EPRI

Energy Storage Fire Prevention and Mitigation

Key Learnings and Research Portfolio

ENERGY DELIVERY AND CUSTOMER SOLUTIONS

Dr. Stephanie Shaw, Technical Executive
Lakshmi Srinivasan, Principal Team Lead

Wisconsin Distributed Resources Collaborative
April 19, 2024

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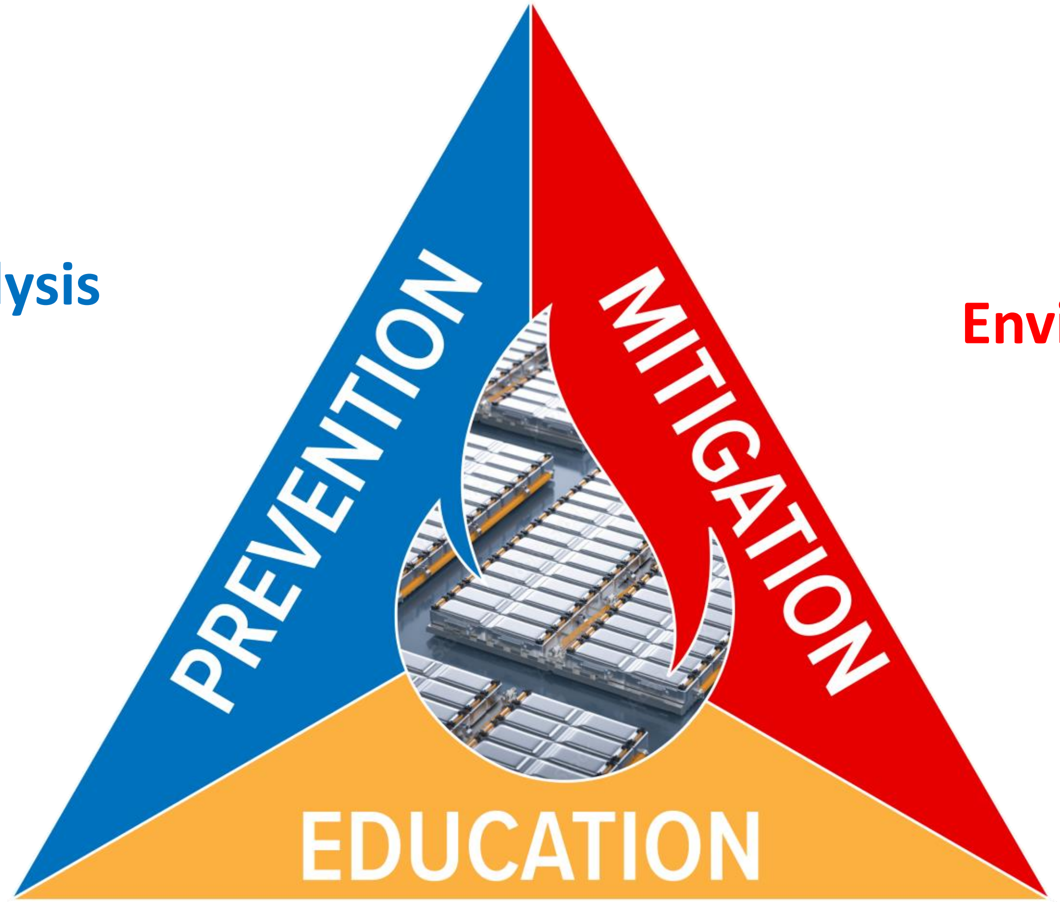
Fire Prevention and Mitigation Portfolio

Characterize Failures
Hazard Mitigation Analysis
Design and Siting
Installation and O&M



Emergency Response
Environmental Monitoring
Incident Recovery

First Responders, Permitting Authorities, Regulators, Public

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Electric Power Company Participants

- FM Global
- Southern California Edison
- SRP Salt River Project
- Austin Energy
- Portland General Electric
- New York Power Authority
- exelon
- PG&E
- conEdison
- aps
- synergy
- enel
- Hawaiian Electric
- SMUD
- Southern Company
- LA DWP Los Angeles Department of Water & Power
- Duke Energy
- Eskom
- Ameren
- TVA Tennessee Valley Authority

Industry / Academic Advisory Committee

- Exponent
- American Fire Technologies (A Division of The Hiller Companies, Inc.)
- Texas – The University of Texas at Austin
- TÜV SÜD
- Sandia National Laboratories
- UL
- HSE Health & Safety Executive
- Jensen Hughes
- FDNY
- NREL
- Pacific Northwest National Laboratory
- Hazard Dynamics
- ESRG Energy Safety Response Group

Collaboration across industries to accelerate safety knowledge and practices

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EPRI Storage Safety Public Wiki Page

Page | Read | Search EPRI Storage Wiki

Main page

StorageWiki Contents

- ES 101
- ES Safety
- Failure Event Database
- DER-VET Guide
- ES Roadmap
- ES Vendor Database
- ES Analysis Case Studies
- BESS Handbook
- Footprint Calculator
- ES Product Database
- SI Articles
- Microgrids
- P&R Foresight

Additional EPRI Resources

- Storage Program at EPRI

Storage Safety

Welcome to EPRI's Energy Storage Safety wiki. This page provides a brief overview of energy storage safety, along with links to publicly available safety research from EPRI. This page will be updated periodically as new resources are published. If you have comments, suggestions, or question, please email Lakshmi Srinivasan.

EPRI's energy storage safety research is focused in three areas, defined in the Energy Storage Roadmap: Vision for 2025.

Establishing safety practices

- Includes codes, standards, and guidelines for safe deployment and operation

Characterize safety hazards

- Understanding failure modes and consequences, and developing mitigations to reduce the likelihood and severity of failures

Develop and demonstrate community solutions

- Intended to support public safety, community resilience (like disaster recovery), and environmental quality

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Failures and Mitigation Strategies

Take-aways from Recent ESS Fires

Prevention

- SOFTWARE DESIGN & VALIDATION
- QUALITY ASSURANCE & VENDOR COORDINATION
- SUBSYSTEM INTEGRATION
- DATA ACQUISITION & TRENDING

Mitigation

- HAZARD IDENTIFICATION & TRADEOFF STUDIES
- PROJECT SITING & RESOURCE PLANNING
- SYSTEM ENVELOPE
- RESPONSE PROCEDURES & INFORMATION SHARING

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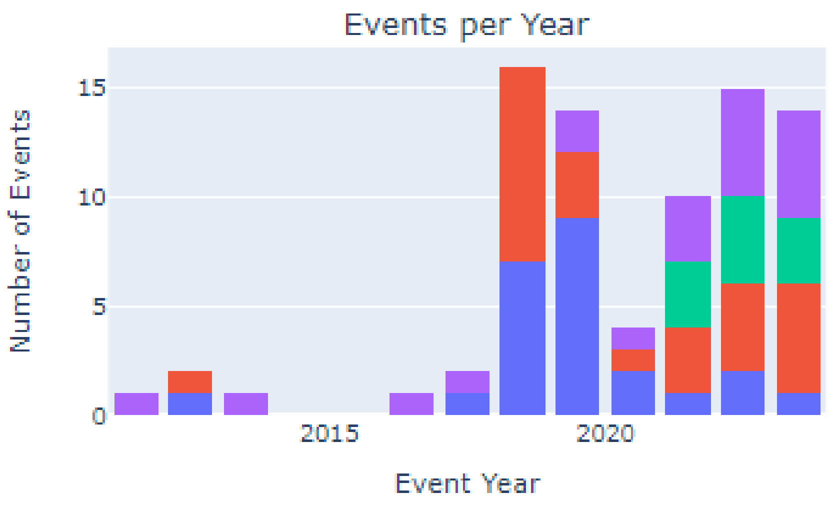
EPRI BESS Failure Event Database

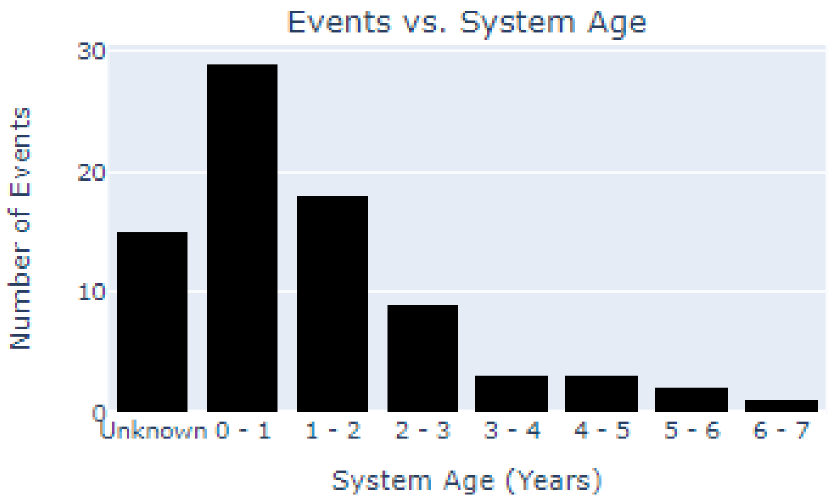
Background

- Developed in 2021
- Focus on utility-scale and C&I stationary storage failures resulting in a safety hazard
- Scope is global and includes all battery chemistries
- Contains information on: capacity, age, technology, application
- Sourced from public information (media, corporate statements, released investigation reports)
  - Caveat: Not all events have media coverage

Purpose:

- Data for analysis and developing lessons learned
- Identify gaps and support safety R&D





https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

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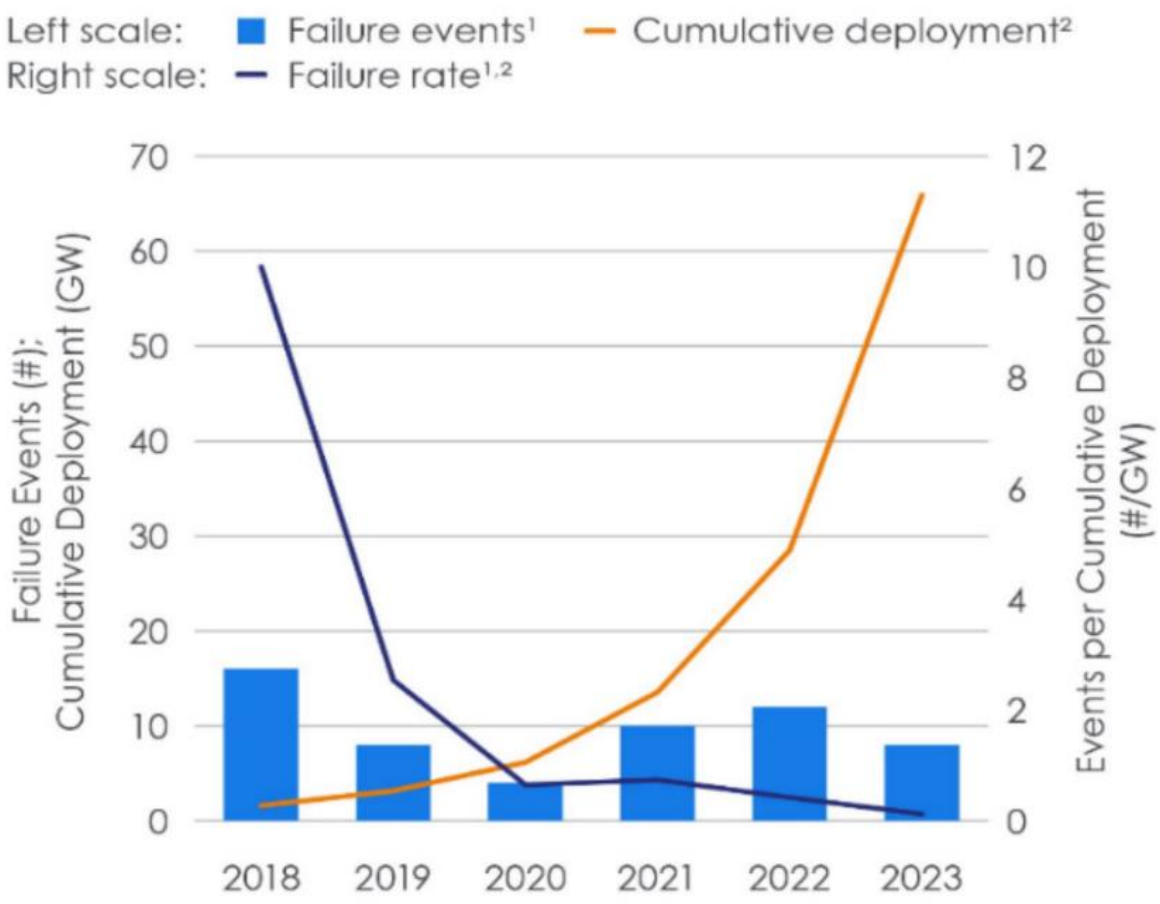
A Study on Battery Fires

"Lithium Ion Battery Fires in the News"

- EPRI published a whitepaper in 2023 to put battery fires into context
- First use of database for analysis
- Conducted data validation through academic papers, other databases, and industry experts

Looking ahead: Build on data gathering to offer additional insights



Sources: (1) EPRI Failure Events Database (2) Wood Mackenzie. Data as of 9/20/23

Read the whitepaper:

[Lithium Ion Battery Fires in the News]

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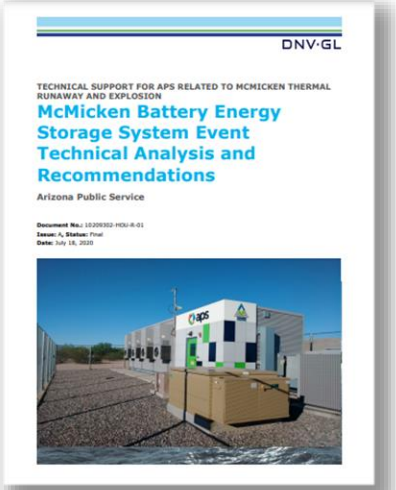
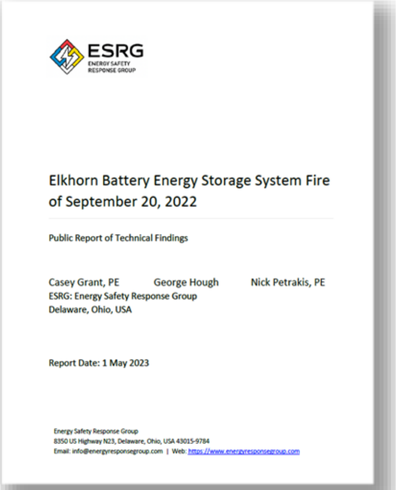
Root Cause Analysis

1 *Can we identify root cause for **ALL** utility-scale and C&I BESS failures?*



[McMicken System, Surprise, AZ](#)

[DNV Investigation Report](#)



[Elkhorn System, Moss Landing, CA](#)

[ESRG Investigation Report](#)

[Carnegie Road System, Liverpool, UK](#)

[EPRI Lessons Learned Report](#)

2 *What insights can we derive from an **aggregate** analysis?*

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Root Cause Categorization

Collaboration with TWAICE and PNNL

Root Cause Failure	Physical Location / Failed Element
Design Manufacturing Integration and Workmanship Operations	Cell/Module Battery Balance of Plant Controls

Notes:

- Incidents can have **multiple root causes**
- Any root cause can pair with any failed element

- Work-in-progress suggests broad distribution of causes and elements to date
- Implies further need for implementing cell-to-cell propagation mitigations

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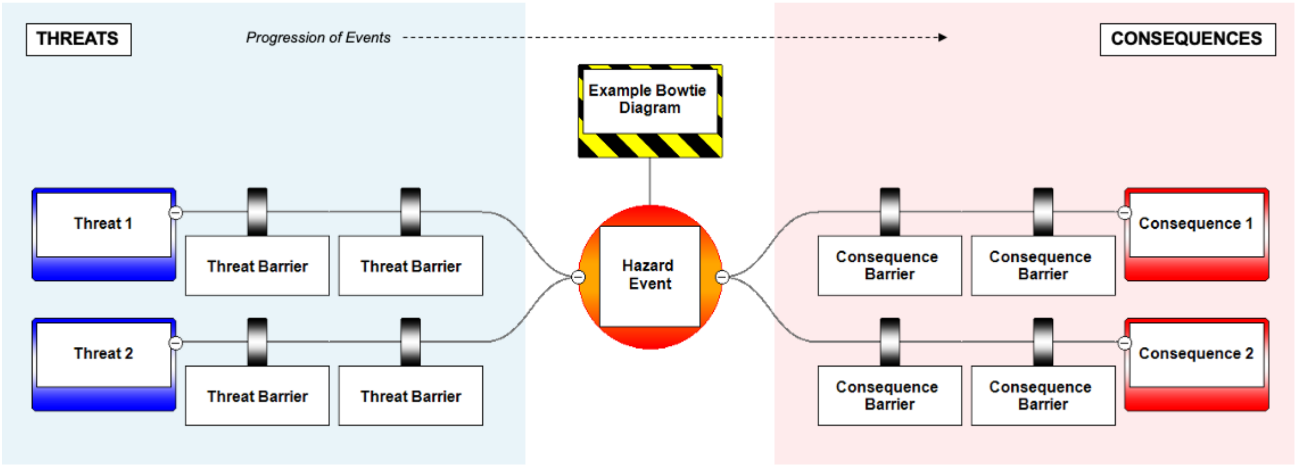
Reference Energy Storage Hazard Mitigation Assessments



- Developed through Energy Storage Integration Council and vendor collaboration
- Lithium-ion HMA completed in 2021 3002023089
- Flow battery HMA finalizing now

- "Bowtie" approach
- Includes detailed threat, threat barrier and consequence assessment descriptions

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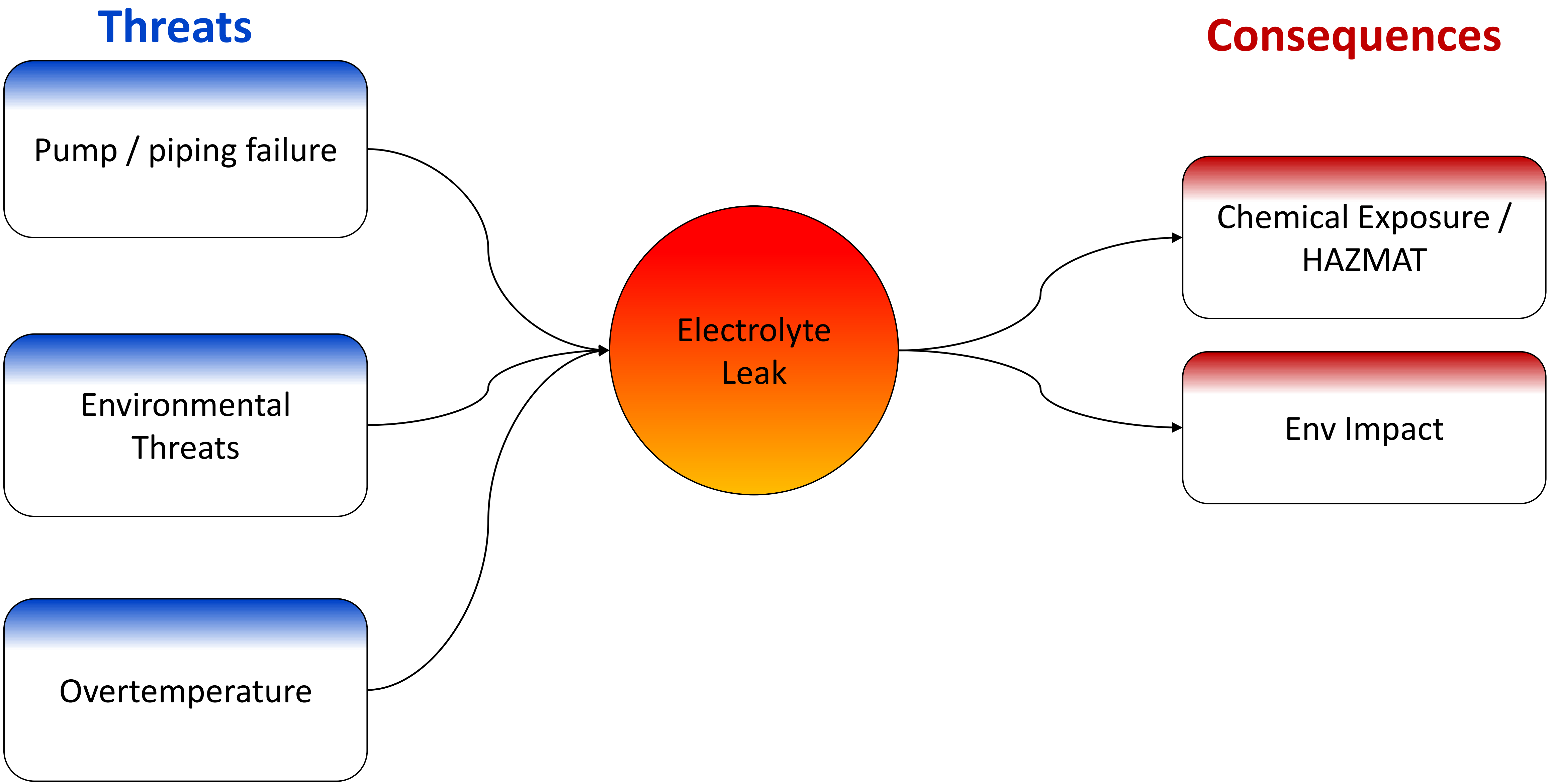
Example Flow Battery Electrolyte Leak



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Putting the HMA into Practice

Findings from EPRI's Fire Prevention and Mitigation Project (2020 – 2021)

	Cell Abuse Tolerance	Electrical Controls	Thermal Controls	Vent Gas Routing	Fire Suppression	Deflagration Protection	Response Plans	System Design & FMEA	System Certification
ESS 1	Partially addressed	Fully addressed	Fully addressed	Not addressed	Not addressed	Not addressed	Not addressed	Not addressed	Partially addressed
ESS 2	Partially addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Not addressed	Not addressed
ESS 3	Not addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Not addressed	Not addressed
ESS 4	Not addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Partially addressed	Not addressed	Not addressed
ESS 5	Not addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Not addressed	Not addressed
ESS 6	Not addressed	Fully addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Partially addressed	Not addressed	Not addressed
ESS 7	Partially addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Not addressed	Not addressed
ESS 8	Partially addressed	Fully addressed	Partially addressed	Partially addressed	Partially addressed	Not addressed	Not addressed	Not addressed	Partially addressed

Fully addressed   Partially addressed   Not addressed

Source: EPRI Battery Storage Fire Safety Roadmap

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Incident Highlight

Incident Highlight | Elkhorn BESS - Sep 20th, 2022

- 183 MW / 730 MWh system, consists of 256 Tesla Megapacks
- Commissioned April 2022
- One unit caught fire, no propagation to adjacent units
- No injuries reported
- Site evaluation through FPaM ph 1
  - Fire or over-temp alarm de-energizes system, notification to on-site personnel
  - Remote Incident Command center with HMI and camera feeds
  - Coordination with local FD

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Elkhorn Report Summary

Event progression detailed

- 1 Megapack involved
- Water use on adjacent exposures
- Road closures / shelter in place

Root Cause

- Rainwater intrusion
- Loss of isolation

Confounding Factors

- Firmware not updated
- Isolation alarm not elevated to operator

Elkhorn Battery Energy Storage System
Fire of September 20, 2022

Public Report of Technical Findings

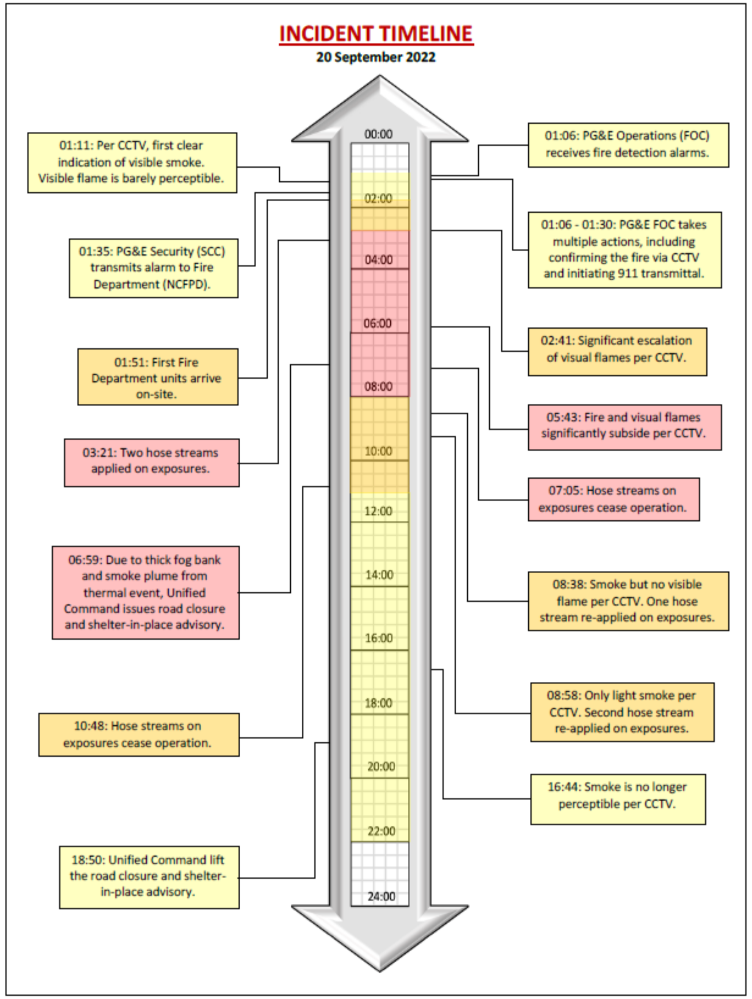

Figure 2: Incident Timeline for 20 September 2022
(Note: Figure shows Timeline Phases B though F only)

https://www.pgecurrents.com/articles/3833-report-elkhorn-battery-energy-storage-system-fire-september-20-2022

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Elkhorn Report Lessons Learned

Delay in notifying FD of fire

Periodic walkthroughs and tabletop **drills**

Incident command **response and training**

Critical Operation **Power Supply** – CCTV power

Water application of **limited value**

Air Monitoring: thresholds and data

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Training and Response Strategies

Ends of the Lithium Ion Response Spectrum

“Let it Burn”

Pros:

- Reduce direct exposure for first responders
- Reduce H2O runoff

Cons:

- Gas plume spread
- Reputational damage
- Unconventional response
- Shelter in place?

Fight Fire

Pros:

- Possibly extinguish faster
- Reduce propagation & additional damage

Cons:

- Difficult to extinguish
- Requires *copious* amounts of H2O
- Produces toxic runoff concerns
- Increased exposure to hazards
- Stranded energy?

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Ends of the Lithium Ion Response Spectrum

"Monitor and Contain"

Pros:

- Reduce direct exposure for first responders
- Reduce H2O runoff

Cons:

- Gas plume spread
- Reputational damage
- Unconventional response
- Shelter in place?

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Proactive First Responder Engagement & Training

- Reach out early in the design phase
- Develop emergency response plans with input from first responders
- Conduct training & walk- throughs often
- Build your BESS expertise & SMEs
- Don't wait for an emergency!

Proactive First Responder Engagement for BESS Owners and Operators

Technical Brief — *Environmental Aspects of Fueled Distributed Generation and Energy Storage*

Battery Energy Storage Systems (BESS) have an important role to play in the future of the electric grid, but only if they can be designed, operated and decommissioned in an environmentally responsible, safe, reliable and affordable manner. The evolution of BESS and associated technologies is occurring faster than the development of safety codes and standards can be created. Many options for safety design actions and emergency planning processes are available, despite ongoing updates and flux in the code development process. Consideration of these options during BESS development is increasingly important, as more than 30 large-scale BESS sited across the world, of varied designs and applications, have experienced catastrophic failures in the past four years (EPRI 2021a). Issues such as the subjective nature of safety evaluations, and the observation that ownership models can determine safety management and responsibilities, also play a role in robust safety management (EPRI 2021c; EPRI 2021d). As a result, there is a great need for insight, guidelines and best practices for creating safe and effective BESS design and use. There is as great a need for clear and effective communication of that information to a range of necessary stakeholders, including first responder organizations who must be prepared to safely mitigate emergency events, such as destructive fires, if a failure occurs.

This technical brief serves as a starting point for discussion on how BESS owners and operators can proactively interact with first responder organizations, such as fire fighters, paramedics or police, on environmental health and safety management aspects of BESS facilities. The focus is on *Pre-Incident Planning*, and covers practices that could be undertaken before a BESS has been installed or up to the point of operation. These pre-incident items have been found to provide critical value to owners, operators, responders and system integrators through clarification of responsibilities and detailed discussion of protocols and technologies. Possible preparatory or preventative activities in anticipation of the unlikely event of an emergency or abnormal operations will be included, but this document should not be used as a playbook in the event an emergency occurs. Such procedures should be contained in an *Emergency Response Plan* (ERP), which each facility should have on site to guide utility and first responder personnel to appropriate action.

In support of the development of this brief, EPRI hosted a workshop discussion with a range of electric utility representatives from several research programs,[1] as well as first responder and fire safety consultancy personnel. This allowed for the crowdsourcing of insights based on the

Figure 1. Common site elements and layout for a stationary storage facility. Image not to scale (e.g., larger spacings between containers, and between containers and fenceline, are now recommended).

real-world experiences of the participants in developing and evaluating BESS facilities, and allowed compilation of lessons learned from prior experiences of owner/operator engagement with first responders. Finally, specific practices from several electric utility companies were reviewed and highlights provided of their first responder engagement practices.

In summary, this brief provides a range of practical actions, discussion

[1] Program 94 - Energy Storage and Distributed Generation; Program 197 - Environmental Aspects of Fueled Distributed Generation and Energy Storage; and the Fire Prevention and Mitigation project (EPRI 2021b).

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Site-Specific Emergency Response Plan Reviews

Low Hanging Fruit

- Establish public alert criteria and protocol
- Specify likely chemical hazards
- Detail procedures for root cause analysis, incident reporting, and ERP revision
- Create standards for communicating incidents to first responders, as well as coordinating communications as the event is ongoing
- Describe how to confirm that a BESS unit is sufficiently de-energized to be safely approached
- Diagram a quick-reference guide to direct responders to the relevant section(s) when time is of the essence

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Non-Asset Impacts

Understanding and Mitigating Battery Fire Impacts

EMISSIONS	PLUME EVOLUTION	IMPACTS
1 Do we know hazardous products that could be released?	**2** Do we have the tools to assess propagation distance after release?	**3** Do we know the EH&S impacts to ensure first responders and the public take appropriate precautions?
3002018741; 3002016582; 3002019937; 3002020241 (video);	3002020094; 3002023295; 3002024677; 3002027795 (upcoming)	3002021777; 3002021634; 3002021774

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BESS Fire Air Plume Modeling Value

Potential first responder exposure

Range of efficacy for protective actions

Potential consequences offsite

Environmental impacts

Site-specific emergency response plans

Success of design and mitigation actions taken

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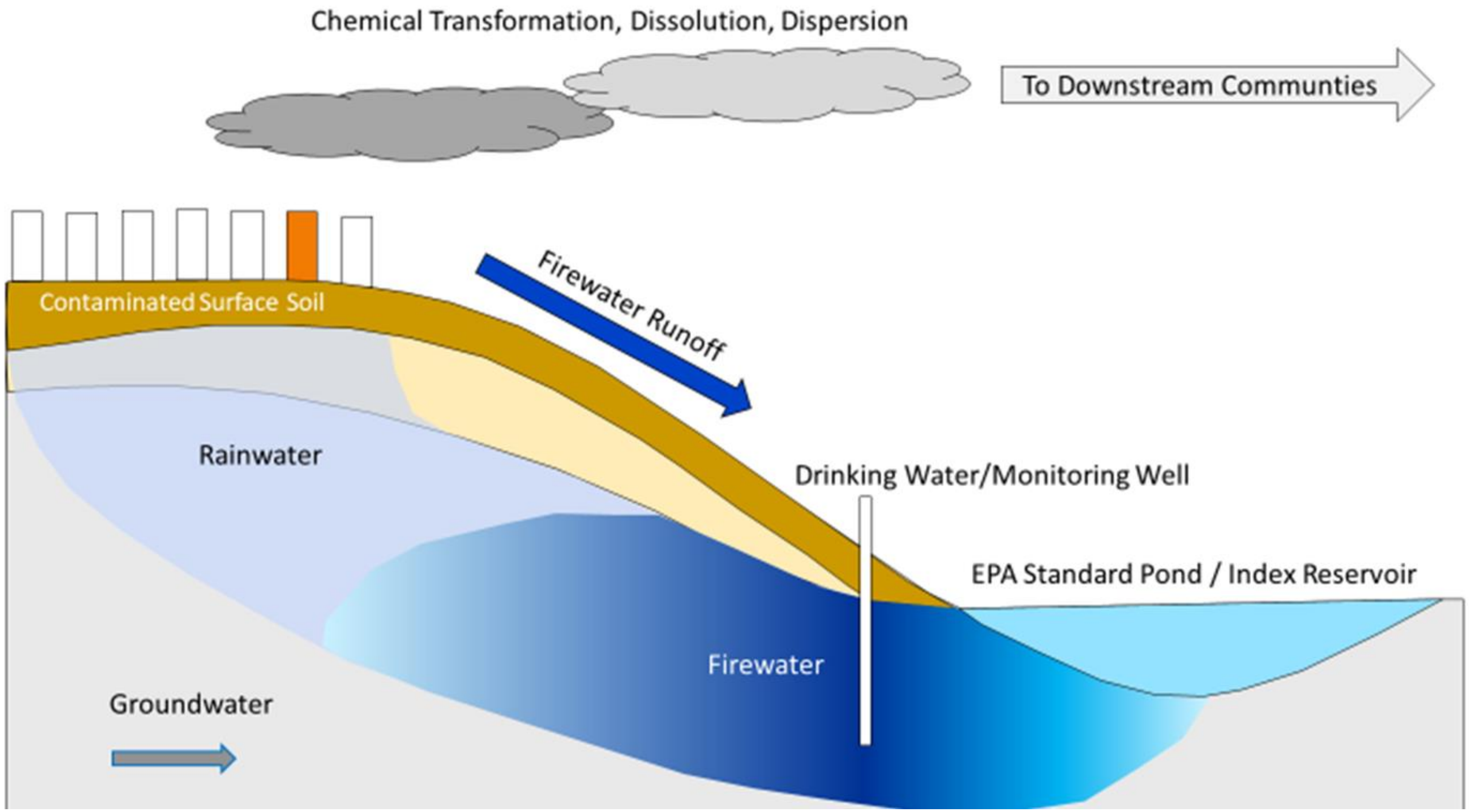
Fire Suppression Water Runoff Modeling



- Water composition
- Dissolved elements vs. trapped in soil
- Need reactive chemistry in model
- Compare to other fire types

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Environmental Monitoring Challenges

- All assessments rely on **imperfect, and too few, emissions / effluent composition data**
  - High burn variability
  - Scaling not necessarily clear

- **Transparent information sharing** from real-world events needed
  - "Not toxic" is great to hear, but what was measured? How? When? Where?

- **Context needed** – comparison to homes, various industries, etc.

Collaborative Research on Environmental and Health Monitoring is Needed

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Thoroughly Addressing Community Concerns

1. Who from the **community** was included in determining the location for the BESS?
2. What third-party studies are typically completed to justify an installation?
3. How are **health and safety** risks to the community being considered?
4. What **chemicals** will the BESS emit during operation?
5. Do people have to shelter in place or **evacuate** if there is a fire?
6. How is this system better than those that have failed before?
7. Who is **benefitting** from the battery and what value will the surrounding neighborhood get? How will this affect my electric bills? What will the **impact** be to property values?

Proactive, transparent, and frequent communication is key as social license to operate is crucial

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Fire Prevention and Mitigation Toolkit

Fire Prevention and Mitigation Project Life Cycle Toolkit

Planning	Procurement	Deployment	O&M	Decommissioning
Explosion Calculator Community Engagement	Safety specifications DC Arc Flash Guide HV Arcing Hazards during Thermal Runaway BESS Codes & Standards	Air Emissions Plume Modeling for Failures Emergency Response Plan Guides Hazard Mitigation Assessments	Safety Retrofit Guide Safety Analyses Throughout the Project Life Cycle	Carnegie Road Energy Storage System Failure Response, Recovery, and Rebuild Lessons Learned

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Planned Safety Toolkit Expansion

Planning	Procurement	Deployment	O&M	Decommissioning
Siting Considerations Flashover Risk Assessment	Burn testing for failure progression, explosion risk, emissions Fire suppression water composition Cell-level testing System safety testing and validation	Hazard Mitigation Assessments, including emerging technologies FAQs and Common Misconceptions Educational Resources to support community engagement	Safety guidelines for maintenance Operational guidelines Augmented reality O&M tool VR training for first Responders	Incident recovery best practices Environmental monitoring tools during failures Decommissioning safety guide

Collaborative effort to help advance industry safety practices

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Battery Energy Storage Fire Prevention and Mitigation: Phase III

OBJECTIVES AND SCOPE

- **Quantify** fire, explosion, and emissions hazards created by energy storage **thermal runaway**.
- Insight on public **health** and **environmental** impacts of event **mitigation** options.
- Guidance on **siting risks** near critical infrastructure.

VALUE

- **Expert** engagement from across ESS industry
- Strategies for incident **response** and **recovery,** and **safe** operation and maintenance

DETAILS	CONTACT
Duration 2 years **Price** *Collaborators*: \$60,000 *Site Hosts*: \$100,000 (varies by custom scope) **SPN 3002028531**	**Lakshmi Srinivasan** +1 (202) 510-7387 LSrinivasan@EPRI.com **Stephanie Shaw** +1 (650) 391-8203 SShaw@EPRI.com

Eligible for self-directed funds, Tailored Collaboration, or co-funding. May be spread over 2023-2025

Provides robust, data-driven guidance on safety for BESS owners and industry stakeholders

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TOGETHER…SHAPING THE FUTURE OF ENERGY®

Stephanie L. Shaw, Ph.D.
Technical Executive, EPRI
sshaw@epri.com

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