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Emerging Hazards of Battery Energy Storage System Fires

Grant Number: EMW-2016-FP-00833
Principle Investigator: Ofodike Ezekoye Ph.D., P.E.
University of Texas at Austin

In April 2019, an unexpected explosion of batteries on fire in an Arizona energy storage facility injured eight firefighters. More than a year before that fire, FEMA awarded a Fire Prevention and Safety (FP&S), Research and Development (R&D) grant to the University of Texas at Austin to address firefighter concerns about safety when responding to fires in battery energy storage systems of all sizes. Professor O.A. ('DK') Ezekoye is working with other engineers, firefighters, and industry partners to develop a better understanding of the magnitude of the fire hazards.

There has been a dramatic increase in the use of battery energy storage systems (BESS) in the United States. These systems are used in residential, commercial, and utility scale applications. Most of these systems consist of multiple lithium-ion battery cells. A single battery cell (7 x 5 x 2 inches) can store 350 Whr of energy. Unfortunately, these

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lithium cells can experience thermal runaway which causes them to release very hot flammable, toxic gases. In large storage systems, failure of one lithium cell can cascade to include hundreds of individual cells. The hot flammable gases can result in an explosion, or a very difficult to extinguish fire.

Although the fire service routinely responds to explosive scenarios, such as those associated with natural gas leaks, standard operating procedures do not exist for scenarios like a battery energy storage system for which there is no way to cut off the gas supply. The fire service is unaware and inexperienced with the fire and explosion hazards of BESS.

The FP&S R&D study started with a laboratory test in which a single cell failed in one commercial storage module containing a total of 14 cells. In one of the early tests, when a single cell failed, smoke and gases were released that ignited and burned intensely for 12 seconds. Toxic smoke and gases filled the test space.

The research team has subsequently connected small-scale battery failure test results to large scale fire and explosion consequences associated with these systems. Through this research, one of the biggest lessons learned for the fire service is that the utilities and commercial entities that own large battery systems are equally unfamiliar with the potential fire hazards. As well, there remain many questions about the toxicity of the battery vent gas.

From 2014 to 2018, residential BESS installations have increased by 200% annually. Further research into residential BESS hazards is essential as BESS hazards could eventually become a regular part of dwelling fires.

According to Professor Ezekoye, the results of this study will lead to wider awareness of the BESS hazards, a greater understanding of the underlying fire behavior of these systems, and eventually the development of safe standard operating guidelines and procedures for firefighters.

Link: www.UTFireResearch.com

For more information on Fire Prevention & Safety Grants including how to apply, please visit https://www.fema.gov/fire-prevention-safety-grants. 3-67

Tags:

- Assistance to Firefighters Grants

Last updated October 27, 2020

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National Terrorism Advisory System

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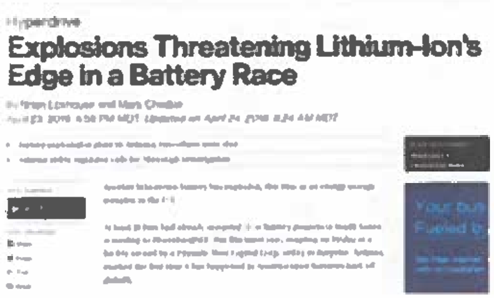
Safety is critical to the widescale deployment of energy storage technologies.

Bloomberg

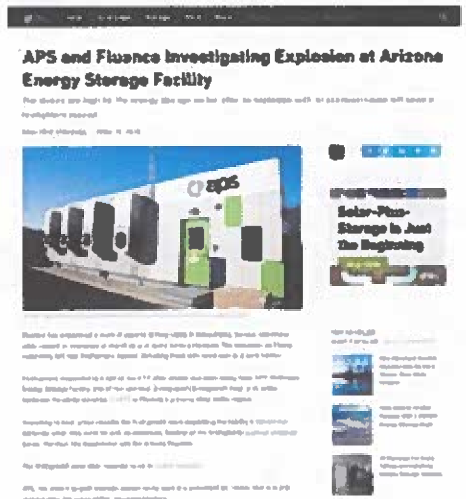


Hyperdrive

Explosions Threatening Lithium-Ion's Edge in a Battery Race

https://www.bloomberg.com/news/articles/2019-04-23/explosions-are-threatening-lithium-ion-s-edge-in-a-battery-race

Greentech Media



APS and Fluence Investigating Explosion at Arizona Energy Storage Facility

https://www.greentechmedia.com/articles/read/aps-and-fluence-investigating-explosion-at-arizona-energy-storage-facility#gs.gpky5k

The Korea Times

Biz & Tech

Frequent fire raising concerns over safety of solar energy

https://www.koreatimes.co.kr/www/tech/2018/12/133_260560.html

There is a tendency to use the availability heuristic when considering risk.

To avoid this, consider how many batteries continue to operate without problems every day.

Part I Understanding battery fires and vent gas

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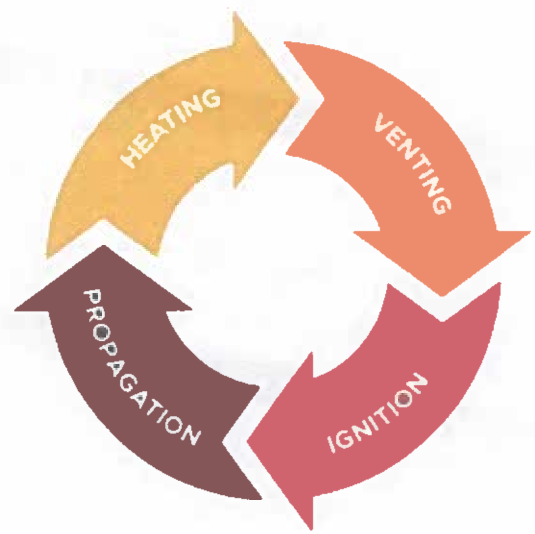
Hazards – Thermal Runaway

"The process where self heating occurs faster than can be dissipated resulting in vaporized electrolyte, fire, and or explosions"

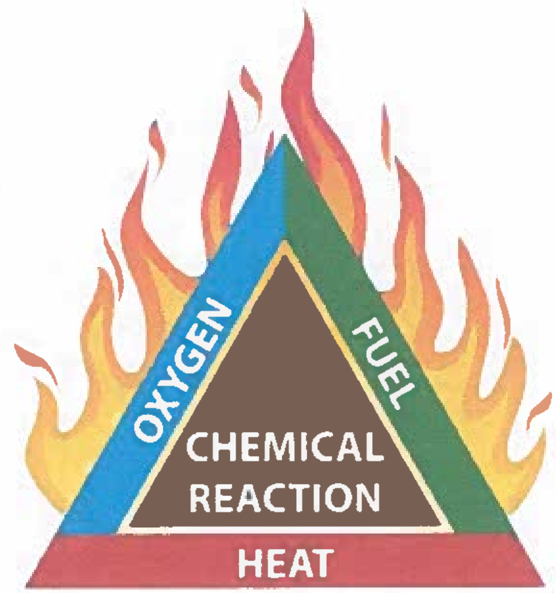
- Initial exothermic reactions leading to thermal runaway can begin at 80° - 120°C.
- Venting of electrolyte gasses
- Ignition of gasses (fire or explosive)
- Propagation within module
- External flame initiates preheating of additional cells/modules



Credit: This slide was prepared by Matt Paiss of PNNL (PNNL-SA-149573)

Fire Tetrahedron

- Typically, all that is required for fires to occur is O2, Fuel, and Heat.
- Some chemistries contain oxides that release rapidly under high heat conditions.
- Li-ion fires can occur in low O2 atmospheres
- Flammable gasses will continue to be produced.



PREVENTING/REMOVING HEAT IS KEY

Credit: This slide was prepared by Matt Paiss of PNNL (PNNL-SA-149573)

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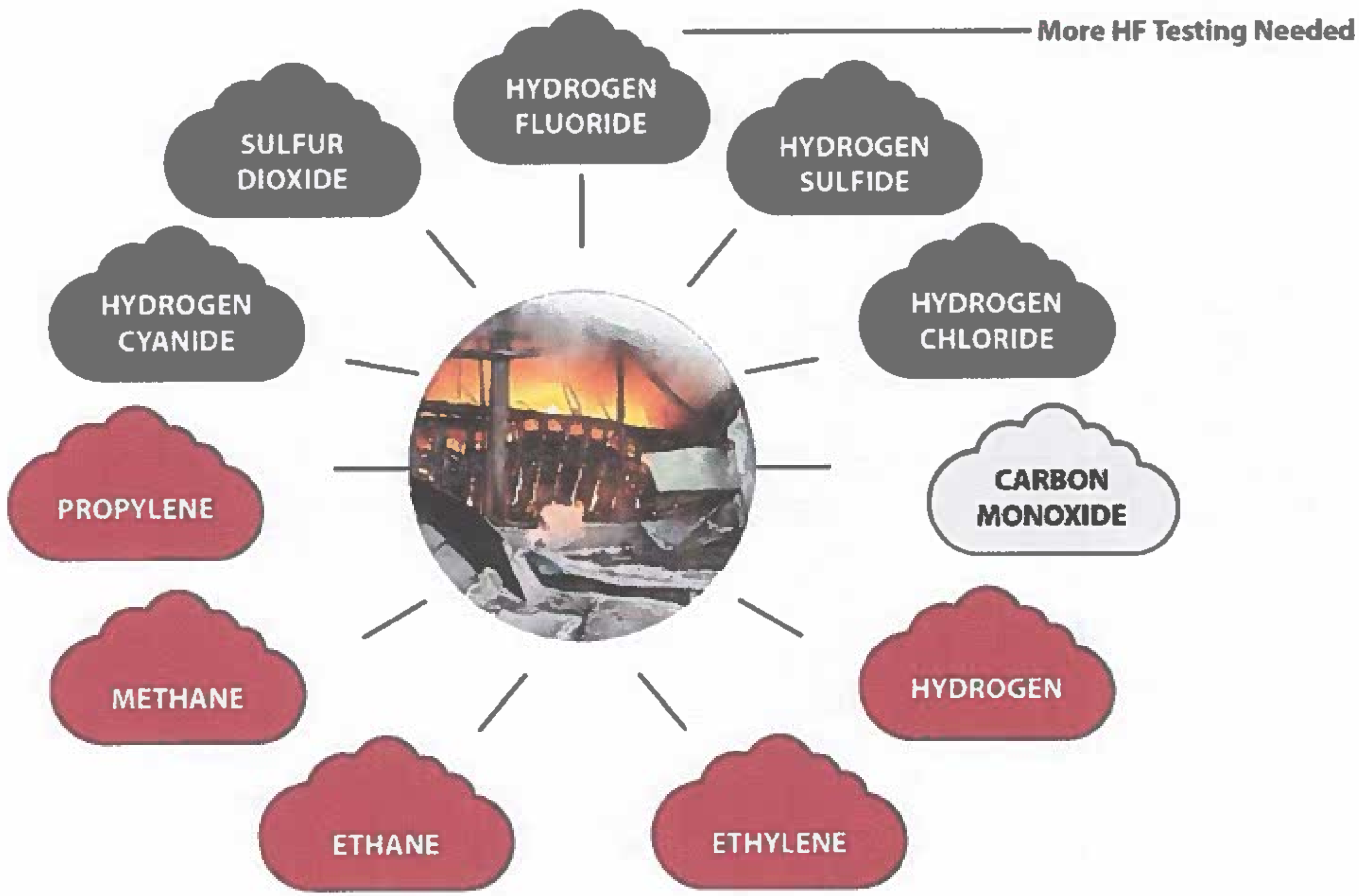
9 | # Hazards – Flammable/Toxic Gases



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Mechanics of Thermal Runaway

How does thermal runaway start?

- Thermal, electrical, or mechanical "abuse"
- However, "abuse" thresholds are statistical properties and can change with time, usage, and environment

Thermal runaway measured via accelerated rate calorimetry (ARC)

1. Self-heating onset temperature
2. Thermal runaway onset temperature
3. Total heat release (ΔT)

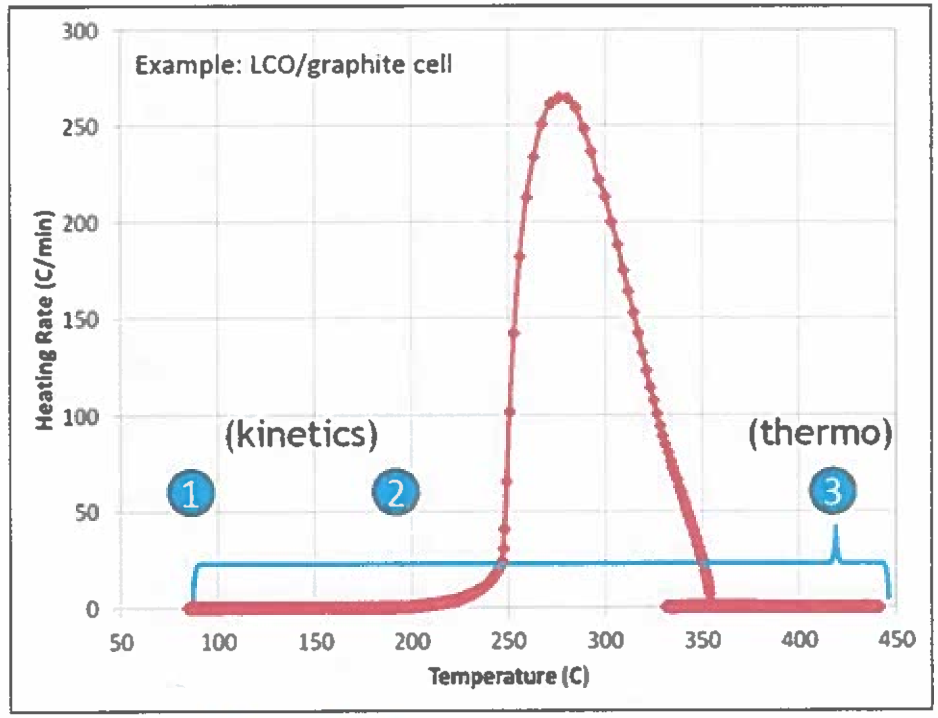

Figure Credit: Yuliya Preger https://custom.cvent.com/5B9E896FC2FC4AC69710004DEF407285/files/f4910d8f6dec42fb8b312e3934da8826.pdf

Cell to Cell Propagation

Thermal runaway in one cell can drive nearby cells into thermal runaway.

Whether or not thermal runaway cascades through a module, and how quickly it does, depends on **abuse thresholds, heat capacity, heat generation rates, and heat dissipation rates**.

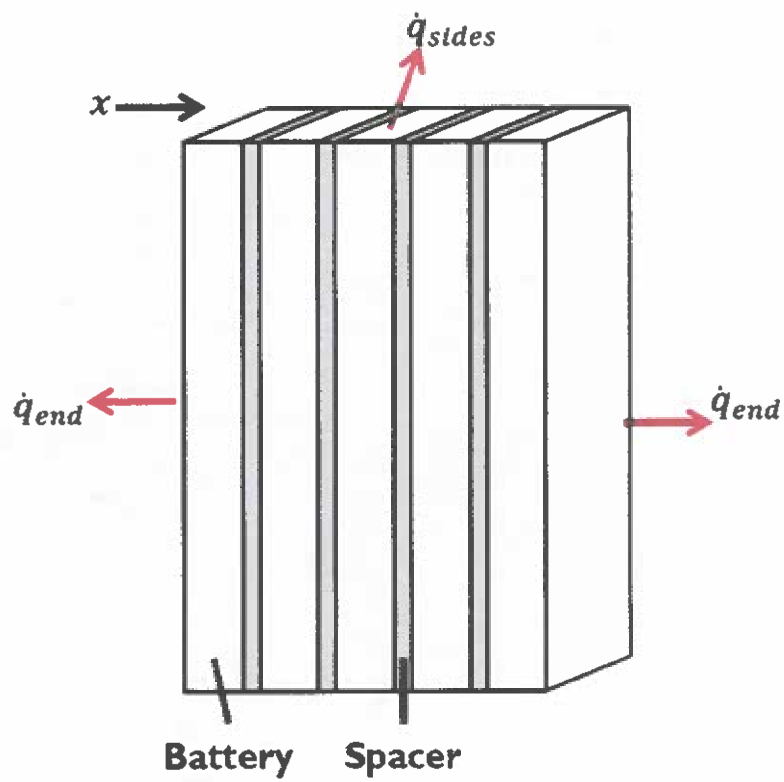

Figure Credit: John Hewson https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/ESSRF/Hewson_John.pdf

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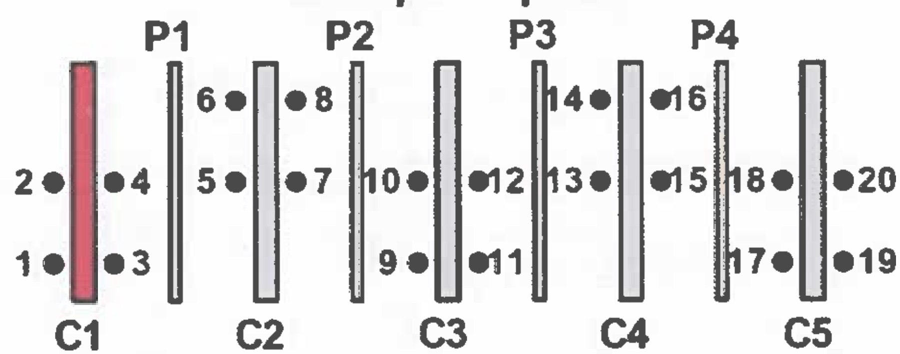
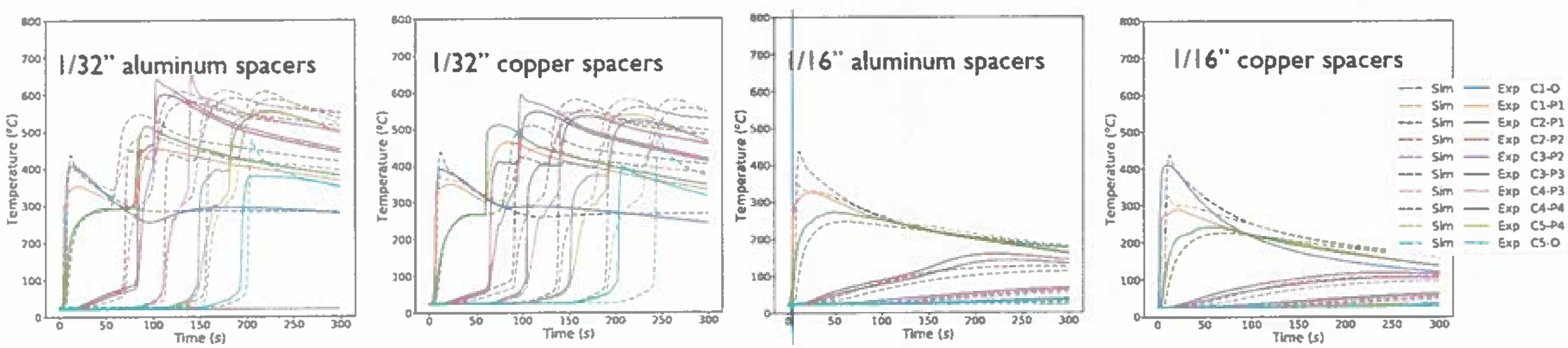
Cascading failure modeling/testing

- Successful prediction over a range of reduced SOC and metallic inserts.
- Collectively add heat capacity & increase time delay for cell runaway.
- Prevent propagation for 30% increase in net heat capacity.

Thermocouple Locations with spacer plates





Kurzawski, A., et al. (2020). "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks." Proc. Combust. Instit. 38.

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Enclosed environments and gas buildup

If thermal runaway occurs and,

If it propagates through a module,

How might the gasses produced be hazardous?

For one cell type, thermal runaway vent gasses were found to be combustive above 6.3% concentration in air. Combustive strength for this sample was in-between methane and propane.

Source: K. Marr, V. Somadepalli, Q. Horn, Explosion hazards due to failure lithium-ion batteries, Global Congress on Process Safety (2013).

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Deflagration Challenges

- System with clean agent suppression system.
- TR continued after deployment
- Deflagration occurred @ 44min
- Event required direct water application.

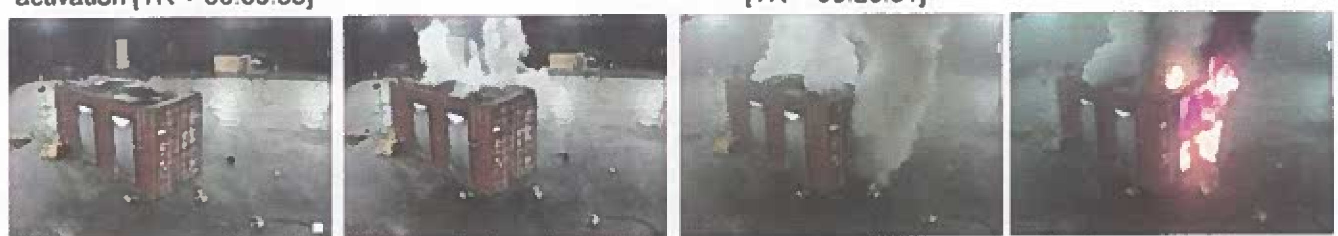
Demonstration 2 – Timeline of Major Events

Smoke accumulation at second smoke detector activation [TR + 00:00:55]

Novec 1230 discharge [TR + 00:00:58]

Smoke stratification before ignition [TR + 00:26:51]

Ignition [TR + 00:28:32]



Partial volume deflagration [TR + 00:44:39]

Continued thermal runaway propagation [TR + 00:46:26]

Smoke plume from open door [TR + 02:09:27]

Flashover and flaming from open door [TR + 02:09:48]

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https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf

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Deflagration Challenges

- System with 0.5 gpm sprinkler system.
- Deflagration 30 min post water application.
- UL demonstration of deflagration risks highlights that no matter what the suppression system – **deflagration still occurs.**

Demonstration 3 – Timeline of Major Events

Smoke accumulation and first response of LEL at the ceiling [TR + 00:00:29]

Ignition leading to sustained flaming [TR + 00:08:49]

Water flow initiated at 0.5 gpm/ft^2 [TR + 00:10:13]

Smoke and gas release from TR propagation [TR + 00:30:49]

Deflagration vent operation [TR + 00:42:02]

Water flow discontinued [TR + 01:05:55]

Thermal runaway propagation after end of water flow [TR + 01:13:05]

TR propagation continues after water flow restarted [TR + 01:49:54]

https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf

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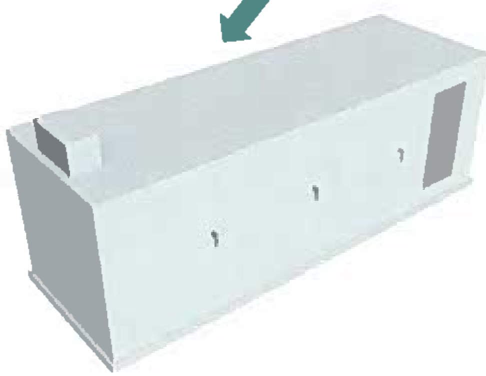
Different mitigation design strategies

Some of the design options available

- Prevent thermal runaway (e.g. non-lithium-ion chemistry)
- Limit the size (energy) of any one module
- Don't put the battery in an enclosure
- Enclosure deflagration venting



PNNL's INTELLIVENT Technology:
Smoke detector activated ventilation

Andrew F. Blum and R. Thomas Long Jr. "Hazard Assessment of Lithium Ion Battery Energy Storage Systems FINAL REPORT" Fire Protection Research Foundation, 2016, Available: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFFireHazardAssessmentLithiumIonBattery.ashx

Special Topics: Early Detection

Li ion batteries release trace amounts of vent gas in the self-heating phase prior to thermal runaway.

If these gasses are detected, then shutting down charge/discharge may prevent thermal runaway.

The effectiveness of early detection depends on all the same factors as for propagation: abuse thresholds, heat capacity, heat generation rates, and heat dissipation rates.

Early detection can help serve as a part of an effective wholistic propagation resistant design but is not in-and-of-itself sufficient to ensure that a battery cell fire will not occur.

From Published "Li-ion Tamer®" data

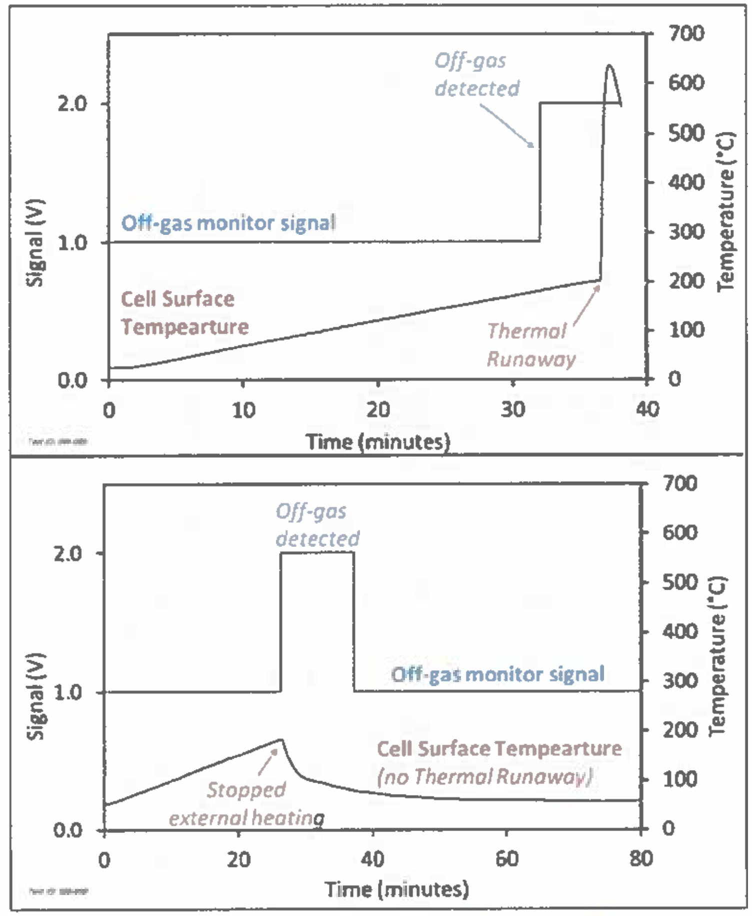


Image source: https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/ESSRF/18_Frank_Nick_S6.pdf

Special Topics: Battery Management During an Outage

Safe Storage temperature of lithium-ion batteries tends to be much wider than their operating temperature. Hence it is rarely a safety issue for the **temperature management** systems to be without power for a matter of a few days. This does not hold true in extreme climates where temperatures in an enclosure can exceed safe storage temperatures.

However, a BMS collects battery fault data that could be very useful in a post-incident analysis. If a power outage stops data acquisition, then it can be difficult to determine what went wrong. Hence, **it is recommended that a BMS includes some backup power** (often in the range of 4-8 hours). This is often accomplished with a small bank of VRLA batteries.

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Special Topics: Access Control

Batteries are not hazardous to passing pedestrians, so access control is less about the potential hazard they pose and more about the hazard that people could pose to them.

- Batteries are expensive/valuable so it is conceivable that they could be stolen.
- Batteries are sensitive to mechanical abuse so a car accident could start a fire.
- In cybersecurity terms, a malicious actor with physical access to the battery management system could cause significant damage or conceivable even a fire.

Take-Aways From Part I

Design should prevent thermal runaway propagation at every level of integration.

Design should mitigate vent gas combustion hazard.

Part 2 Emergency Response Coordination

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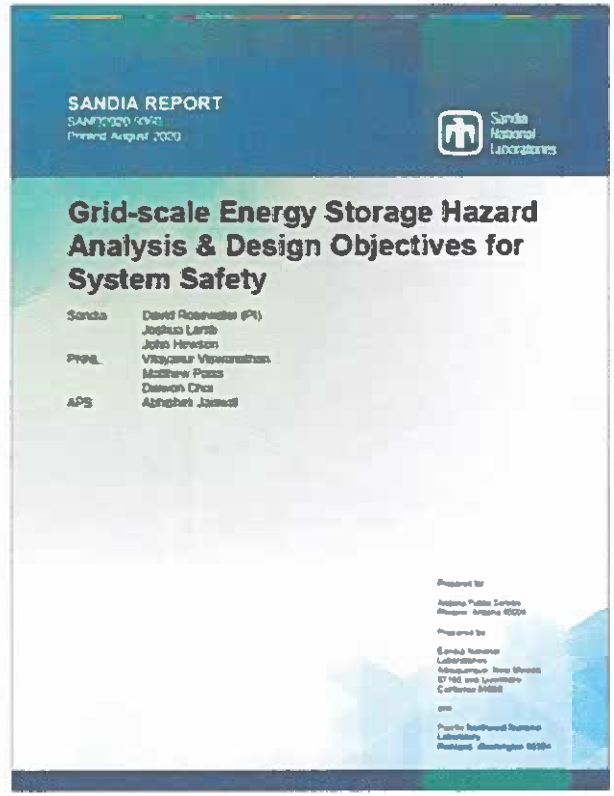
Hazard analysis report

The objective of this research is to prevent fire and explosions in lithium-ion based energy storage systems. This work enables these systems to modernize US energy infrastructure and make it more resilient and flexible (DOE OE Core Mission).

The primary focus of our work is on lithium-ion battery systems. We apply a hazard analysis method based on system's theoretic process analysis (STPA) to develop **"design objectives" for system safety**. These design objectives, in all or any subset, can be used by utilities "design requirements" for issuing requests for proposals (RFPs) and for reviewing responses as a part of their procurement process. The design objectives can also serve as model standards for standard development organizations (SDOs) to consider in the course of their consensus-based work.

Similar Efforts:

- EPRI Guide to safety in energy storage system
- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems
- UL 9540 Ed 2, ANSI/CAN/UL Standard for Energy Storage Systems and Equipment
- FDNY: 2020 NYC Fire Code –Section 608 STATIONARY STORAGE BATTERY SYSTEMS


SANDIA REPORT

Printed August 2020

Sandia National Laboratories

Grid-scale Energy Storage Hazard Analysis & Design Objectives for System Safety

The full report can be found at:
https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

Design objectives for firefighter safety

When firefighters arrive on the scene of a battery system fire, they initiate an ongoing hazard assessment with priorities being life, property, then environment.

The system must be designed such that firefighters can understand the current state of the system without being exposed to a hazard.

When firefighter action is required, such as in the case of an uncontrolled runaway reaction that may spread to nearby structures, options must be available for actions that do not expose firefighters to the hazards inside the system.

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

Safety critical information availability to firefighters

Design objective 1.1: The system includes a durable, external display, accessible from a safe location, for firefighters to access the following information: 1) **what percentage of the cells in the system have vented**, 2) is the **ventilation system** working as expected, 3) **what voltages are present** in the system, 4) what the **temperature trending** history is internally, 5) what actions have been taken by the **automated systems (e.g. fire suppression)**, and 6) the **presence or absence of any gases in hazardous concentrations (including smoke)**. Note that this design objective is dependent on local firefighters having the training to interpret the information provided, as discussed in Section 2.3.6.

OR

Design objective 1.2: The system includes continuous monitoring by a designated individual . This designee may be a trained and qualified utility employee or integrator employee. This designee must be able to provide firefighters with the following information: 1) what percentage of the cells in the system have vented, 2) is the ventilation system working as expected, 3) what voltages are present in the system, 4) what the temperature trending history is internally, 5) what actions have been taken by the automated systems (e.g. fire suppression), and 6) the presence or absence of any gases in hazardous concentrations (including smoke). To meet this design requirement a designee must be available at all times to respond to the site within a specified time period. The emergency telephone number must then be provided to the fire department and posted visibly and durably on the outside of the enclosure. Note that this design objective is dependent on local firefighters having the training to interpret the information provided, as discussed in Section 2.3.6.

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

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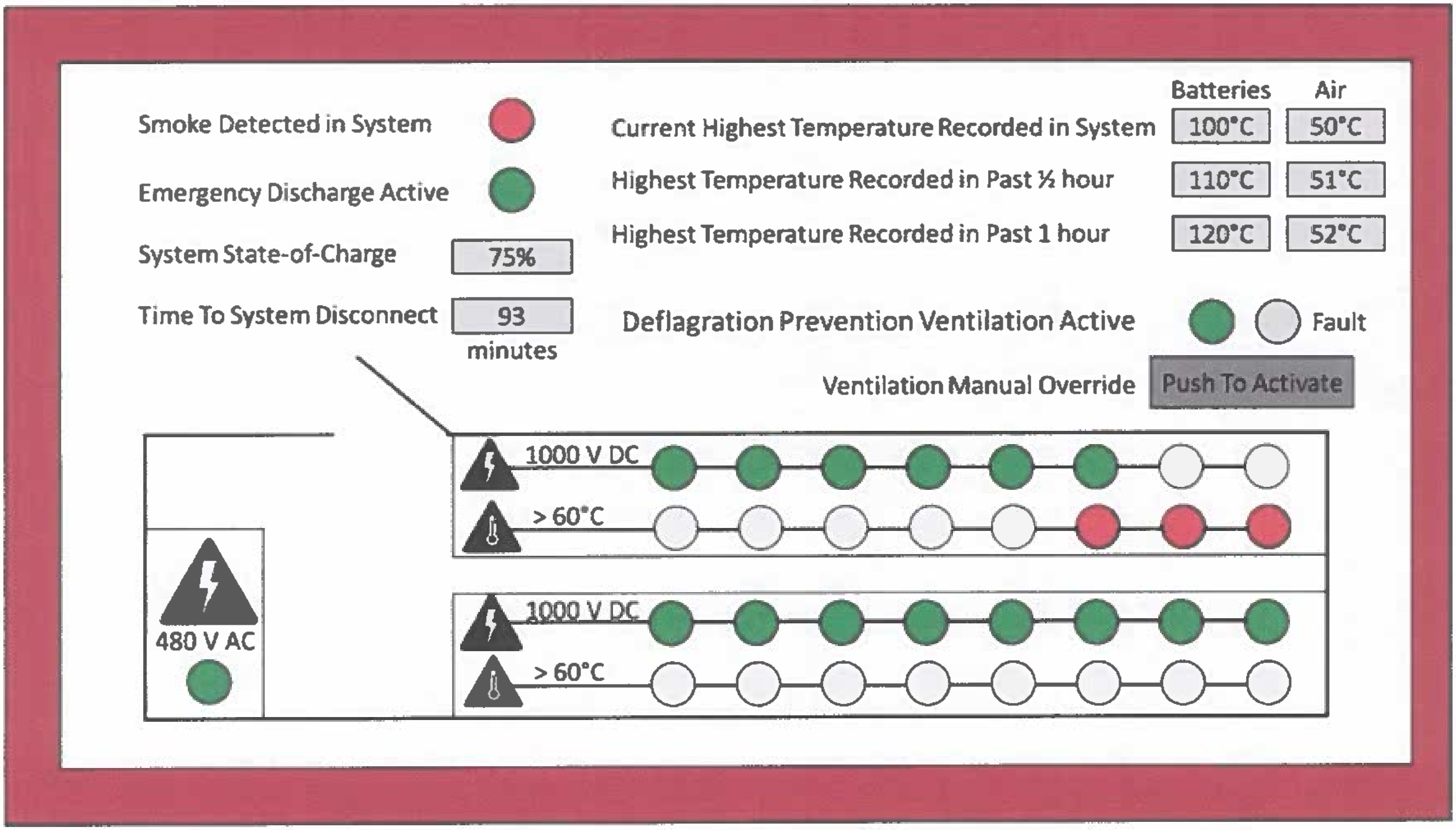
Example layout for an energy storage fire alarm control panel



From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

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Design for safe firefighter interaction

Design objective 1.3: The system includes one or more methods for firefighters to **extinguish fires** and/or **ventilate the environment** inside the system **without being exposed to fire** or a potentially explosive environment. At a minimum this includes a grid-disconnect (E-Stop) switch.

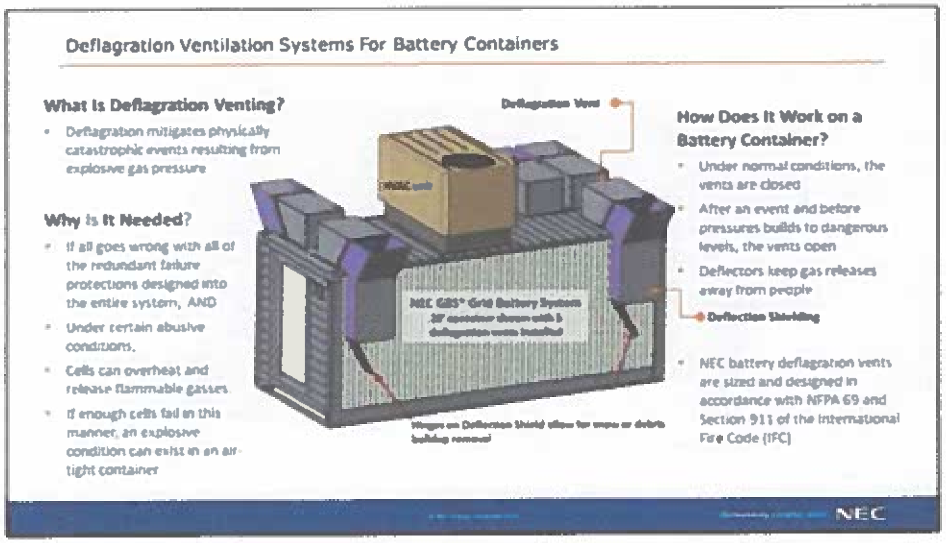

Figure source: https://share-ng.sandia.gov/ess/wp-content/uploads/2019/04/4a_Hoff_GSS-Safety-Overview-v15.6_MHOFF-with-Notes.pdf

Image source: https://www.fireengineering.com/fire-prevention-protection/energy-storage-system-installations-fire-service-awareness/#gref

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Firefighter Training Objectives

Training objective: This training will be classroom based and will focus on hazard identification, risk assessment, and actions that can be taken in different example scenarios. Firefighters will be trained to recognize the presence of lithium-ion batteries. They will be trained to recognize high voltage hazards, and compounding factors (such as an enclosed spaces). **They will be trained to recognize that the smoke vented from batteries during a fire could be combustible and should be allowed to ventilate before it is safe to approach.** Trainees will be instructed on how to interpret system state information provided by the operations designee to perform on-site risk assessment. This information will include system hazards such as 1) what percentage of the cells in the system may have vented, 2) is the ventilation system working as expected, 3) what voltages are present in the system, 4) what the temperature trending history is internally, and 5) what actions have been taken by the automated systems (e.g. fire suppression). Guidance will be provided on how a visual inspection may provide sufficient information to assess the hazard. Finally, best practices will be provided on **determining safe entry, methods for limiting the spread of a battery fire, identifying when the best approach is to not put out the fire** (letting hazardous stored energy be dissipated safely), and **determining when it is safe to leave an incident site**.

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

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Impact of a Lithium-Ion Fire to Adjacent Populations

In general, as we understand currently, the smoke from a lithium-ion battery fire is as toxic to human health as a fire in a similar mass of common plastics. However, sometimes the safest/best firefighter response to a propagating battery fire is to simply let the fire consume the active material, thereby dissipating the stored energy, while protecting nearby structures. This may mean that a battery fire will produce smoke for a longer duration than fires in plastics. As toxic impact to human health is based on both severity and duration of exposure a battery fire in a neighborhood could have a greater impact than a fire in a comparable mass of plastics. Because of this, **it is recommended that siting policy consider the smoke produced during conflagration, whether generated by thermal runaway or external fire, and the population potentially exposed to the smoke. This consideration impacts duel-occupancy structures, locations where evacuation options are limited, and a location's proximity to vulnerable populations such as schools or elderly care facilities.**

Table 2: Estimated battery energy to reach the IET and FLET values for the NO, CO, HCl, SO2 and HF toxic gases (exposure time of 60 minutes, fire occurring in a 50 m3 room) (adapted from [3])

(Wh)	HF	CO	NO	SO_2	HCl
IET	60	290	280	530	1320
FLET	110	1140	2080	4710	7880

Source: P. Ribiere, S. Grugeon, M. Morcrette, S. Boyanov, S. Laruel-lea, G. Marlair, Investigation on the re-induces hazards of li-ion battery cells by re calorimetry, Energy and Environmental Science 5 (2012) 5271{5280.

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

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Impact of a Lithium-Ion Fire to Adjacent Structures

The risk that a battery fire spreads to nearby structures should also be considered. **Rules structuring the placement of large, oil-filled transformers can offer reasonable guidance on how to structure the siting/offset requirements that could be applied to battery systems.** These rules should be based on the total volume of fuel and how much heat it produces during a fire. For a given battery type these data can be found in the abuse test data for the cell, multiplied by the number of cells per enclosure. Fire barriers can also be considered (similar to oil-filled transformer siting requirements).

The risk of an explosion should also be considered in the design as well as location of the system (see design objective 3.3 in Section 2.3.3).

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

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30 ## Keep in mind - the status quo is not risk neutral

Proximity to fossil power plants is associated with higher rates of asthma, birth defects, and even early death [see references below]. PV and Battery energy storage can provide similar services without harmful emissions.

Perera, Frederica P. "Multiple Threats to Child Health from Fossil Fuel Combustion: Impacts of Air Pollution and Climate Change." Environmental health perspectives vol. 125,2 (2017): 141-148. doi:10.1289/EHP299

Schwartz, Joel. "Air pollution and children's health." Pediatrics vol. 113,4 Suppl (2004): 1037-43. https://pubmed.ncbi.nlm.nih.gov/15060197/

https://noharm-uscanada.org/sites/default/files/documents-files/828/Health_Effects_Coal_Use_Energy_Generation.pdf

https://www.catf.us/educational/coal-plant-pollution/

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31 Take-Aways From Part 2

Battery systems should be designed to isolate hazards and readily provide safety critical information in order to protect firefighters.

The permitting process should consider the localized impacts of a possible fire (including smoke).

The status quo is not risk neutral.

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Questions?

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Thank you to Dr. Imre Gyuk, DOE - OE

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Backup Slides on Safety Codes and Standards

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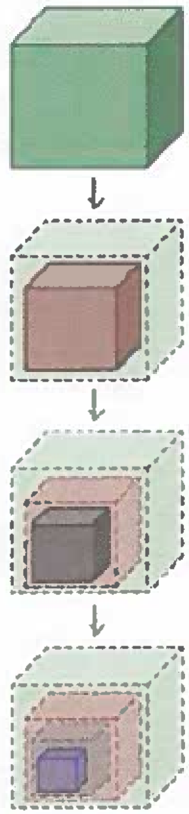
CODES AND STANDARDS UPDATE

Publication released quarterly

The following activities support that objective and realization of the goal:

1. Review and assess C/S which affect the design, installation, and operation of energy storage systems (ESS)
2. Identify gaps in knowledge that require research and analysis to provide data for technical committee inputs
3. Identify areas in C/S that are potentially in need of revision or enhancement and can benefit from activities conducted under research and development
4. Develop input for new or revisions to existing C/S through individual stakeholders, facilitated task forces, or through laboratory staff supporting these efforts



BUILT ENVIRONMENT

- iCodes – IFC, IRC, IBC
- IEEE – C2, SCC 18, SCC21
- NFPA 5000, NFPA 1, ISA

ENERGY STORAGE SYSTEMS

- UL 9540, MESA
- ASME TES-1, NECA
- NFPA 791

INSTALLATION / APPLICATION

- NFPA 855
- NFPA 70
- UL 9540 A
- IEEE C2
- IEEE 1635/ASHRAE 21
- IEEE P1578
- DNVGL GRIDSTOR
- FM GLOBAL 5-33
- NECA 416 & 416

SYSTEM COMPONENTS

- UL 1973
- UL 1974
- UL 810A
- UL1741
- CSA 22.2 No. 340-201
- IEEE 1547
- IEEE 1679 Series

Available: https://www.sandia.gov/energystoragesafety-ssl/

Codes & Standards Landscape

- Building & Fire Codes are adopted typically at a state level
- Product and installation Standards are referenced in the Codes.
- Codes & Standards have evolved, but much slower than deployments
  - Typically updated every 3 years.
- Energy density and system sizes increasing
  - Cabinets not mentioned in NFPA 855 or IFC
- Challenges with fire protection
- Product listing expensive and time consuming
- Inconsistent Code adoption state-state

Credit: This slide was prepared by Matt Paiss of PNNL (PNNL-SA-149573)

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International Fire Code (IFC)

2021 International Fire / Residential Code

- IFC Section 1207 – IRC Section 327
- Changes from 2018
  - Harmonizes with NFPA 855
  - Requires listing to UL9540
  - Scope ads O&M, retrofit, commissioning, decommissioning
  - Exemption for telecom using Pb & NiCd @ < 60VDC
  - Suppression system based on 9540a
  - Explosion control: NFPA 68 or 69
  - Post-Fire Mitigation Personnel
  - Emergency Response Plan & Training

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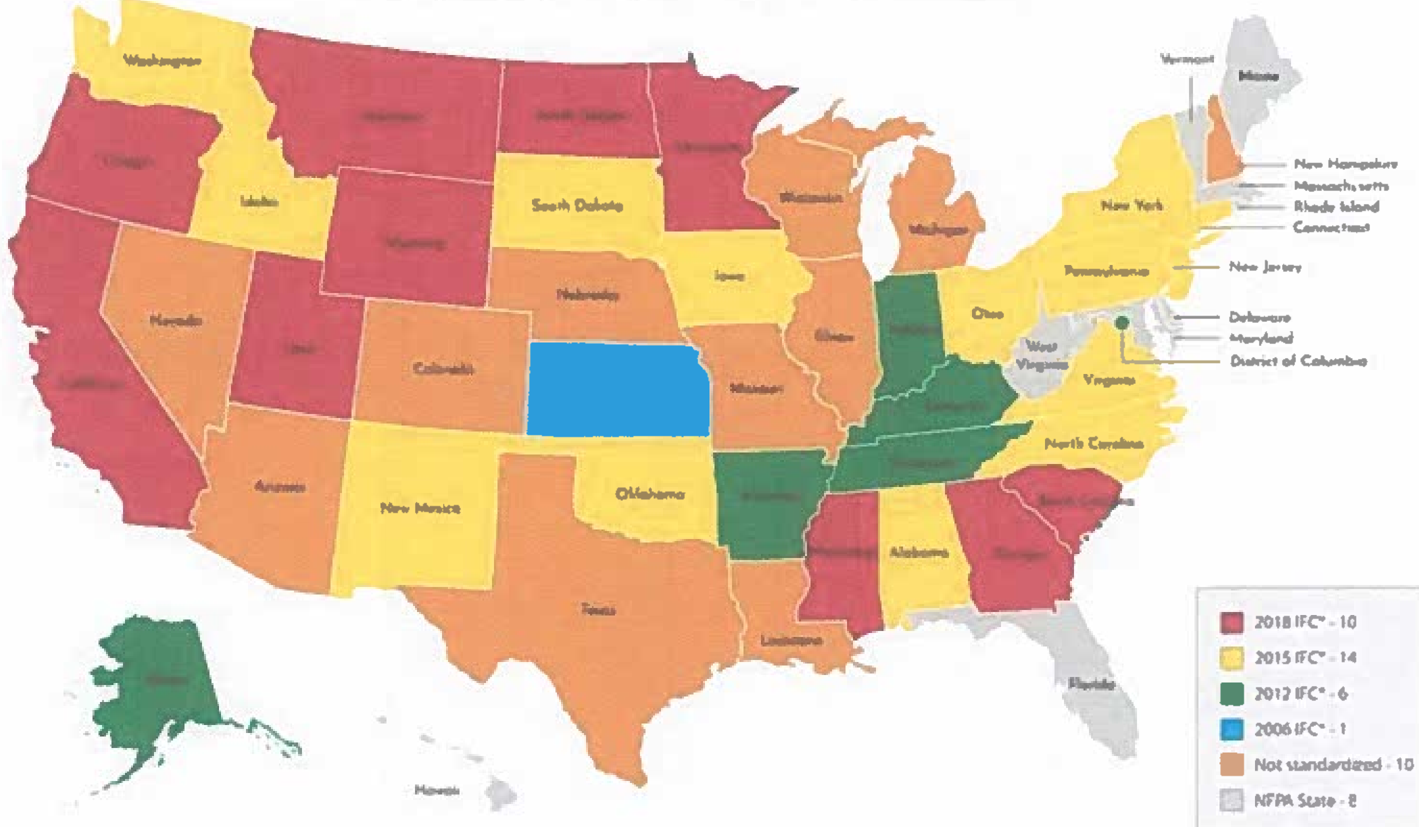
IFC Adoption Map

International Fire Code (IFC)® in Effect



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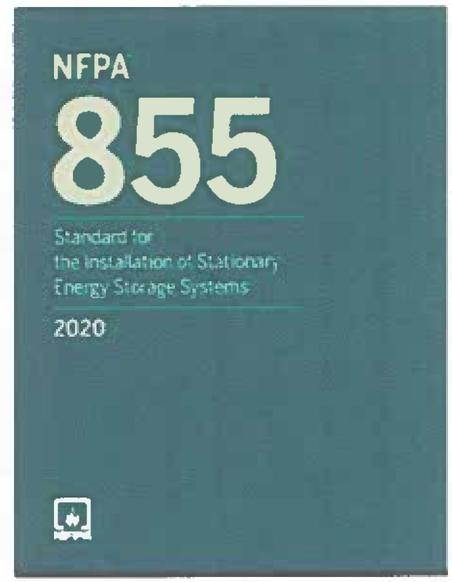
National Fire Protection Association (NFPA) 855

2020 NFPA 855 Standard for the Installation of ESS

- 1st Edition published
- Scope reserved for next cycle based on appeal by utilities for exemptions.
- Covers
  - Installation
  - Commissioning
  - O & M
  - Emergency Response
  - Decommissioning
- Referenced directly in 2021 NFPA1 Fire Code



Rooms, areas within buildings, and walk-in units require:

1. Automatic sprinkler w/ min density of 0.3gpm/ft2
2. or, based on UL9540a fire testing data

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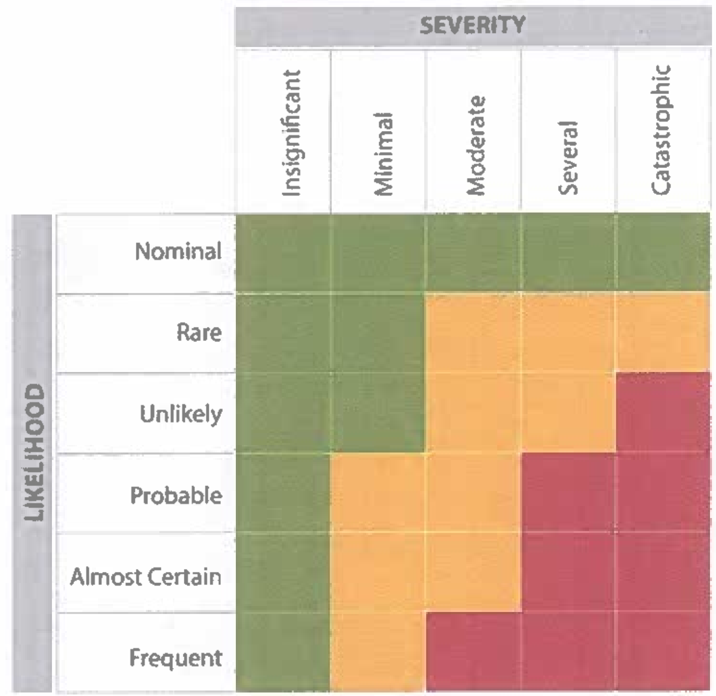
NFPA 855 Hazard Mitigation Analysis (HMA)

Hazard mitigation analysis (HMA) shall be provided for:

1. Battery technologies not specifically covered (Other)
2. Multiple battery technologies in a room with a potential for adverse interactions
3. When allowed as a basis for increasing MAQs



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HMA Continued

The HMA evaluates single fault failures

- Thermal runaway in a single battery array
- Failure of the energy management system
- Failure of ventilation system
- Voltage surges on the primary side
- Short circuits on the load side of the batteries
- Failure of the smoke or gas detection, fire suppression

The fire code official can approve deviations or new ESS technologies based on the HMA.

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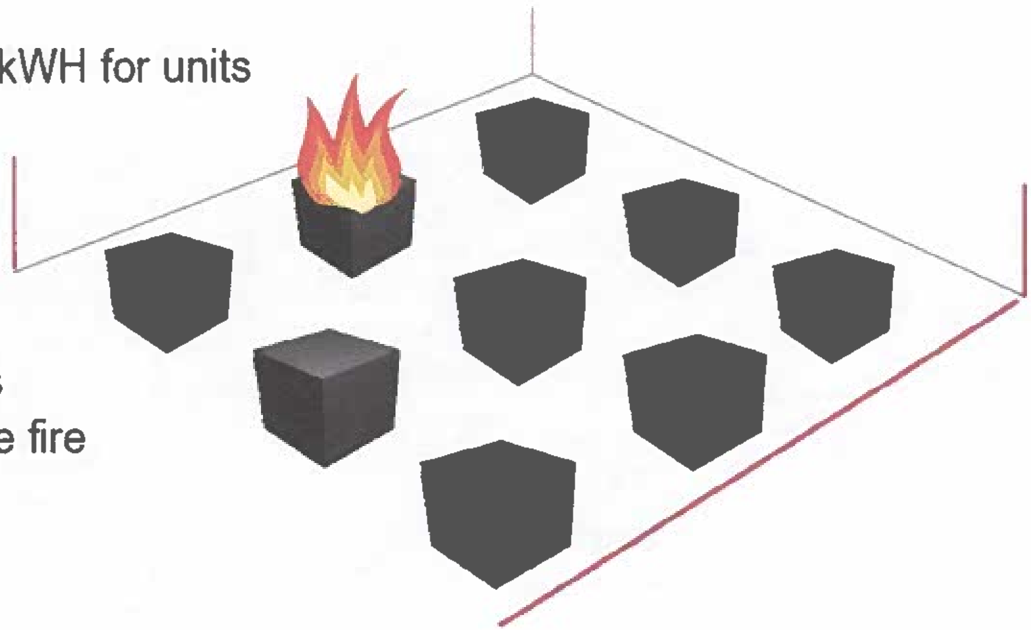
Size, Separation & Minimum Acceptable Quantity (MAQ) Limits

Max 50 kWH for units



Other arrangements based on large scale fire testing

Spaced min. 3 ft. from other arrays and from walls

Max. 600 KWh aggregate/fire area (200 kWH other)

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Explosion Protection

Two options for meeting requirement:

1. NFPA 68 – Deflagration Venting.

Blow-out panels to protect structure from explosion based on max gas production in cell tests.

2. NFPA 69 – Deflagration Prevention.

Exhaust system designed to keep below 25% of LEL in area.

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Large Scale Fire Testing

The fire code official can approve the following installations based on large-scale fire testing:

- Increased array (unit) size
- Reduced spacing to adjacent units and/or walls
- Increased MAQ in a fire area

Testing to be conducted by an approved test lab and show:

- A fire in one unit will not propagate to an adjacent unit
- A fire in one unit will be contained within the test room
- UL 9540A was developed to conduct these fire propagation tests

2021 IFC/NFPA1 specifies UL 9540A for this testing

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UL 9540 Listing

- This is a SYSTEM listing, not for components.
- Includes a UL1973 listed battery & UL1741 listed inverter
- Construction & Performance
- Mechanical & Environmental Tests
- Communications Systems
- Functional Safety
- HVAC
- Includes requirements for UL9540a fire testing


ANSI/CAN/UL 9540:2020

STANDARD FOR SAFETY

Energy Storage Systems and Equipment

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UL 9540a Test Method

- Test method, NOT a listing or certification
- 4th edition has clarifications on module test
- Used to characterize gas characterizations for chemistries that go into TR.
- Used to design fire protection and explosion studies.

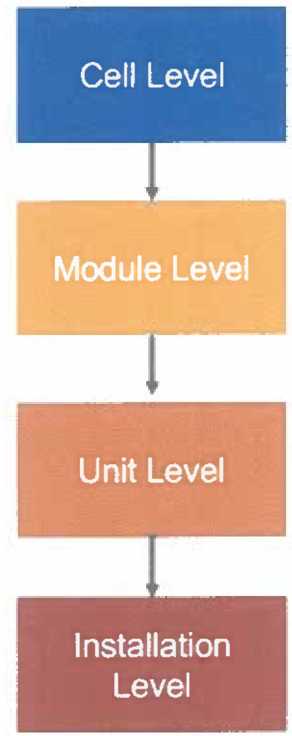
Evaluating/interpreting test results can be challenging


JOINT CANADA-UNITED STATES NATIONAL STANDARD

ANSI/CAN/UL 9540A:2019

STANDARD FOR SAFETY

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems



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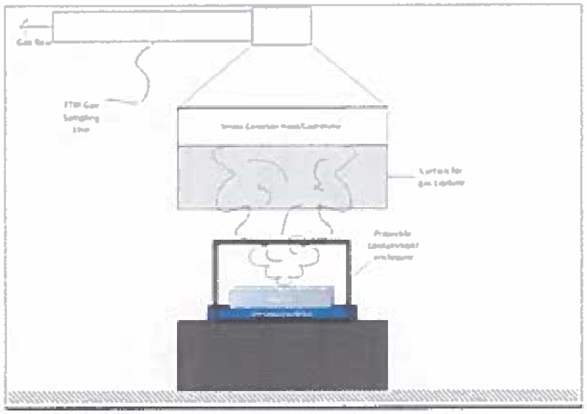
UL 9540A Cell/Module Level Testing

Cell Testing :

- Determine if thermal runaway can be induced,
- If so, document thermal runaway methodology, instrumentation,
- Determine cell surface temp at venting and thermal runaway,
- Measure gas generation and composition.

Module Testing :

- Evaluate thermal runaway propagation within a module,
- Develop data on heat release rate and vent gas generation rate and composition,
- Document fire and deflagration hazards.



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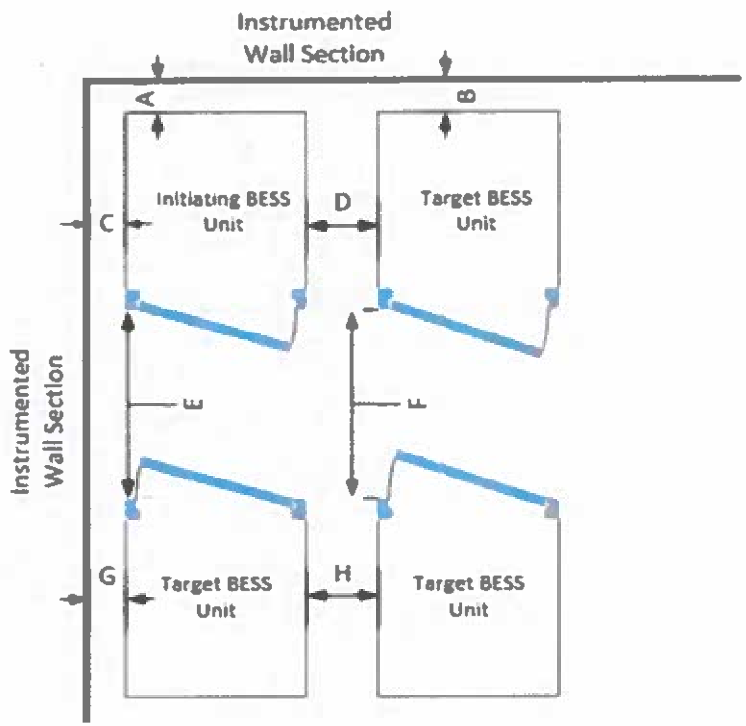
UL 9540A Unit Level Testing

- Document thermal runaway progression within the unit,
- Document if flaming occurs outside the unit,
- Measure heat and gas generation rates,
- Measure surface temperatures and heat fluxes in target units,
- Measure surface temperatures and heat fluxes on walls.



Acceptable results * :

- ❑ No flaming outside the unit under test
- ❑ No explosion hazard observed (incl gases <25% LEL)
- ❑ Maximum temperatures on target units ≤ the vent temperature in the cell level test, and maximum surface wall temperature rise ≤ 97 °C (175 °F) above ambient.

* Deviations from above will require the test will be conducted with a manufacturer recommended automatic sprinkler system or other fire protection system present.

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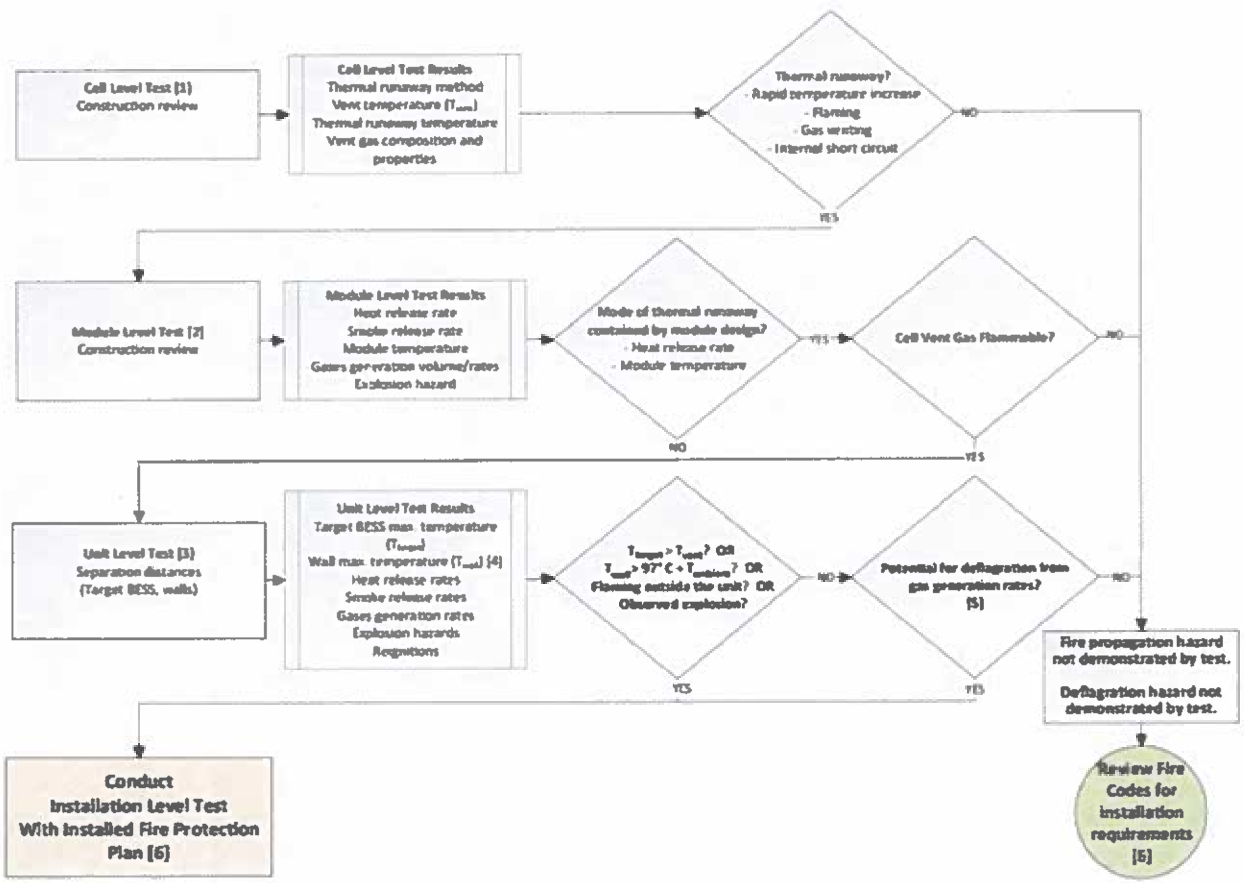
Figure A.1
BESS Fire Propagation Assessment Flow Chart – Cell, Module and BESS Unit Level Test



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Take-Aways From Part 3

The burden of proof is on the installation. They must positively show that their chemistry/design/installation is safe. This is done through a hierarchy of tests and analyses by third parties.

Standards continue to evolve as we learn more and as new design strategies are developed.

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Are lithium-ion batteries a big fire risk? Depends what you compare them to

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By Thomas Fudge / Science and Technology Reporter

Published July 5, 2024 at 6:00 AM PDT

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May, threatening to ignite the many lithium ion batteries that are stored there. May 23, 2024

The fire started on May 15th in a lithium-ion battery storage facility in Otay Mesa. The large number of batteries in the huge warehouse raised the possibility of a devastating, facility-wide explosion.

“They sent robots into the space to try to measure the atmosphere. Is there hydrogen present? How much hydrogen is there? Is there an explosive atmosphere?” said Robert Rezende, a battalion chief for the San Diego Fire-Rescue Department. “And they confirmed yes, there was hydrogen present. Yes, there was the potential for an explosive atmosphere.”

But that warehouse fire ended with a whimper, not a bang. Rezende, an expert on lithium battery fires, said the control of that fire came down to many things. They included good firefighting and the size of the warehouse.

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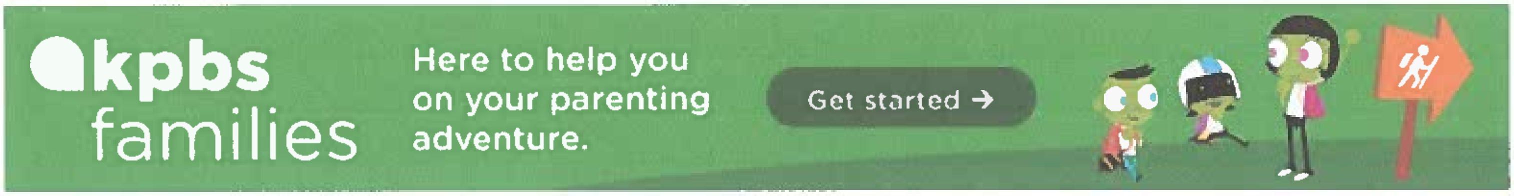

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"Now, we did have battery explosions inside. I was at the incident. We heard the batteries exploding. But again, it's a massive space," Rezende said. "So the sheer fact that it was a really large space meant that it was less likely to have a catastrophic event."

Many fires have shown the volatility of lithium-ion batteries, and their use is increasing exponentially.

That has begun a debate over how dangerous they really are, especially when compared to other sources of energy.

Lithium batteries: The dangers we know

Lithium-ion batteries release very flammable gases — notably hydrogen — when they burn. But even in a normal state they can become combustible.

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In his lab at UC San Diego, chemistry professor Kent Griffith uses a special chamber to make lithium metal batteries. He uses equipment to help control the atmosphere in it, reaching in through glove holes to reduce the risk of fire.

"It's what we call a glove box," Griffith said. "It's basically a low-oxygen chamber. It has extremely low oxygen content and extremely low moisture content."

He said most rechargeable consumer batteries don't use highly combustible lithium metal. However, even lithium-ion batteries, which use graphite to hold and release ionized particles, are at risk of fire.

"Anything you do to create that short circuit that causes all that heat to be released, means you're heating up a lot in a very small volume. So that has the possibility to turn into a fire if there's a source of fuel around," he said.

One source of fuel that's immediately available in a lithium-ion battery, is the flammable electrolyte that physically separates the batteries' positive and negative electrodes.

Chief Rezende said the buildup of heat in these batteries that leads to fire is called a thermal runaway. It can also lead to powerful explosions.

Videos show what these explosions look like when, for instance, a battery on an electrical bike gets exposed to heat in an apartment fire.

"More often than not, we arrive at the incident to find the windows were blown out. The doors are off the hinges. And of course for us in the fire service that makes it a more complicated incident, because now we have a ventilated fire, a fire that has all the air it wants and needs to go very fast and very hot and very quick," Rezende said.

Pondering the future, he said the billions of lithium-ion battery cells being created can only mean more flawed batteries, more short circuits and many more fires, which cannot be smothered with a blanket or extinguished with water.

But how common are these battery fires, really, when compared to other technology?

"What's actually amazing is, in some sense, how safe lithium-ion batteries actually are. Right?" Griffith said. "We produce billions of these every year and every car has, you know, something on the order of several thousand batteries in it. And yet still, we have very very few fires in the context of all of that."

He said we should compare the risk of fire in a battery-powered car to one that runs on an internal combustion engine. One estimate showed old-fashioned combustion engines were more than 10 times more likely to catch fire than EVs with lithium-ion batteries.

Chief Rezende agrees. Car fires are much more common per vehicle when they use an internal combustion engine. But remember, he said, lithium-ion battery fires are very tough to put out.

"From a fire department's perspective, an electric vehicle fire is much more difficult to manage. It's going to take a lot longer. An internal combustion engine fire we can handle in five to ten minutes, max. An electric vehicle fire, you're lucky if you get out of there in two hours," he said.

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A threat to homes and hospitals?

There are other issues. Some hydrogen gases emitted by lithium battery fires are considered toxic. That's been used as an argument against locating a battery storage facility in Eden Valley, near homes and hospitals.

The proposed Seguro Battery Storage Project would be located less than a mile from North County's Palomar Hospital. Project opponent Joe Rowley, a former vice president of project development at Sempra U.S. Gas and Power, told KPBS it is also surrounded by nearby homes.

"It should not be near residences. It should not be near a hospital or schools," Rowley said. "When batteries burn they emit hydrogen fluoride, hydrogen chloride, hydrogen cyanide."

Chief Rezende said a lithium-ion battery fire does release toxic gases, adding that any large structure fire will produce hydrogen cyanide, as plastics and synthetic fabrics catch on fire.

He said many gases that are released by burning batteries are present at the site but quickly dissipate as they move through the air and they tend to have a small footprint. This is true of some of the so-called "acid gases" that are released from burning lithium ion batteries.

"They don't have a long persistence in the atmosphere," he said. "They break down pretty readily within a short distance."

One fact remains. Griffith said no other technology we know stores energy as well as a lithium ion battery. So as our power supply moves from fossil fuels to electric battery power, don't expect those batteries, or their fire risk, to go away.

Public Safety

Thomas Fudge

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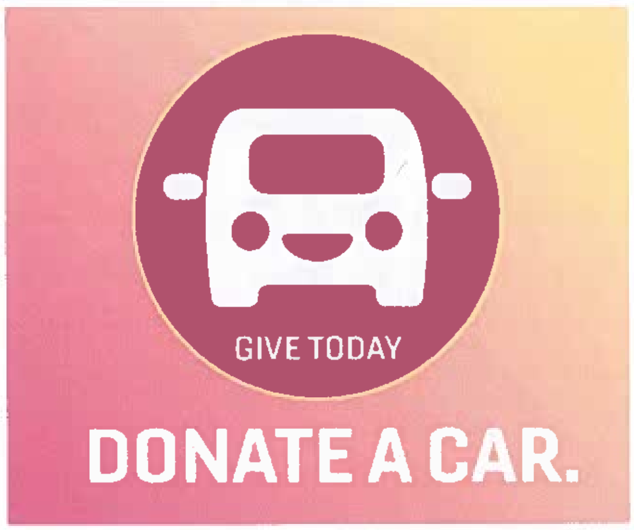
A journalist with 30 years of experience, Tom covers science and technology stories for KPBS' platforms. He has received recognition for his outstanding work in hosting and public affairs reporting from the Unity Awards, the Northwest Broadcast News Association, and the San Diego chapter of the Society of Professional Journalists.

See stories by Thomas Fudge



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KPBS News: Public Safety Policy

KPBS has created a public safety coverage policy to guide decisions on what stories we prioritize, as well as whose narratives we need to include to tell complete stories that best serve our audiences. This policy was shaped through months of training with the Poynter Institute and feedback from the community. You can read the full policy here.

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Emerging Issues

Line of Thought: Residential Battery Energy Storage Systems and Homeowners Risk

May 03, 2024

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By **Greg Scoblete**, CPCU
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Key Takeaways

- Whether attached to solar power systems or used as a backup generator, battery energy storage systems (BESS) are growing in popularity for homeowners in numerous states.

- These units may provide safer, cleaner backup power during outages.
- Like lithium-ion batteries generally, residential BESS may catch fire or even explode.
- BESS operating software may be a target for cyberattacks which could, in turn, heighten property or liability risks for homeowners.

Residential battery energy storage systems (BESS) can serve two overarching purposes for homeowners. They can capture the energy generated by solar power systems and save it for use when the sun goes down (or when utility rates go up).[1] They can also be used as a backup generator, providing saved power during an outage.[2]

PFAS Litigation Could Generate Billions in Ground-Up Losses

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Read More

Learn about the potential commercial property risks of battery energy storage systems. Read more.

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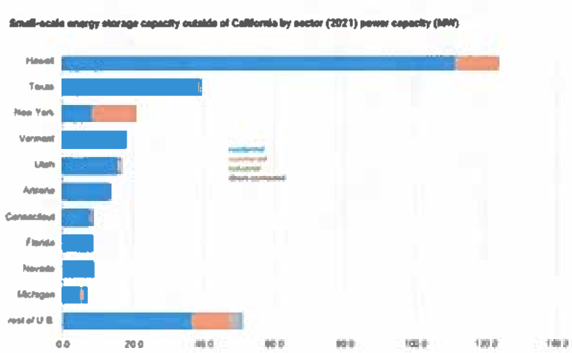
Charting the Growth

BESS units may be sold (or "attached") to a solar panel installation. By one account, nearly 13 percent of all residential solar power installations in the U.S. have been accompanied by a BESS.[3]

The lion's share of residential BESS are installed in California. In 2021 (the most recent year for which finalized data is available from the Energy Information Agency), California had 482 MW of residential battery storage capacity.[4] The rest of the United States had roughly 160 MW of storage capacity, mostly centered in Hawaii.[5]



Source: Energy Information Agency.

Much like in the commercial sector, demand for residential battery systems appears poised for future growth. According to one recent report, the U.S. will see four times as many residential BESS installations in 2027 compared to 2022.[6]

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BESS Tech

Residential BESS units typically leverage lithium-ion batteries (such as nickel manganese cobalt or lithium iron phosphate) that are either combined into a single unit with other components, such as inverters, or split into discrete units.[7] They can hold between 5 to 30kWh of energy.[8] The National Fire Protection Agency's installation standard for energy storage systems (NFPA 855) classifies residential units as those with energy capacities ranging from 1 to 20 kWh—higher than 20 kWh, and the unit would be considered a commercial installation.[9]

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Battery Energy Storage System Benefits

For homeowners, these systems can offer a few additional benefits on top of those we mentioned at the open:

Safety during power outages: Portable gas generators kill about 85 people a year in the U.S.[10] The vast majority (81 percent) of those who suffer fatal carbon monoxide poisoning from a generator are in residential locations. BESS units are not without potential risks (see below), but carbon monoxide poisoning isn't among them.

Energy monitoring: When paired with residential solar, battery systems may provide monitoring systems that offer real-time insights into household energy consumption.[11]

Improved resale value: Homes with solar energy systems appear to command a market premium compared to those without, and since many battery systems are tied to solar systems, it may be reasonable to assume they may enjoy a similar halo effect.[12]

Environmental: Batteries powered by the sun may contribute fewer heat-trapping greenhouse gases to the atmosphere compared to homes powered by burning fossil fuels. In an environmental life-cycle analysis, the International Energy Agency found that storing solar energy in a battery can be environmentally beneficial if the local utility generates electricity using fossil fuels.

Battery Energy Storage Systems: Homeowners Insurers Consideration

Fire: One of the marquee concerns surrounding BESS units is the potential for a thermal runaway—a chemical reaction in the battery that leads to a fire or an explosion (or both).[13] As we noted in our piece on commercial systems, while there doesn't appear to be a definitive accounting of how frequently residential BESS fires occur, they seem to be a very small fraction of the total number of recorded lithium-ion battery fires.

According to a recent report, there have been 141 BESS "incidents" globally to date (60 of which involved residential units)—the majority of these incidents were fires.[14] The 141 BESS incidents were a tiny fraction—just 1.8 percent—of the overall catalog of lithium-ion battery fires/incidents recorded by researchers, which numbered over 8,000.

Of those 141 failure events, BESS explosions accounted for a little over 10 percent of all incidents.[15] These explosions can be powerful. In one test, a BESS explosion blew a closed garage door clean off its hinges and hurled it across a driveway.[16] The potential for flying debris following a thermal runaway could raise the risk of additional property damage not just for the owner

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of the BESS, but for neighboring households as well.

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BESS fires may potentially be triggered by environmental conditions such as excessive humidity, flooding, extreme swings in temperature, or the accumulation of dust.[17] Faulty installations, power surges, or physical damage to the unit may also present a fire risk.[18]

Cyber: BESS appear vulnerable to cyberattacks.[19] According to one report, the operational technologies employed by some BESS units to collect data or remotely manage these systems may lack basic cybersecurity protections.[20] Cyberattacks targeting those technologies could not only disrupt or possibly exfiltrate data, but could tamper with the physical components of the unit in such a way as to potentially trigger fires or malfunctions—particularly if those attacks target the unit's battery management system.[21]

Costs: A BESS could cost the

homeowner $12,000 to $22,000 depending on the technology, which might influence the overall value of the insured property. [22]

Line of Thought connects the dots between Emerging Issues and an insurance line of business.

For more information on evolving homeowners risks, please visit our Homeowners hub.

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References

Alternative Energy

Lithium Batteries

Homeowners

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Greg Scoblete, CPCU

Greg Scoblete is an analyst with Verisk's Emerging Issues team. Greg came to Verisk after a successful journalism career, writing about technology, photography, and consumer products. Today, Greg is responsible for research, analysis, and content development for the Emerging Issues team, helping insurers keep up with the evolving risks facing their business. Greg has earned the designation of a Chartered Property Casualty Underwriter (CPCU).

Melissa Thelen

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Melissa is an emerging issues solutions architect working with the personal lines coverage products team. Melissa joined Verisk in 2023 bringing with her 9 years of insurance industry experience, including roles in claims and underwriting. She graduated from Davenport University (MI) with a Bachelor's degree in Legal Studies.