Energy Storage Fire Safety

Lessons from Real-world Systems

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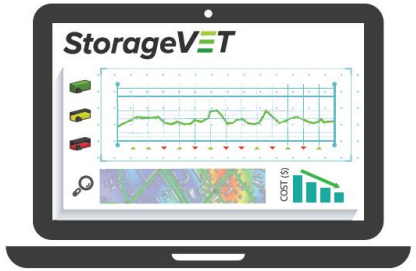
Energy Storage at EPRI

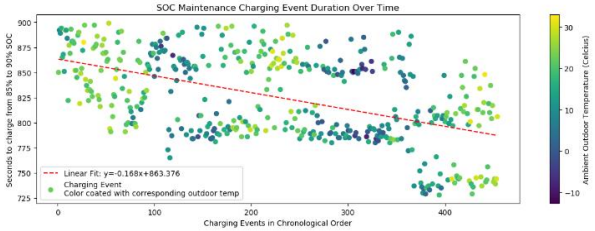
MISSION

Advance integration and use of safe, reliable, cost-effective and environmentally responsible **energy storage, distributed generation**, and **microgrids.**

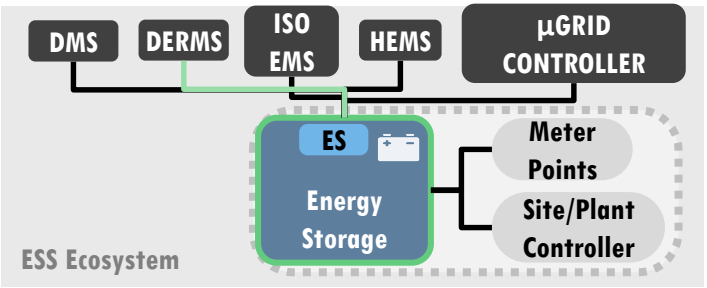
Analysis
Valuation and Grid Impacts



Technology
Evaluation, Testing, Demonstration



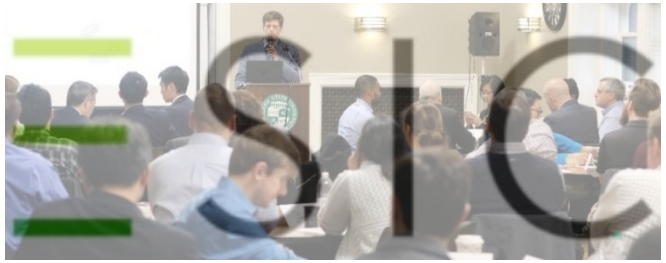
Implementation and Operations
Project Lifecycle and Controls



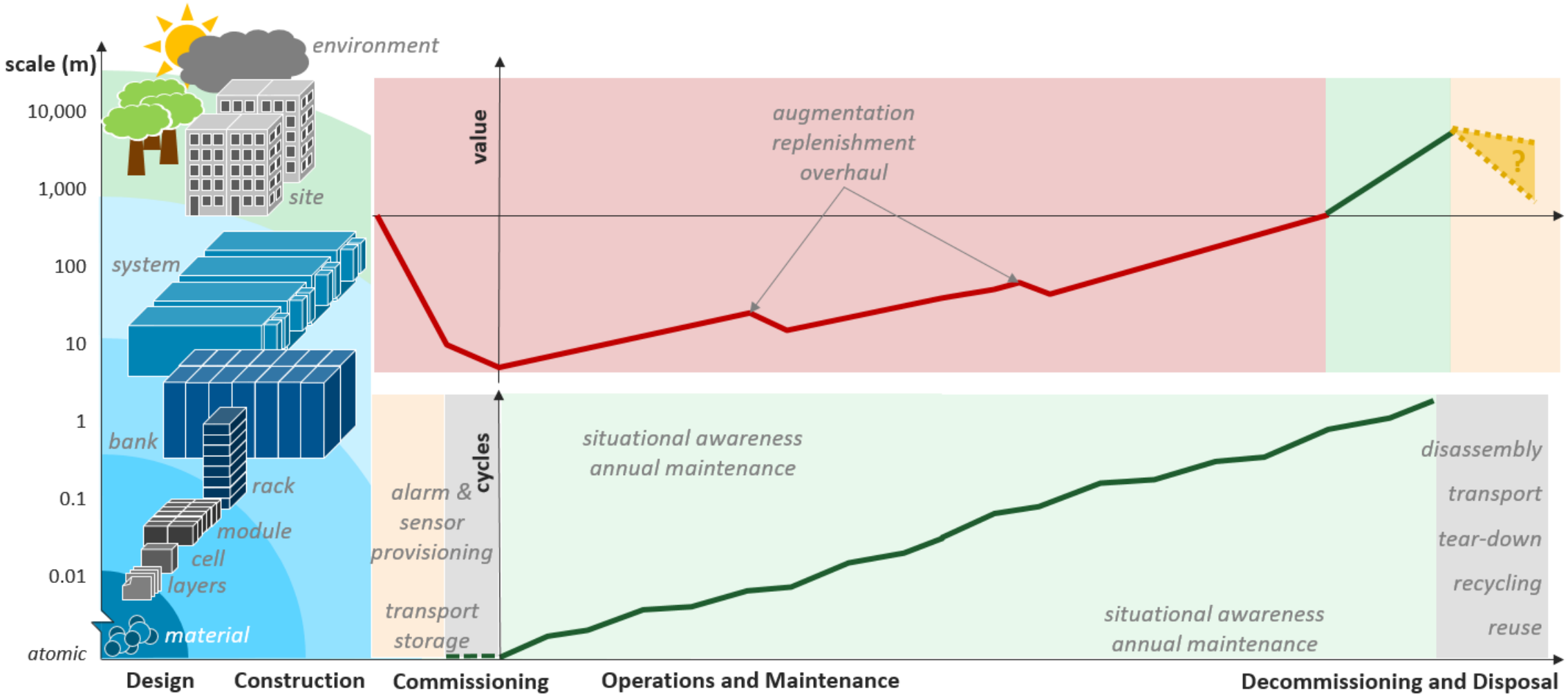
Asset Management
Safety and Reliability

Environmental Issues
Analyzing Impacts and Sustainability

Industry Engagement
Advancing Common Approaches

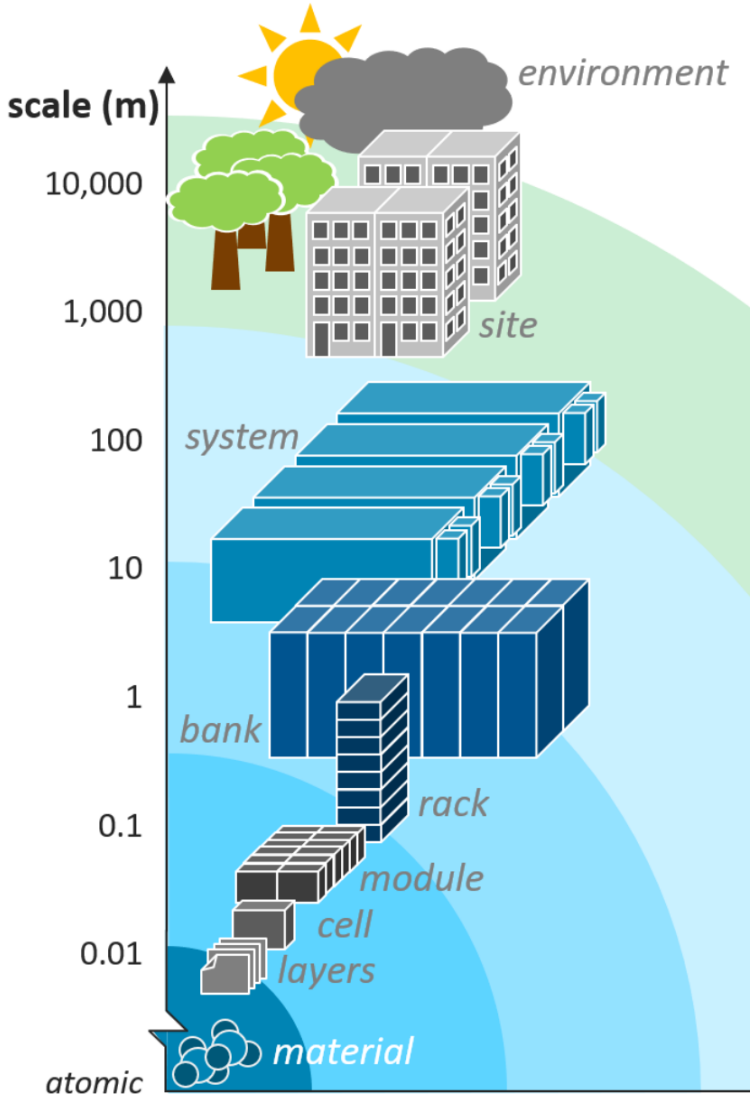


Scope of safety permeates every subsystem, cell-to-city, and each stage of life, design-to-disposal.



The Challenges

- Lack of codes and standards adoption
- Widespread misinformation about fire safety hazards
- Absence of benchmarks for comparison between technologies and products
- Disparate perspectives of diverse stakeholders



Early Market Fire Failures Affected > 1% Installed Capacity

- Fires affected over 180 MW of energy storage systems through 2019, with a reported global deployment of 17.9 GW (WoodMac)

Site of Battery Fire in Belgium
(Source: GreenTechMedia)

Site of Battery Fire in South Korea
(Source: Korea Times)

… and new incidents continue to arise …

Recent Lithium Ion Energy Storage System Fires

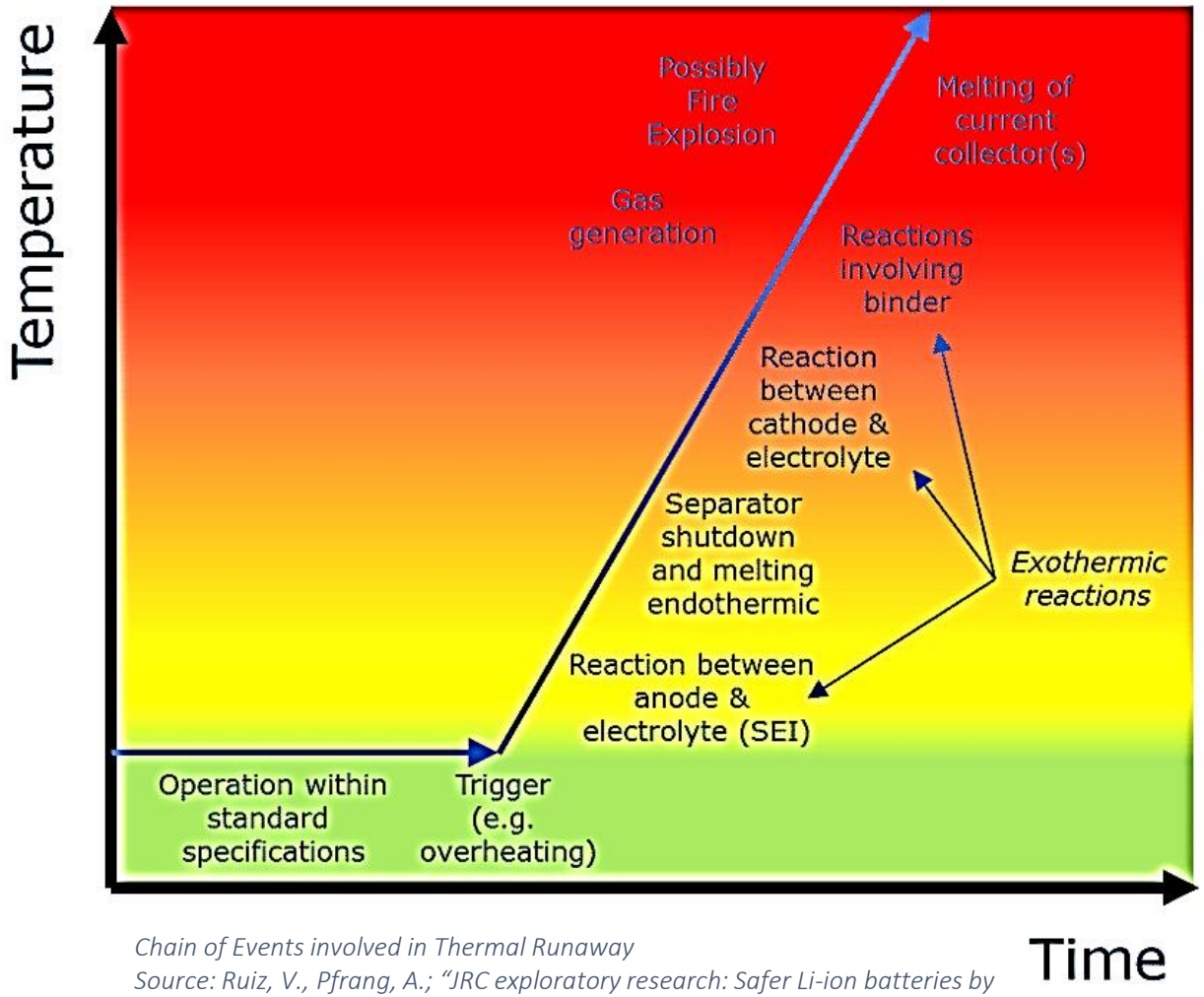
Location	Capacity (MWh)	Capacity (MW)	Application	Event Date	System Age (yr)	Source
US, HI, Kuhuku	10.0	15.0	Wind Integration	4/22/2011	1.0	Hawaii Free Press
Japan, Ibaraki Prefecture	unknown	unknown	unknown	9/21/2011	unknown	NGK
US, WA, Port Angeles	unknown	unknown	Energy Shifting	7/3/2013	unknown	Peninsula Daily News
US, WI, Franklin, S&C	unknown	unknown	unknown	8/10/2016	0.0	S&C
Korea	1.5	unknown	Wind Integration	8/2/2017	0.0	MOTIE Investigation, June 2019
Belgium, Engie	unknown	6.0	Frequency Regulation	11/11/2017	unknown	GTM
Korea	8.6	unknown	Frequency Regulation	5/2/2018	1.8	MOTIE Investigation, June 2019
Korea	14.0	unknown	Wind Integration	6/2/2018	2.4	MOTIE Investigation, June 2019
Korea	19.0	unknown	Solar Integration	6/15/2018	0.5	MOTIE Investigation, June 2019
Korea	9.7	unknown	Wind Integration	7/21/2018	1.6	MOTIE Investigation, June 2019
Korea	18.0	unknown	Demand Charge Mgmt	7/28/2018	0.0	MOTIE Investigation, June 2019
Korea	6.0	unknown	Solar Integration	9/1/2018	0.7	MOTIE Investigation, June 2019
Korea	6.0	unknown	Solar Integration	9/7/2018	0.0	MOTIE Investigation, June 2019
Korea	0.2	unknown	Solar Integration	9/14/2018	4.0	MOTIE Investigation, June 2019
Korea	1	unknown	Frequency Regulation	10/18/2018	2.6	MOTIE Investigation, June 2019
Korea	7	unknown	Solar Integration	11/2018	0.8	MOTIE Investigation, June 2019
Korea	[illegible]	unknown	Solar Integration	11/2018	0.9	MOTIE Investigation, June 2019
[illegible]	4.2	unknown	Solar Integration	11/21/	[illegible]	MOTIE Investigation, June 2019
Korea	1.3	unknown	Solar Integration	11/21/2018	0.6	MOTIE Investigation, June 2019
Korea	9.3	unknown	Demand Charge Mgmt	12/17/2018	1.0	MOTIE Investigation, June 2019
Korea	2.7	unknown	Solar Integration	12/22/2018	1.0	MOTIE Investigation, June 2019
Korea	3.3	unknown	Demand Charge Mgmt	1/14/2019	0.8	MOTIE Investigation, June 2019
Korea	5.2	unknown	Solar Integration	1/14/2019	1.2	MOTIE Investigation, June 2019
Korea	2.5	unknown	Solar Integration	1/15/2019	0.8	MOTIE Investigation, June 2019
Korea	46.8	unknown	Demand Charge Mgmt	1/21/2019	0.6	MOTIE Investigation, June 2019
US, OR, Powin	unknown	unknown	n/a	4/11/2019	unknown	The Oregonian
US, AZ, APS	2.0	2.0	Volt Reg., PQ, Solar int.	4/19/2019	2.0	APS
Korea	3.7	unknown	Solar Integration	5/4/2019	2.3	MOTIE Investigation, June 2019
Korea	1.0	unknown	Solar Integration	5/26/2019	1.0	MOTIE Investigation, June 2019
Korea	3.0	unknown	Solar Integration	7/12/2019	0.6	MOTIE Investigation, June 2019
Norway, Sydnes	2.0	unknown	Ship Hybrid Drive	10/10/2019	<1	Norwegian Maritime Authority
Korea, Haenam	1.8	unknown	Solar Integration	5/27/2020	unknown	E2News.com
UK, Liverpool	10.0	20.0	Frequency Regulation	9/15/2020	1 .5	Energy Storage News

33 Known Incidents

Self-perpetuating Reactions

A battery failure can trigger a heat-generating chemical reaction

- Release of flammable, explosive gases accelerates
  - Fire can propagate, or
  - Gases can build to explosive atmosphere
- Latent heat can reignite fire hours after extinguishment



Chain of Events involved in Thermal Runaway
Source: Ruiz, V., Pfrang, A.; "JRC exploratory research: Safer Li-ion batteries by preventing thermal propagation", Publications Office of the European Union , 31 Oct 2018.

What has the ESS industry learned?

	EVENTS	LESSONS	HAZARD IDENTIFICATION
2000s	Cell Level Failures	• Well-documented incidents with cell phones and laptops • Characterization: public data from DOE, NASA, DNVGL, etc. • Early transport and management guidance	high-temperature fires, off-gas constituents, chemistry / energy density thresholds
2010s	Propagation Hazards	• EV studies and early deployment failures • NFPA 855, UL 9540 • UL 9540A and FPRF tests • Integration Guidance	multi-module failure intensity, water suppression necessity, health warnings
2020	Explosions	• Large failure event forensics • First responder coordination • System-level Test	utility-scale ESS deflagration, life safety threat

Lessons Learned

Prevention

- Maintaining strict operational limits via **robust Battery Management Systems** (BMS) can inhibit thermal runaway
- **Thermal runaway may be initiated** at a cell level due to cell defects or age
- Propagation depends on many factors, such as **cell chemistry, construction** resistance of the module
- **Monitoring** of voltage, current, temperature, and gases may provide failure pre-conditions

SOFTWARE DESIGN & VALIDATION

QUALITY ASSURANCE & VENDOR COORDINATION

SUBSYSTEM INTEGRATION

DATA ACQUISITION & TRENDING

Mitigation

- Clean agent fire suppression (alone) is often incapable of stopping propagating thermal runaway
- Cascading thermal runaway generates large amounts of heat – continuous **water suppression** may be the best option to abate
- Explosive off-gases can build quickly – **ventilation is essential** to avoid deflagration
- Coordination, planning, and communications **before, during, and post event** can save lives and equipment

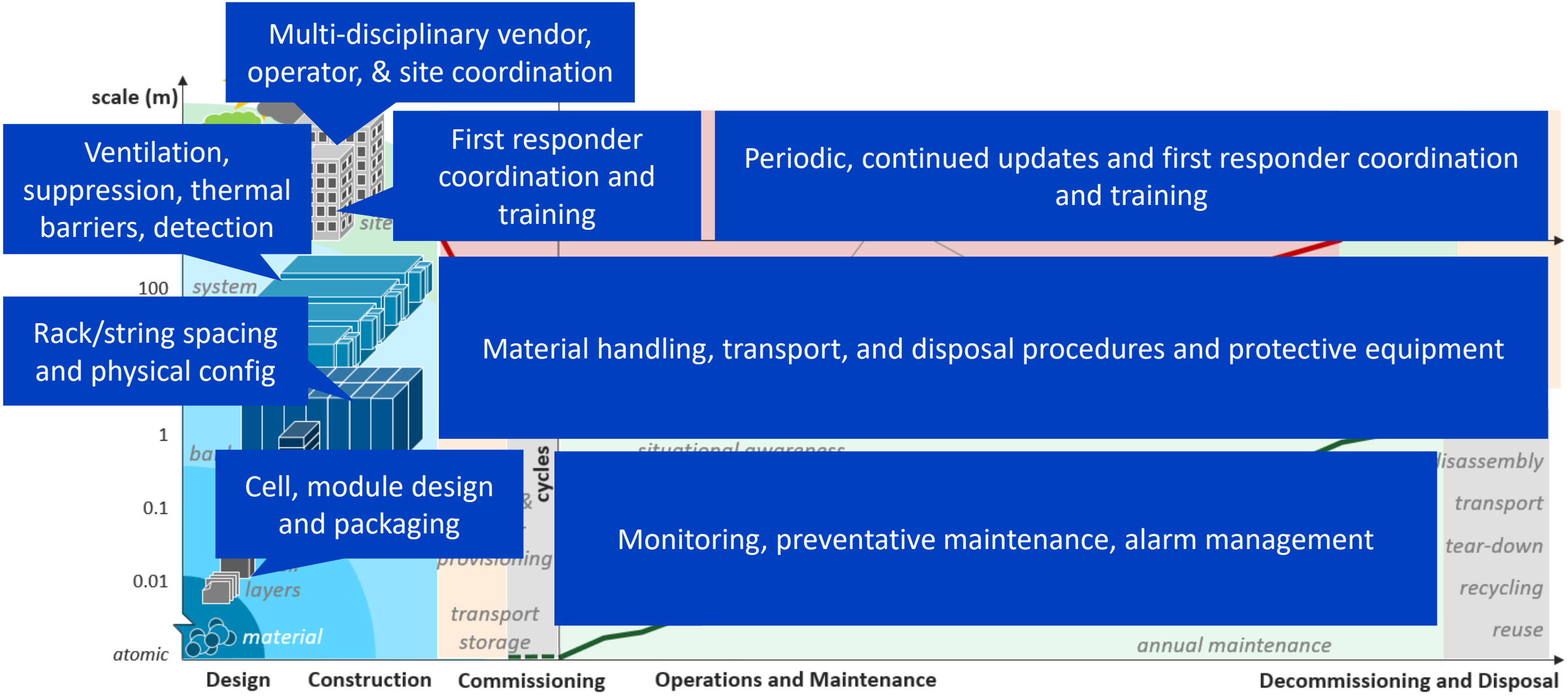
HAZARD IDENTIFICATION & TRADEOFF STUDIES

PROJECT SITING & RESOURCE PLANNING

SYSTEM ENVELOPE

RESPONSE PROCEDURES & INFORMATION SHARING

Many mitigation opportunities exist…



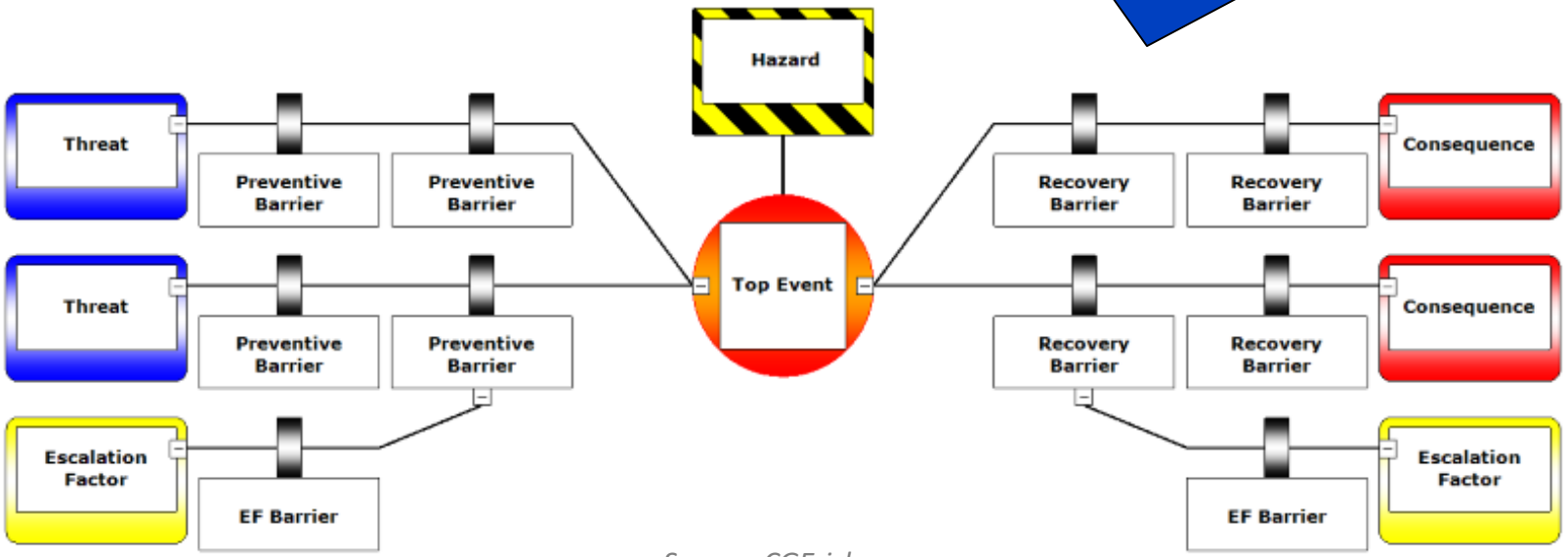
Understanding Hazard Pathways

Types of Hazards:

- **Fire**
- **Chemical**
- **Stranded Energy**
- Electrical
- Physical

Emerging standards address safety, but technology advances faster than standards

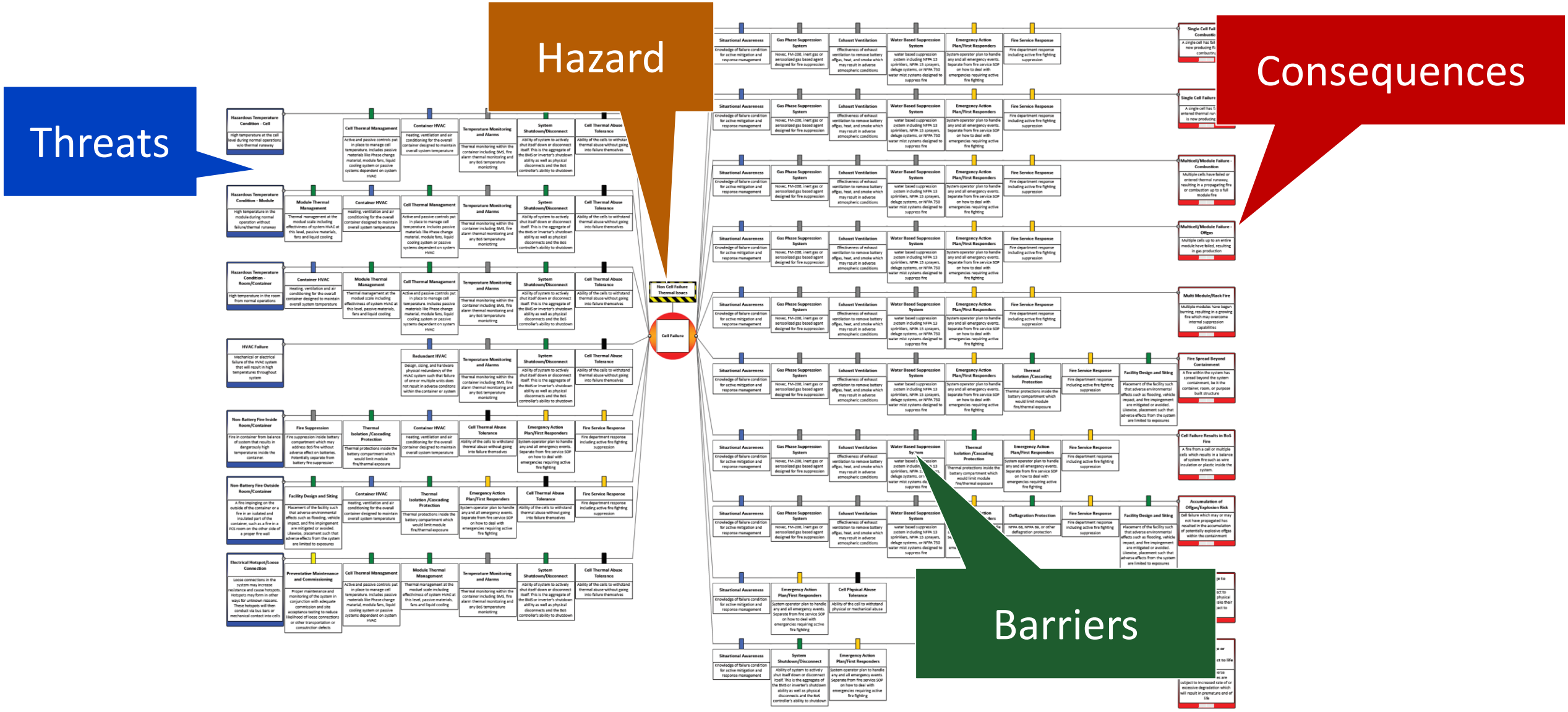
Download EPRI's Energy Storage Reference Fire Hazard Mitigation Analysis at **https://www.epri.com/esic**



Source: CGErisk.com

System Safety Depends Upon Proper Planning and Understanding

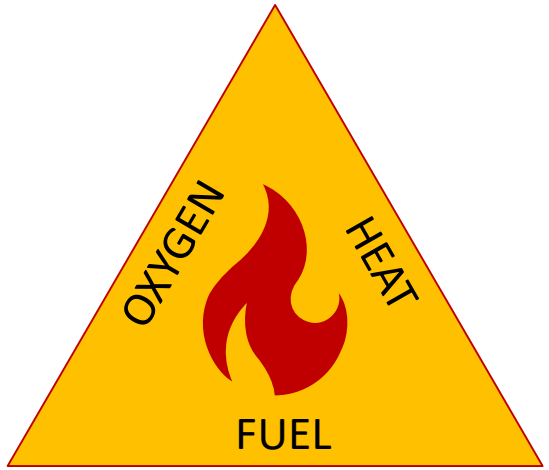
ESS Reference Fire Hazard Mitigation Analysis



https://www.epri.com/research/products/000000003002017136

Mitigation Measures

Measures	Examples
Design Considerations	sizing/arrangement, disconnect placement
Active Hardware	relays, exhaust ventilation
Passive Hardware	fuses, circuit breakers, dead fronts
Continuous Hardware	monitoring, SCADA
Human Factors	procedures, safe operating plans, emergency action plan
System Property	inherent stability, propagation resistance



combustion triangle

EPRI Fire Prevention and Mitigation Project

Expert Collaboration

Assemble external expert advisory committee to collaborate with project participants and identify key knowledge gaps.

Top-Down

Bottoms-Up

Site-Specific Hazard Assessment

Apply ESIC reference battery storage fire hazard analysis to specific projects. Evaluate potential threats, consequences, and mitigations. Assess publicly-available incidents.

Strategic Roadmap

Consolidate research and lessons learned. Coordinate outputs with industry via workshop and report. Establish safety roadmap prioritizing test and evaluation plans.

1. **Prioritized Testing**
2. **Collaboration**
3. **Knowledge Transfer and Communication**
4. **Interim Safety Guidance**

Phase II

ESIC

ENERGY STORAGE INTEGRATION COUNCIL

ESIC Stakeholders

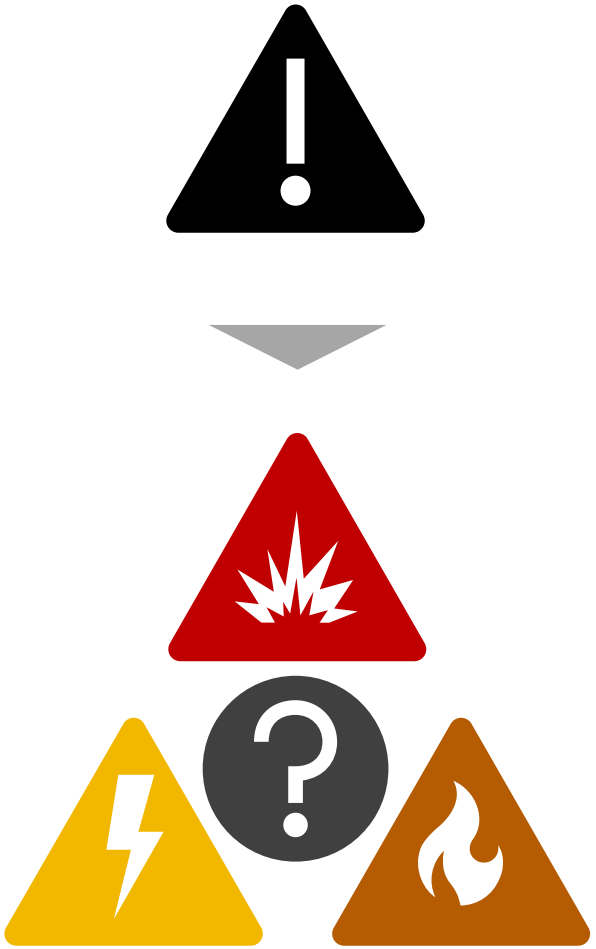
Email esic@epri.com to join the 2000+ industry collaborators

Publicly Available ESIC Resources

- A Guide to ESIC
- Energy Storage **Implementation** Guide
- Energy Storage **Cost** Template and Tool
- Energy Storage **Modeling** Bibliography
- Energy Storage **Technical Specification** Template
- Energy Storage **Test Manual**
- Energy Storage **Commissioning** Guide
- Energy Storage **Safety** Guidelines
- Energy Storage **Reference Fire Hazard Mitigation Analysis**
- Energy Storage **Safety Incident Reporting and Gathering List**
- Energy Storage **Request for Proposal** Guide
- **Common Functions** for Smart Inverters V4
- **StorageVET** and Supporting Documentation
- Electrical Energy Storage **Data Guidelines**
- Available at **www.epri.com/esic**

Interested in learning more?

- EPRI's Energy Storage Fire Prevention and Mitigation Project
  - accepting advisory committee members and sites to evaluate
- Energy Storage Integration Council
  - Participation is free: www.epri.com/esic
  - Safety task force currently discussing alarm management
- Contact with other questions or feedback:



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Together...Shaping the Future of Electricity