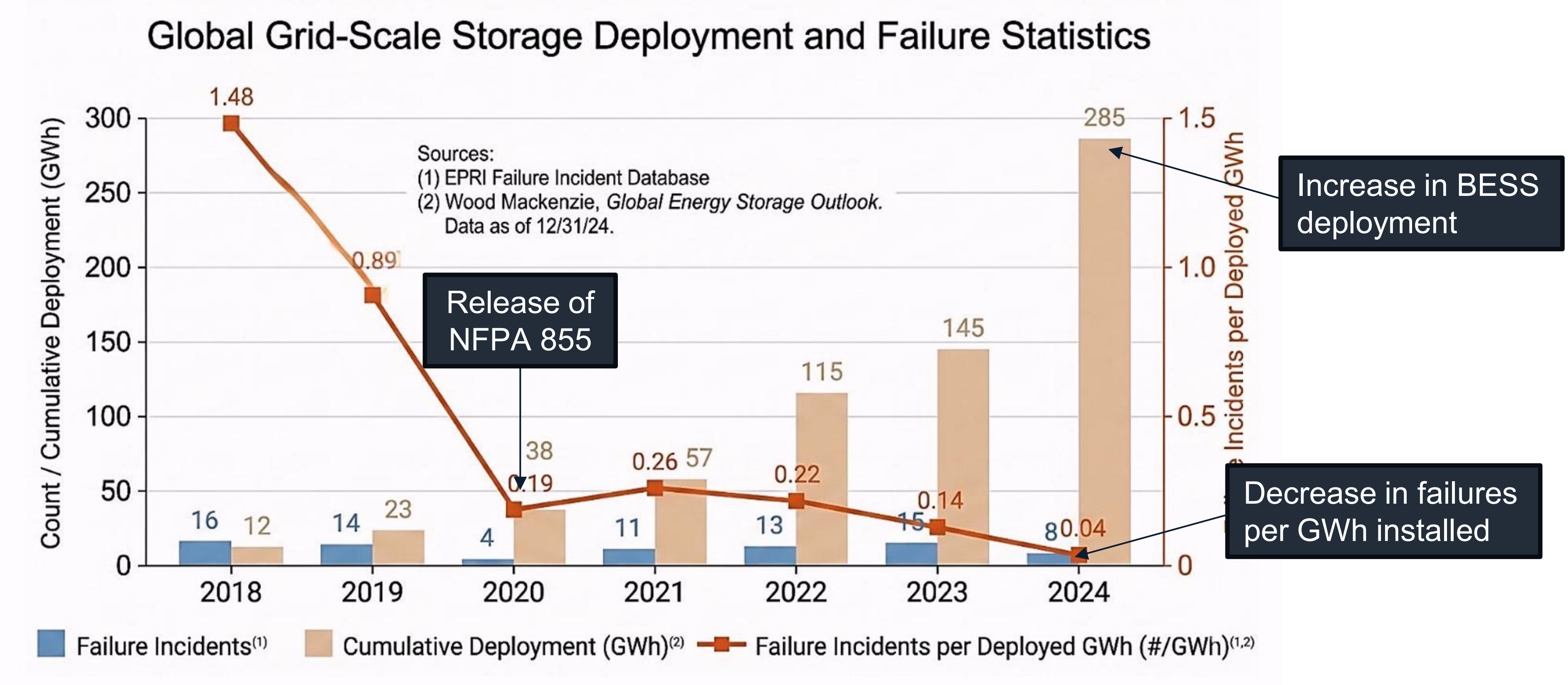
Grand Challenges In

Energy & Infrastructure:

A 10-Year Plan for Strategic Cooperation in Research and Education to Advance Fire Engineering

July 2023

Project Motivation



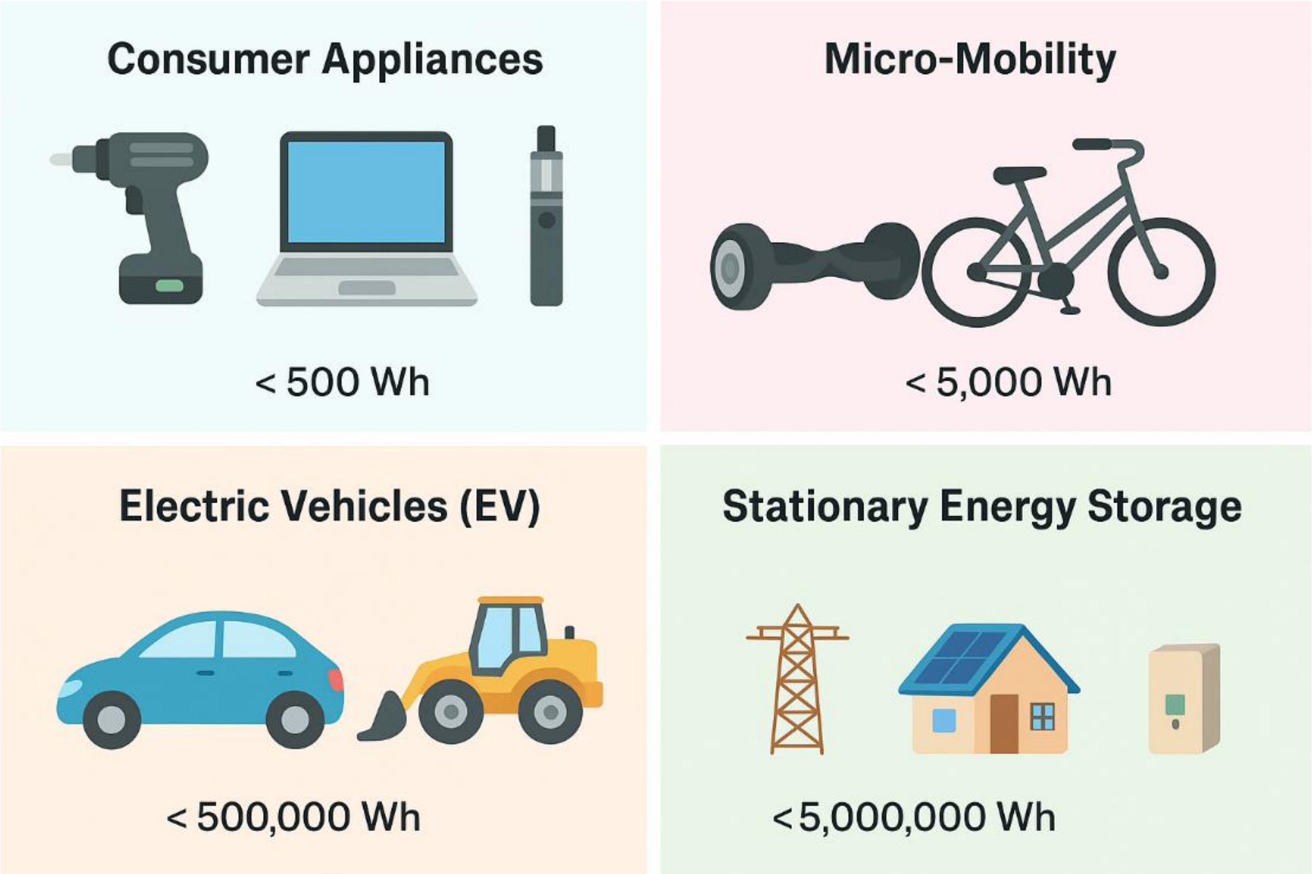
Project Motivation

Each card shows the incident name, confirmed date, and number of news articles identified

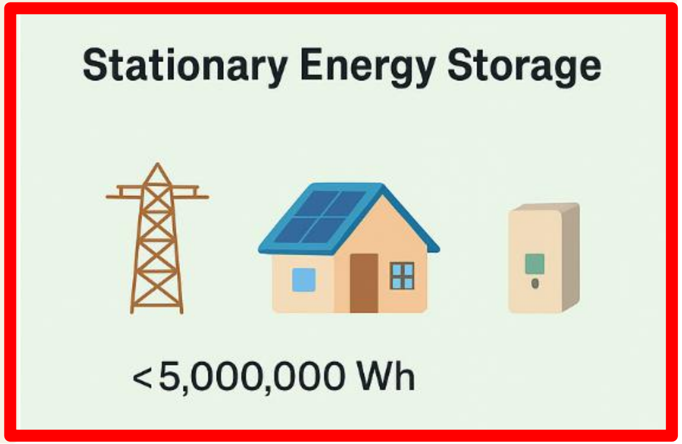
Incident	Date	News articles
McMicken BESS Explosion	19 Apr 2019	7
Victorian Big Battery Fire	30 Jul 2021	5
Moss Landing Thermal Events	Sep 2021–Feb 2022	4
East Hampton BESS Fire	31 May 2023	4
Warwick BESS Fires (×2 sites)	26–27 Jun 2023	5
Chaumont / Lyme BESS Fire	27 Jul 2023	7
Otay Mesa BESS Fire (Gateway)	15 May 2024	4
Escondido BESS Fire (SDG&E)	5 Sep 2024	2
Moss Landing Major Fire	16 Jan 2025	9
Parkfield / CA Flats BESS Fire	30 Aug 2025	5
Boulder City BESS Fire	23–24 Sep 2025	5
Glendale–Peoria BESS Fire	1 Oct 2025	6
Warwick Church St BESS Fire	19 Dec 2025	6

7+ publications (high)   5–6 publications (moderate)   2–4 publications (lower)

Lithium-ion Battery Applications



Lithium-ion Battery Applications



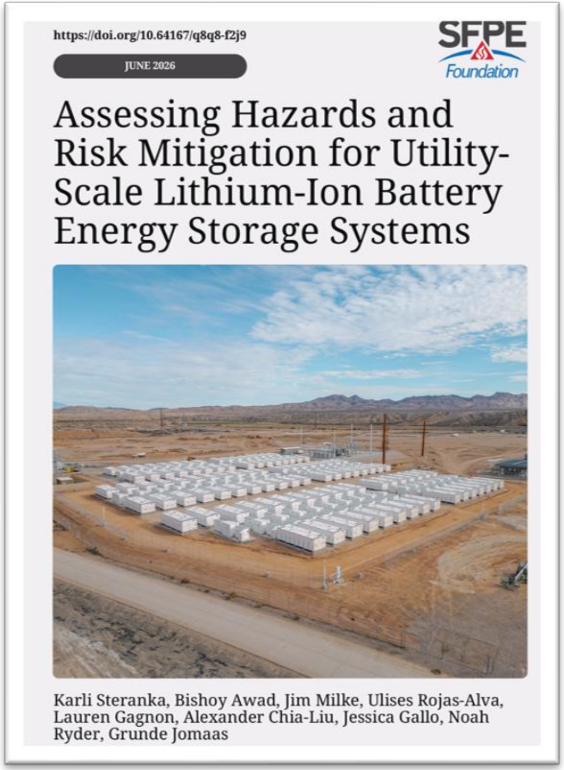
BESS Hazards Research Overview

Report Content

1. Introduction
2. Risk Framework (SFPE Guide to Fire Risk Assessment & NFPA 551)
3. BESS Hazard Identification & Characterization
4. BESS vs Industrial Hazard Analysis Comparison
5. BESS Hazard Prevention & Mitigation Strategies
6. Application of Risk Evaluation Framework to BESS
7. Gaps & Areas of Future Research

Appendix

A. Supplemental Fire Hazard Data from Literature
B. Supplemental Explosion Hazard Data from Literature and Internal Database
C. Summary of Major Industrial Incidents
D. Summary of Codes and Standards for BESS Globally


https://doi.org/10.64167/q8q8-f2j9

JUNE 2026

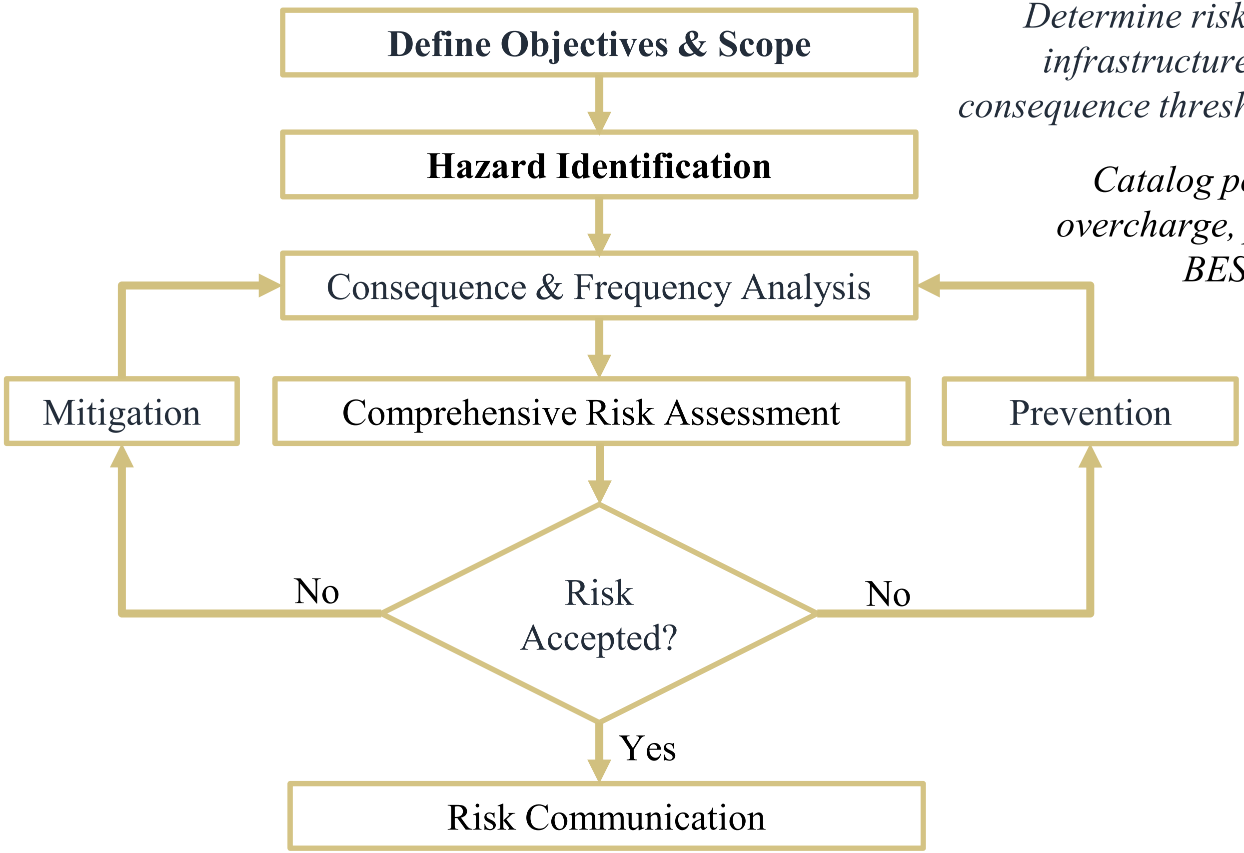
SFPE Foundation

Assessing Hazards and Risk Mitigation for Utility-Scale Lithium-Ion Battery Energy Storage Systems

Karli Steranka, Bishoy Awad, Jim Milke, Ulises Rojas-Alva, Lauren Gagnon, Alexander Chia-Liu, Jessica Gallo, Noah Ryder, Grunde Jomaas

Risk Framework, BESS Hazard Definition, and Quantification

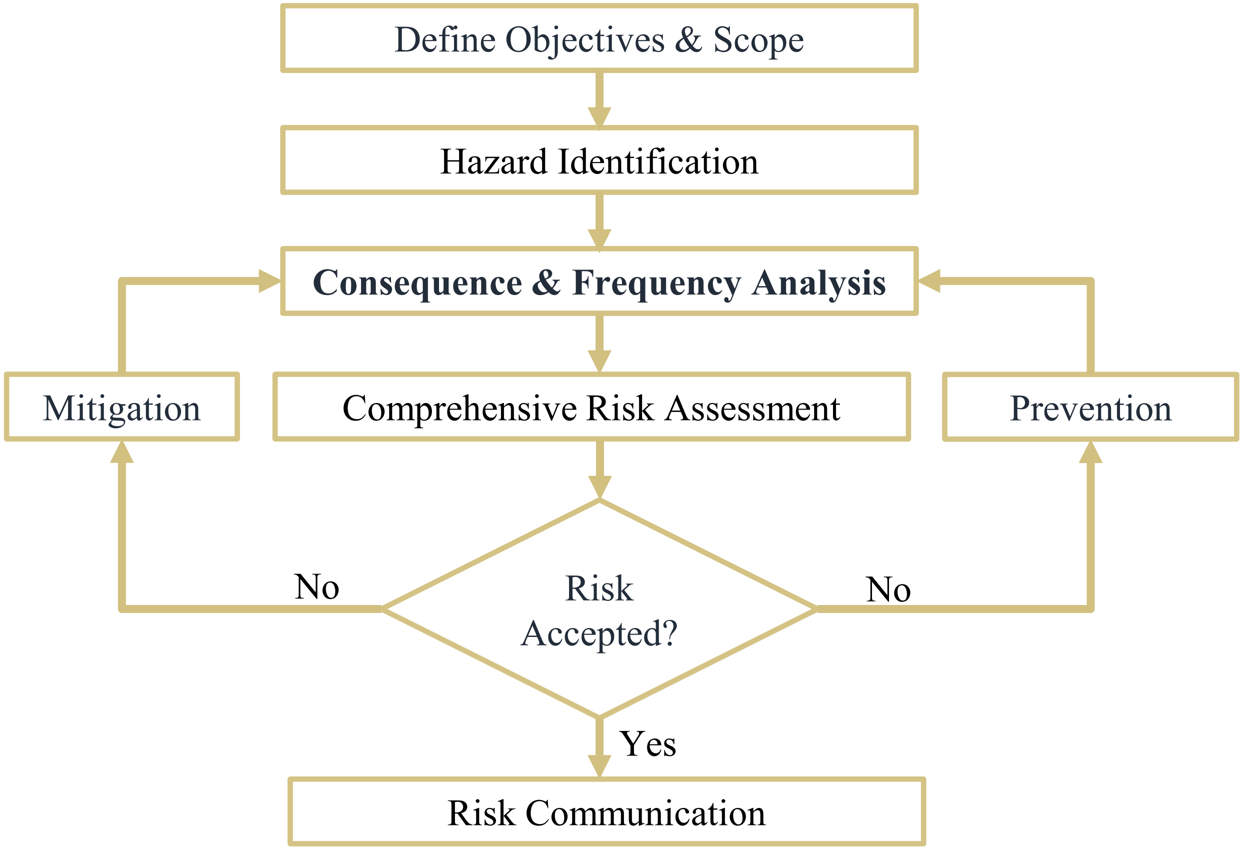
BESS Risk Framework



Determine risk tolerance for personnel safety and infrastructure, consult local authorities. Define consequence threshold limits (heat flux, IDLH, AEGL etc).

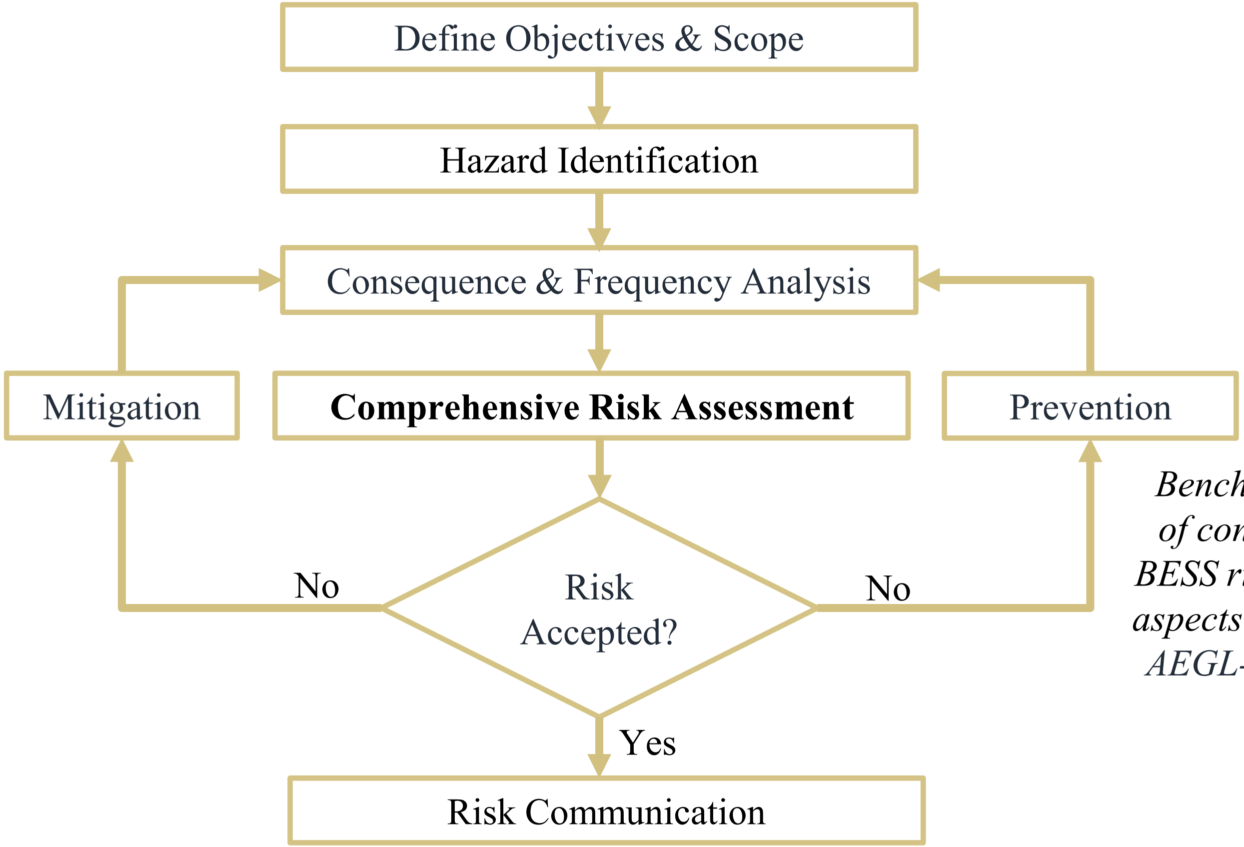
Catalog possible failure scenarios—e.g., overcharge, physical damage, fire external to BESS and associated hazard

BESS Risk Framework



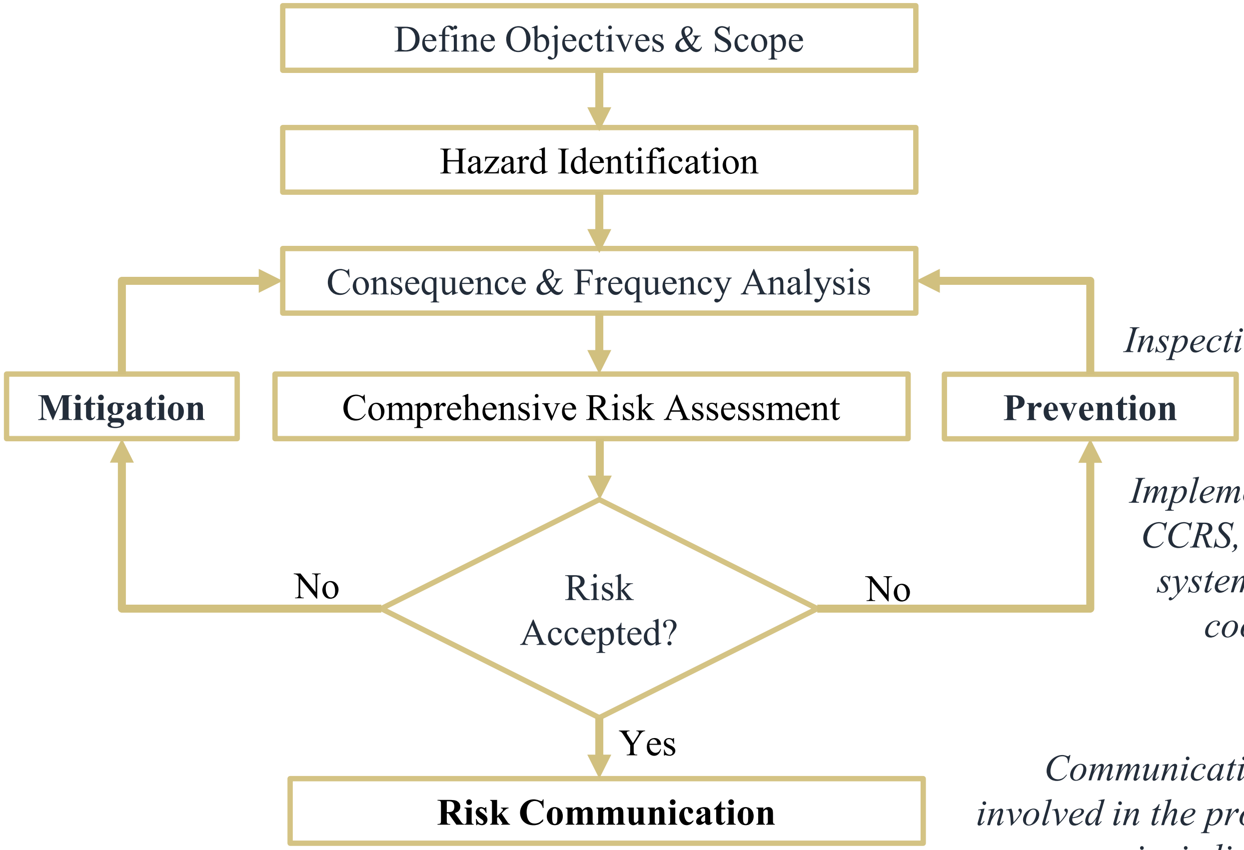
Simulate worst-case fire, explosion, and toxic gas release scenarios to evaluate severity of hazard & consequence extent.

BESS Risk Framework



Benchmark BESS risks (frequency x severity of consequence) against conventional non-BESS risks. Highlight unique and comparable aspects. Compare against safety limits (IDLH, AEGL-2) and consequence threshold values.

BESS Risk Framework



Inspection, Testing, and Maintenance (ITM).

Implement mitigation such as off-gas detection, CCRS, deflagration venting, fire suppression system, emergency response planning, and coordinate with emergency services.

Communication of risk to all stakeholders involved in the project (owner and operator, local jurisdiction, fire department)

BESS Hazards Overview

Fire (thermal) Hazard

Explosion (overpressure) Hazard

BESS Hazards Overview

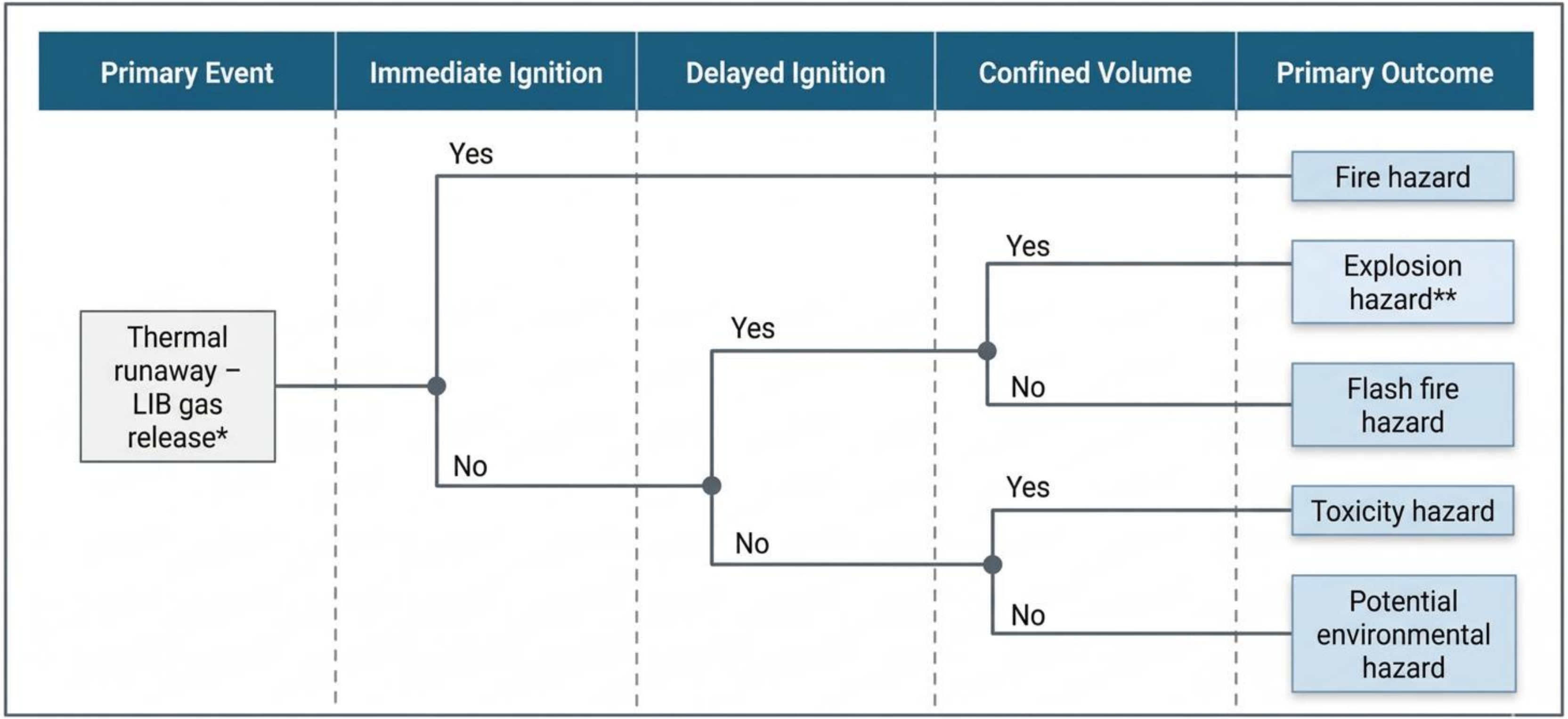
Fires & explosion can happen – how do engineers quantify the fire & explosion hazards and associated consequences?

- Landscape review of current approaches to quantify BESS fire & explosion hazards
- Compilation of publicaly available HRR & gas data in literature
- New data analysis focusing on large format battery cells
- Comparison to non-BESS fires (standard of care)
- Water, soil, and air environmental contamination is a byproduct of the fire and explosion hazard
- Electrical shock and stranded energy*

Victoria Big Battery BESS Fire – July 2021

Image curtsey of Fire Rescue Victoria [4]

Failure Pathways – without mitigation



* Pathways are not mutually exclusive but rather show the primary outcome.
** Explosion hazard assumes LIB gas accumulation in excess of the LFL..

BESS Fire Hazard (Thermal-HRR)

		Pros					Cons/ Limitations						
HRR Estimation Method		Actual representation of fire hazard	Industry Standard§	Cell specific test data	Theoretical & combustion sceince basis	Normlized experimental test data basis	Testing not required globally†	Only 1 data point¥	Testing does not always show flaming behavior	Scaling data is conservative	Limited existing datasets	Assumptions may be required	Existing literature primarily based on old, low energy density battery cells
1	Large scale destructive fire test	X					X	X				X	
2a	Scale UL9540A cell level test data		X	X			X	X	X	X		X	
2b	Scale UL9540A module level test data		X	X			X	X	X	X		X	
2c	Scale UL9540A unit level test data		X	X			X	X	X	X		X	
3	Estimate HRR based on the total electrical energy.				X						X	X	X
4	Estimate HRR based on meta-analysis PHRR to unit energy.					X					X	X	X

!! No guidance exists for which methodology (if any) should be utilized for evaluating ESS fire hazards to determine safe siting and installation level risks !!

!! Methods 2-4 have not been validated against large scale fire test data !!

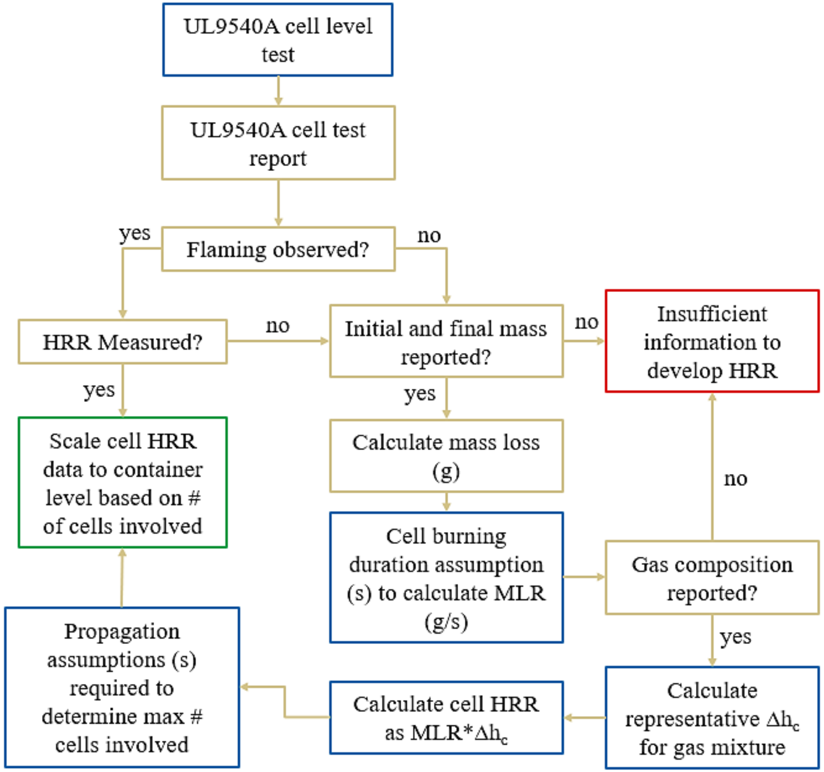
† Testing not required globally refers to jurisdictions outside the US that may not mandate UL9540A compliance nor LSFTing in accordance with NFA 855 (2026).

§ UL 9540A is widely recognized consensus standard for evaluating thermal runaway fire propagation hazards and is explicitly cited in NFPA 855 and the International Fire Code (IFC), demonstrating general industry acceptance

¥ Fire test data derived from a single experiment inherently carries significant uncertainty because it does not capture the natural variability in experimental conditions, measurement error, or stochastic aspects of fire behavior

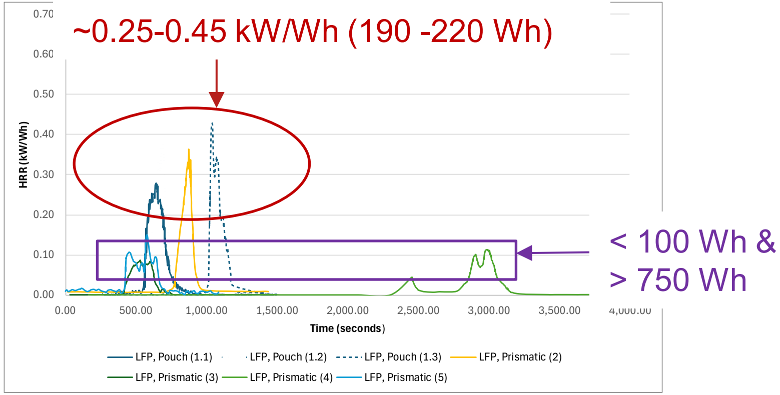
HRR Quantification Considerations

2a. Scaling UL9540A cell level data

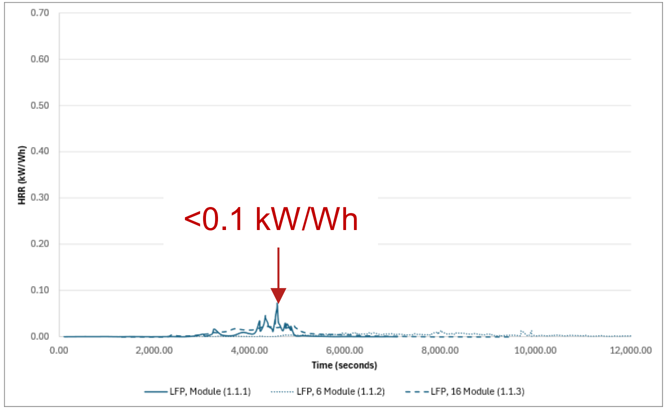


4 Meta-analysis PHRR to Unit Energy

Cell level data



Module & Rack level data



HRR Quantification Considerations

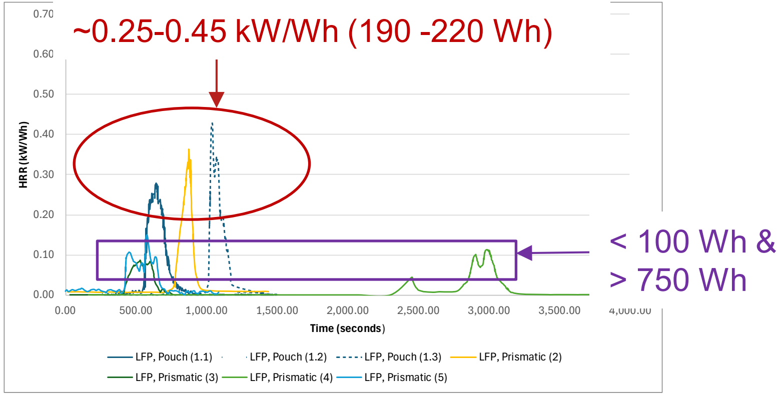
2a. Scaling UL9540A cell level data

Scaling from cell level data is conservative. Intermediate scale fire tests show:

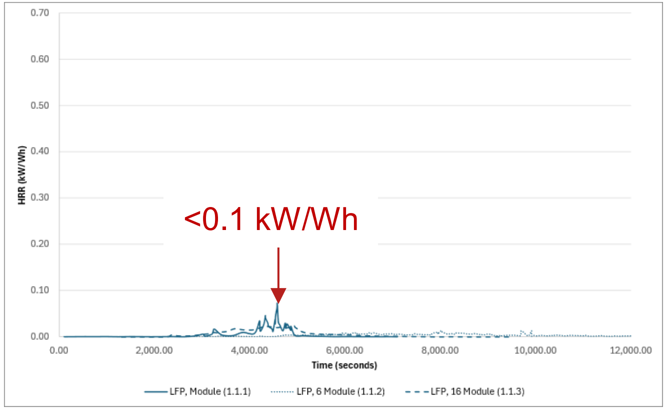
- **Inefficient combustion in module and rack configuration.**
- **HRR may be less dependent on the battery and more dependent on plastics & other combustible contributions**
- **Insufficient data to make statistically significant conclusions**

4 Meta-analysis PHRR to Unit Energy

Cell level data

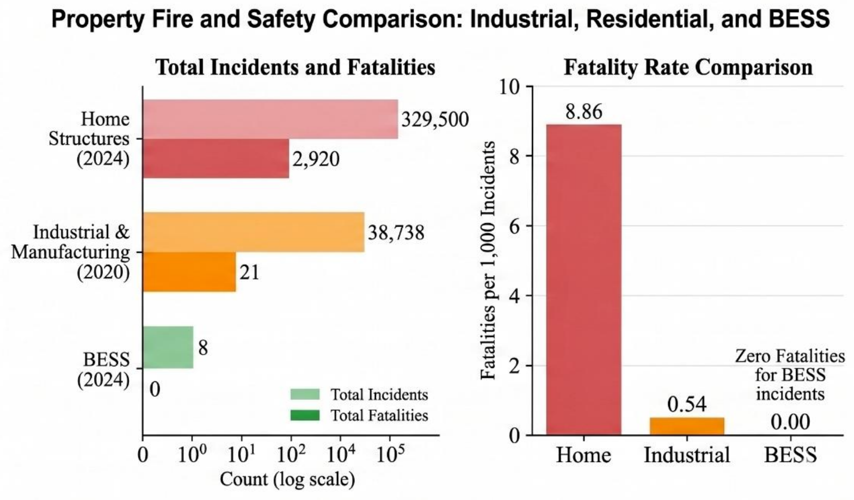


Module & Rack level data



Industrial vs BESS Hazard Case Study Comparison

BESS vs ‘Other’ Industrial Hazard Comparison



Statistic data from EPRI [1] and NFPA [7,8]

- BESS vs ‘other’ industrial fire statistics (as publicly available from other resources)
  - Only BESS statistics tracked globally
- Case study comparison of 7 historical large-scale incidents:
  - Moss Landing (2025)
  - Victoria Big Battery Fire (2021)
  - Escondido BESS Fire (2024)
  - McMicken BESS Explosion (2019)
  - Bio-lab chemical fire (2024)
  - Shell Refinery Fire (2019)
  - Kentucky Industrial Explosion (2024)
- Focus on publicly available investigation reports and direct data
- Utilize news sources for images and visual comparison
- Quantitative and qualitative comparison of consequences
  - Visual flame, smoke, plume and post incident impacts
  - Air, soil , water monitoring comparisons
  - Injury and fatalities comparison
  - Evacuation zone comparison
  - Fire department response tactics
  - Monetary loss and community impacts

PUBLIC PERCEPTION

Survey findings from Firetrace [9] (~4,000 respondents) and University of Oregon [10] (1,217 respondents)

44%

of U.S. respondents have never encountered information about BESS & the survey found lack of knowledge generally correlates with opposition

"2/3

citizens would be more likely to support BESS with additional fire suppression systems which suppress the fire in a few seconds"

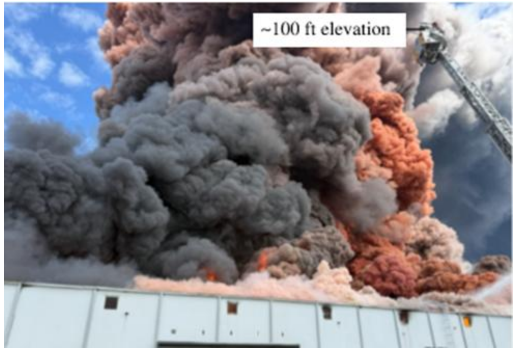
Key Survey Findings

- High-publicity fire events receive significant media attention which may be impacting public perception and perpetuating opposition.
- Trust in science alongside risk/benefit perceptions significantly influence acceptance and perception of risk and benefit shifted based on framing of the message.
- Perceived risks and information gaps remain key barriers to widespread BESS deployment.

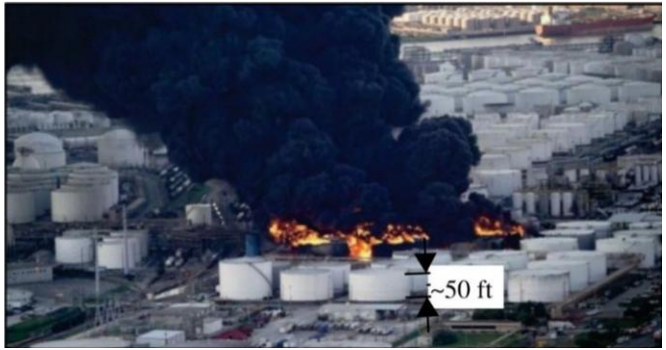
Goal: present data driven insights that help readers understand how the magnitude of large-scale BESS incidents measure up against large-scale industrial incidents

Visual Comparison: Fire, Smoke Plume & Damage

Victoria Big Battery (2021)
Image curtsey of Fire Rescue Victoria [4]



Bio Labs (2024)
Image curtsey of U.S. Chemical Safety Board [11]



Shell Refinery (2019)
Image curtsey of U.S. Chemical Safety Board [12]

Key Takeaway: Containerized BESS provides inherent fuel breaks limiting maximum fire consequence. Industrial buildings concentrate fuel load without equivalent passive separation.

Visual Comparison: Fire, Smoke Plume & Damage

McMicken BESS (2019)

Image curtsey of UL RSFI [13]

Kentucky Blast (2024)

Image curtsey of U.S. Chemical Safety Board [14]

Key Takeaway: McMicken occurred before development of NFPA 855, since development and implementation of NFPA 855 no outdoor BESS explosion incidents have occurred.

Air, Soil & Water Monitoring Comparison

100%

of BESS incidents had air monitoring publicly reported

66%

of industrial incidents had air monitoring reported

0

BESS soil/water samples exceeded public health standards

Key Findings

- BESS incidents more frequently used real-time air monitoring despite producing less dense visible plumes than industrial incidents
- Only 2 incidents reported soil sampling — both BESS related — with all monitored results were reported to be within normal ranges
- Shell Refinery was the only **industrial** incident to publicly report surface water sampling following containment failure releasing hydrocarbons into waterways
- BESS incidents held to higher standard of public transparency; industrial incidents may appear safer simply due to less monitoring data being published

Fire Department Response Tactics

Across BESS and industrial incidents, defensive firefighting strategies were commonly employed.

BESS Response Tactics

- Scene control & establishment of exclusion zones
- Coordination with facility owners
- Exposure protection & external cooling
- Real-time air & gas monitoring
- Extended fire watch for delayed re-ignition
- Interior suppression not attempted once thermal runaway established

Industrial Response Tactics

- Perimeter control & fuel isolation
- Coordination with facility operators
- Controlled burn with exposure protection or suppression from distance
- Aggressive interior attack not feasible for large-scale events
- Structural instability restricts firefighter access

Defensive operations at BESS sites are consistent with standard industrial fire response — not an anomaly unique to batteries. BESS emergency response should be evaluated within the same risk-based framework applied to other complex industrial hazards.

BESS Hazard Reduction Strategies

Hazard Reduction Strategies

Strategy	Method
Monitor LIB cells, modules, racks, and overall installation with ESMS	ESMS (BMS, PCS Controls or SCADA)
Detection of LIB off-gas, smoke, or fire	Gas, VOC/ off-gas, smoke, heat, radiant energy (i.e., flame), or pressure sensors
Notification of detection	Local site notification (audible/ visual devices), remote transmission to supervising station/monitoring center, alert security personnel & emergency responders
Passive barriers, limit fuel loading, and clearance to exposures	Siting of BESS to provide separation to exposures and separation between fuel packages or utilize physical barriers.
Fire suppression system	Defensive cooling through application of. water-based suppression/exposure protection systems (sprinklers, monitors, water spray, or water mist as applicable)[K].
Explosion prevention	CCR (NFPA 69)
Deflagration venting	Passive deflagration vents (NFPA 68), and sparkers
Emergency response	Defensive cooling and exposure protection through application of water by fire service, incident command, manage isolation/exclusion zones, access control, communications, and community protective actions

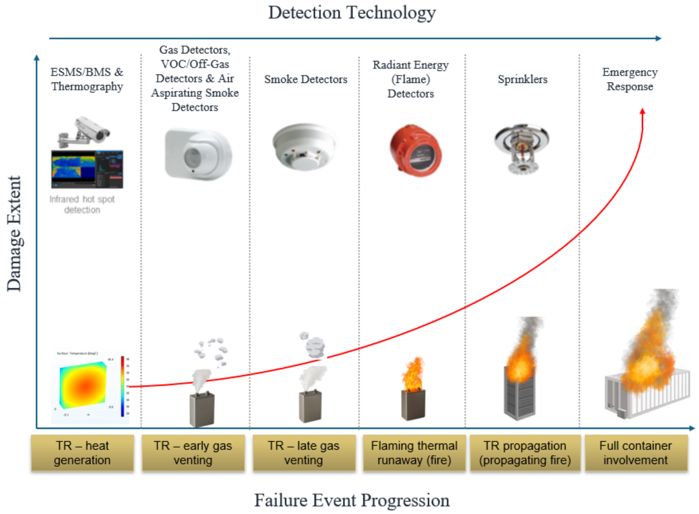
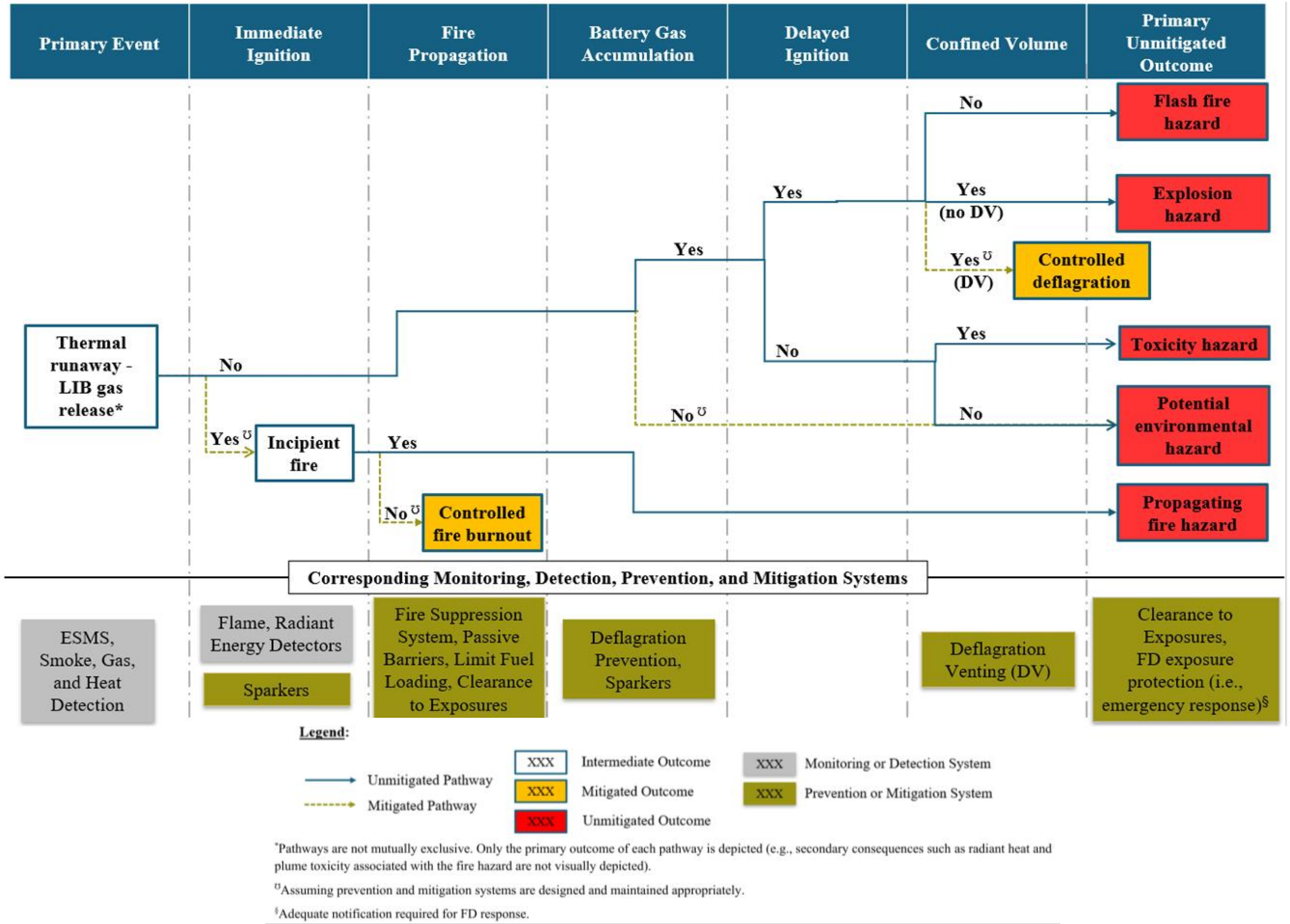


Image curtsey of VisionTIR [15]

Should be implemented where unmitigated consequence is **unacceptable** based on performance objectives – people, property, environment

Failure Pathways – with Mitigation



Explosion Control Design Considerations

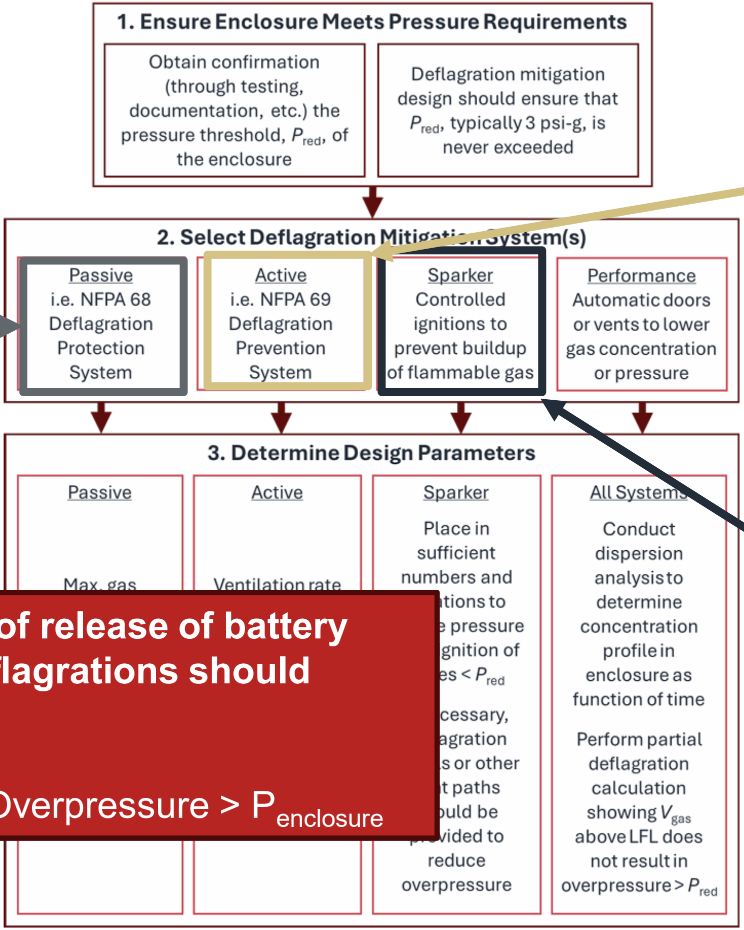


Image curtsey of Fire & Risk Alliance [16]

Goal: prevent catastrophic rupture of enclosure or room due to ignition of battery gases in an enclosed environment. Provide safe means of overpressure relief.

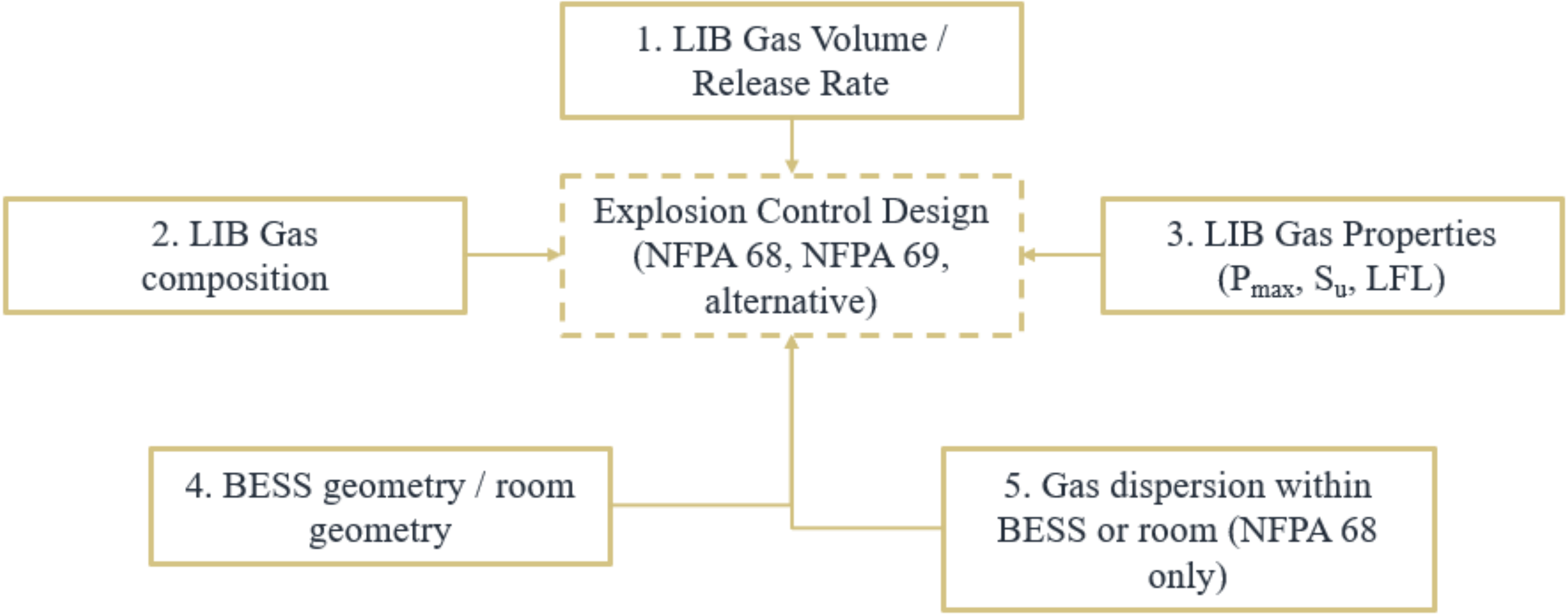
Goal: prevent flammable battery gas from accumulating to an explosive range. Prevents explosive environment.

Goal: prevent flammable battery gas from accumulating to an explosive range. Prevents explosive environment.

Due to the localized nature of release of battery vent gas, partial volume deflagrations should <u>always</u> be considered.

V_{gas} > LFL does not result in Overpressure > $P_{enclosure}$

Explosion Control Input Uncertainty



Application and Conclusions

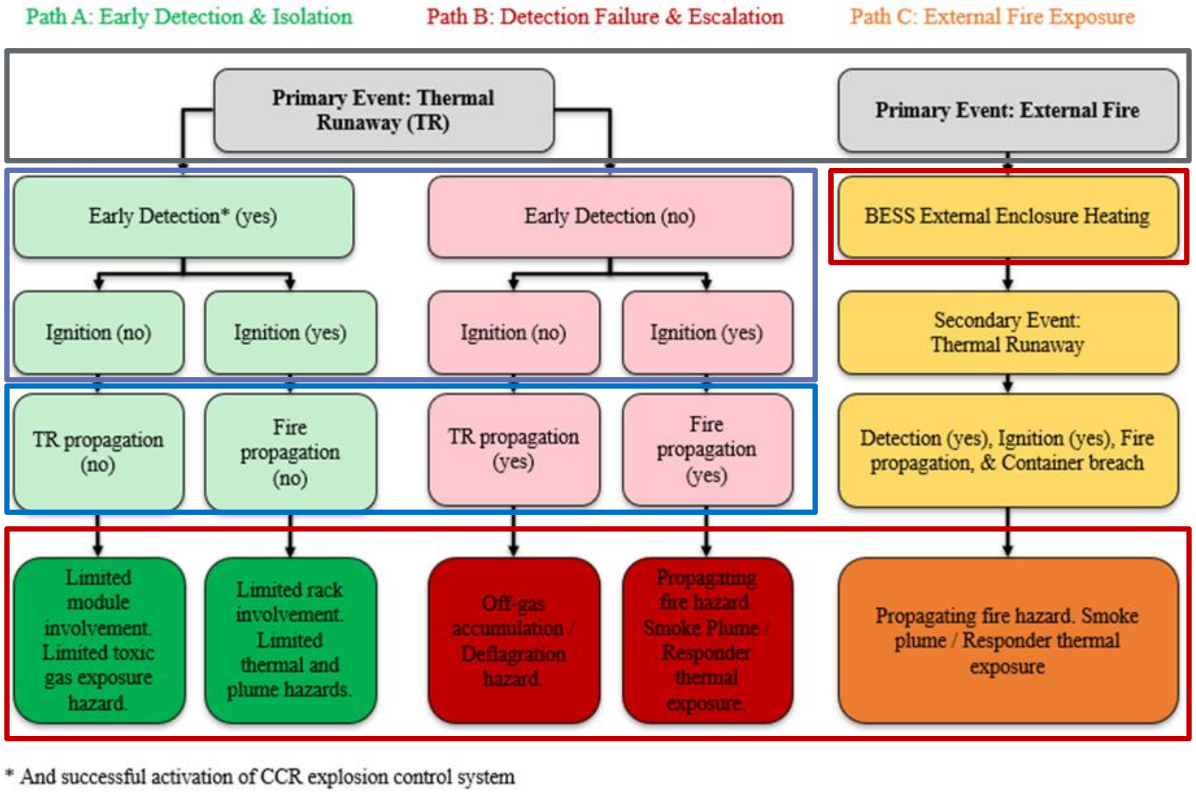
Risk Framework – BESS Application

Clear identification of credible initiating events

Assign conditional probabilities

Assign barrier performance likelihood

Analyze and quantify consequences



Gaps / Areas of Future Research

- Lack of publicly available full-scale failure data
- Lack of publicly available toxicity data (similar to non-BESS fires)
- Need better discretized data to see if older legacy systems are skewing the hazard data
  - Statistical analysis of gas volume generation / Wh
  - Statistical analysis of PHRR and THR / Wh
  - Updated statistical analysis of THR / EE focusing on large format battery cells
- Need failure statistic data for BESS components and battery cells
- Ongoing development of suppression methods and gas characterization
- Need for harmonized international design standards
  - Need for general guidance for risk evaluation framework and risk acceptance in the interim.

Conclusions & Key Takeaways

- Follow the risk framework to evaluate the frequency and consequence of BESS hazards to understand overall risk of new installations
  - Simple in concept complex in practice
- Fire (thermal), explosion (overpressure) & plume (toxic gas) hazards exist – full container / package involvement cannot be discredited
  - Same hazards as other industrial processes & manufacturing equipment
  - Consequences from BESS hazards are often less impactful to personnel (injuries & deaths), property loss, business continuity, & the environment
  - Differences: BESS can both the ignition source and the fuel package, stranded energy (electrical hazards)
- Mitigation Techniques
  - Prevention & mitigation techniques are identical to mitigation methods used for other industrial hazards
  - Gaps in available data to inform design (fire and explosion control)
  - Gaps in available data to inform products of combustion

Research Team

Fire & Risk Alliance

Noah Ryder, PhD, PE

Bishoy N Awad, PhD, PMSFPE

Alexander Chia-Liu

Prof. Jim Milke, PhD, PE

Karli Steranka, PE

Jessica Gallo

FRISSBE, ZAG

Prof. Grunde Jomaas, PhD

Ulises Rojas-Alva, PhD

External Advisory Panel

- Hubert Biteau, Code Red Consultants
- Jacob Dentici, Bowman Fire & Life Safety
- Hong Tsui, LMDG
- Paul Gawrych, Sparc Fire Protection Engineering
- Vinay Premnath, UL Research Institutes' Electrochemical Safety Research Institute
- Ruiqing "Ryan" Shen, Oklahoma State University
- Anil Kapahi, Jensen Hughes

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Questions?

Karli Steranka: ksteranka@fireriskalliance.com