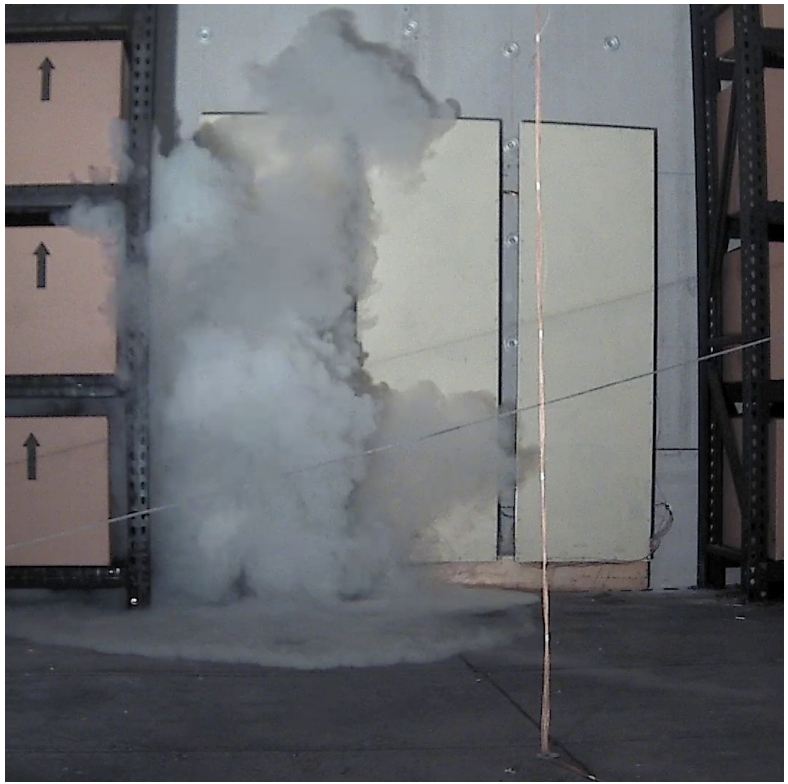
UL Solutions

Translating data into standards

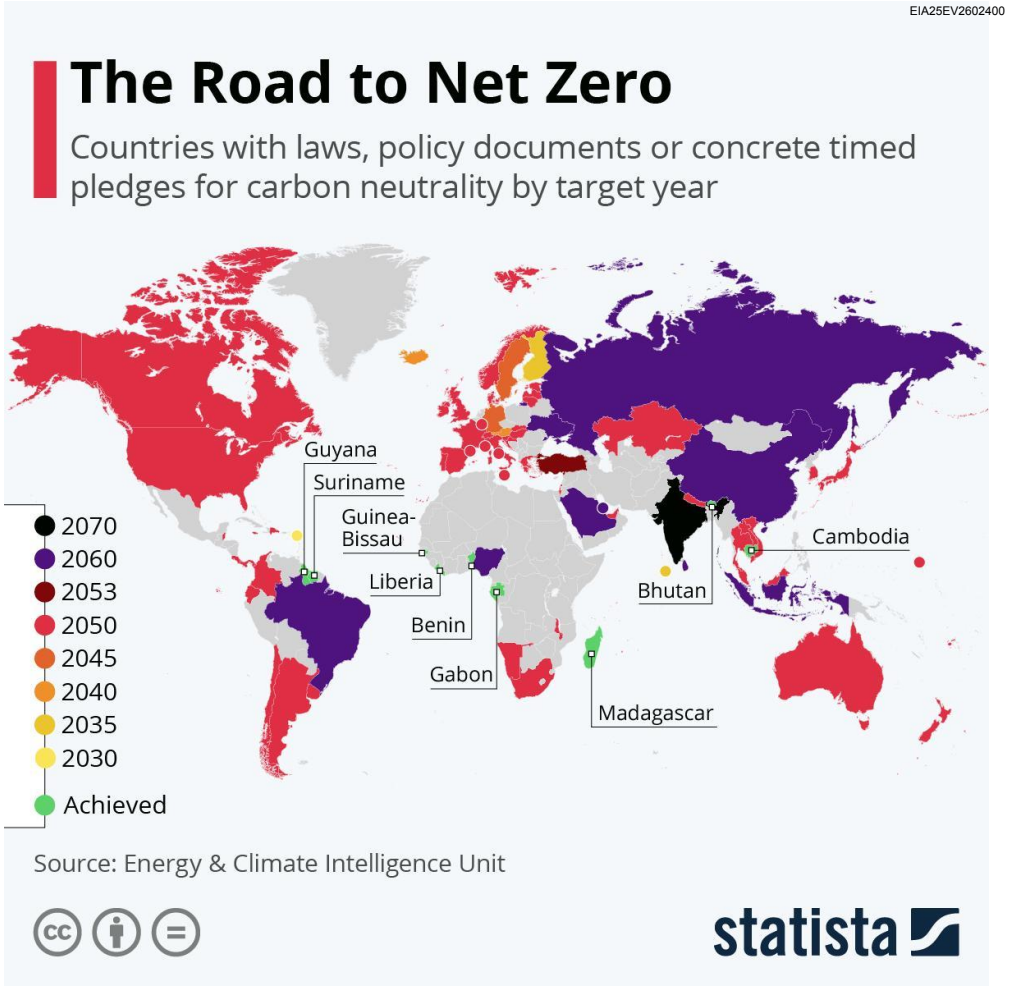
Battery fire propagation research supporting ESS and EV safety and standards development

Alex Schraiber, Professional Engineer
April 25, 2025



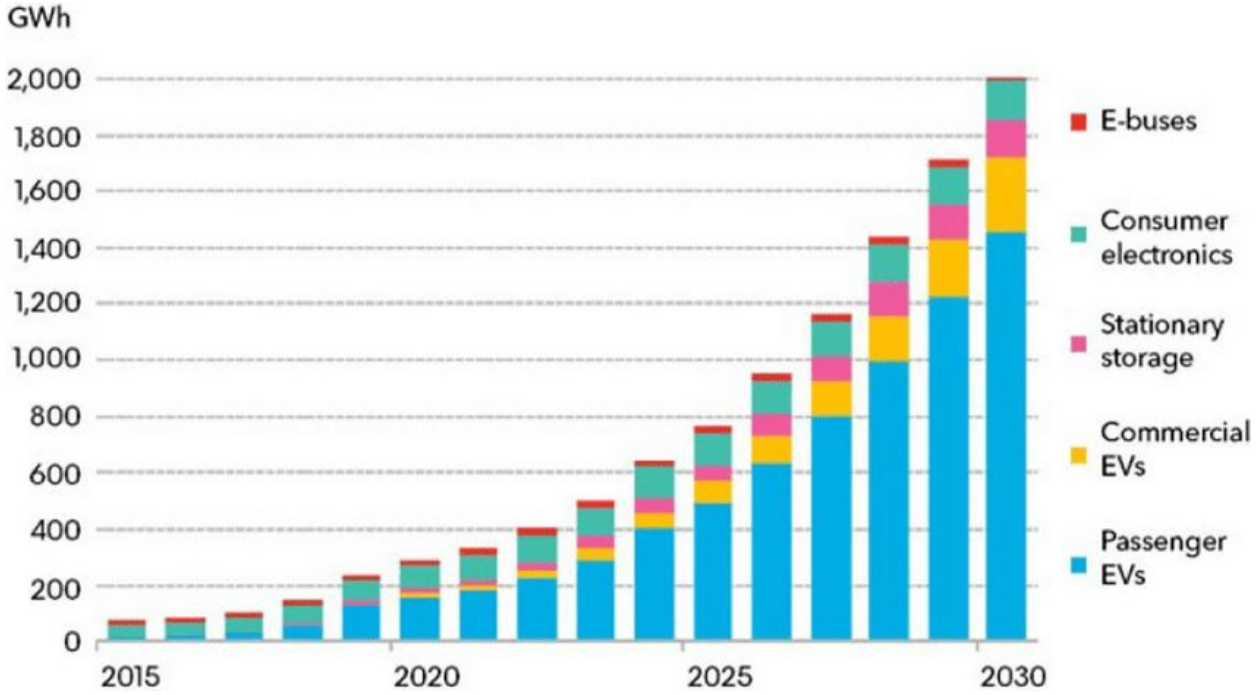
The UL enterprise

The world is committing to a carbon-neutral, i.e., net zero, future



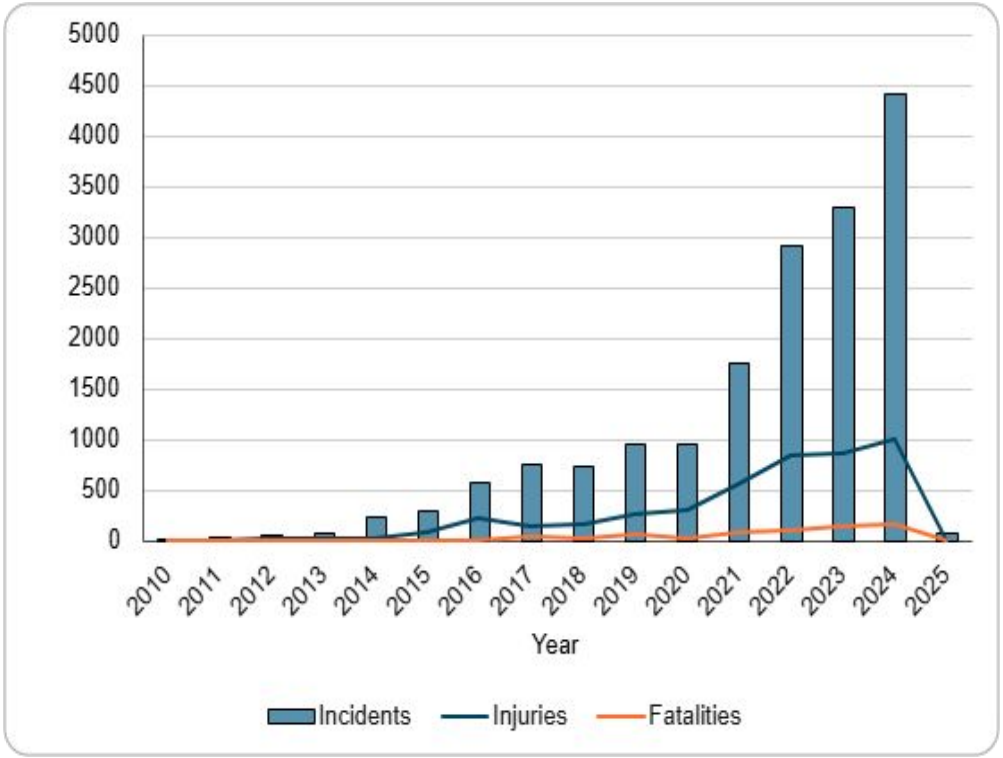
https://www.statista.com/chart/26053/countries-with-laws-policy-documents-or-timed-pledges-for-carbon-neutrality/

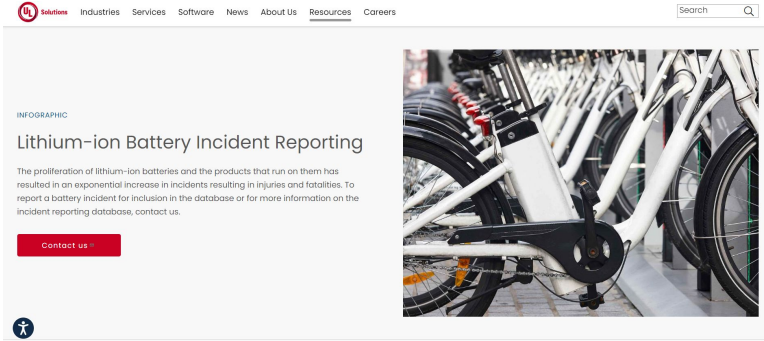
“Electrification of everything” means lithium-ion batteries will be everywhere

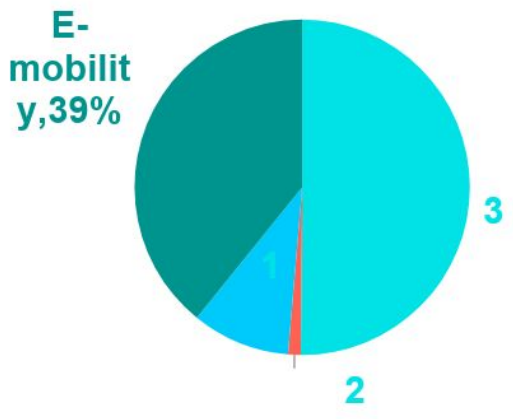


Lithium-ion battery global market size, GWh. Source: Bloomberg New Energy Finance (BNEF)

Battery incidents are proportional to market size







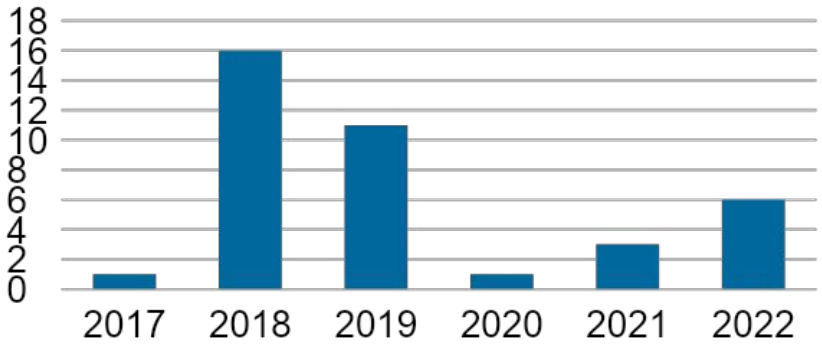
https://www.UL.com/insights/lithium-ion-battery-incident-reporting

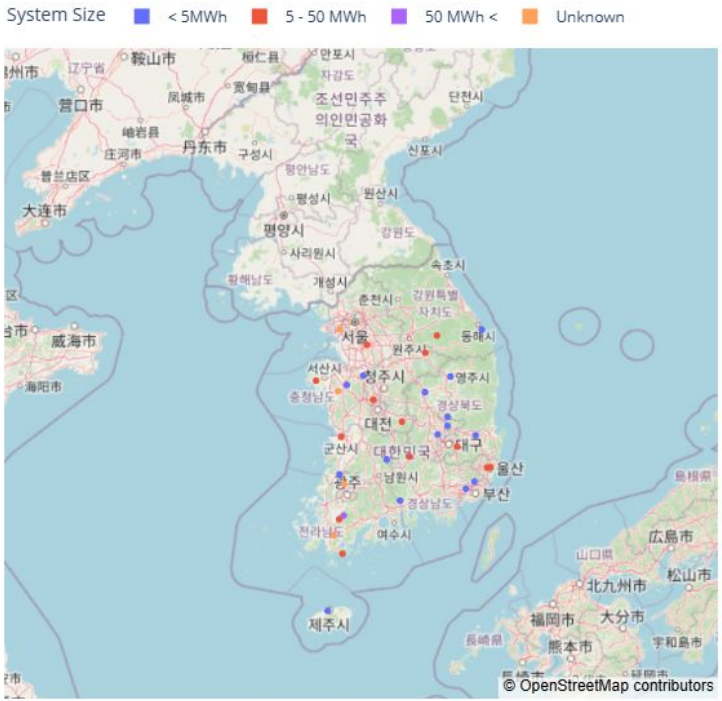
[1]Electric vehicle (EV)
[2]Energy storage system (ESS)
[3]Consumer products (CPr)

How can we learn from failure events to prevent future failures?

Early ESS fires: South Korea

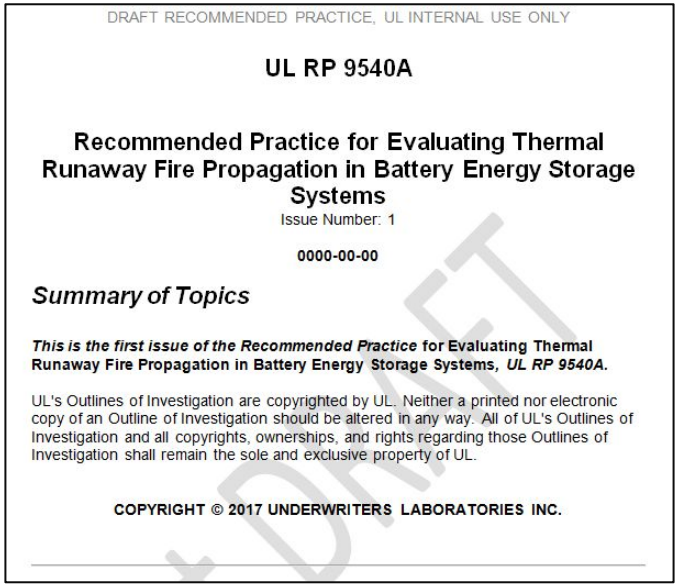
- Twenty-eight ESS fires in South Korea between 2017 and 2019
- Variety of causes, including manufacturing defects, insufficient electrical protections, environmental exposure (moisture, dust, salt mist) and installation practices
- Drove public awareness and standards development





EPRI BESS Failure Incident Database. Accessed April 14, 2025. https://storagewiki.epri.com/index.php/BESS_Failure_Incident_Database.

Research drove UL 9540A development



DRAFT RECOMMENDED PRACTICE, UL INTERNAL USE ONLY

UL RP 9540A

Recommended Practice for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Issue Number: 1

0000-00-00

Summary of Topics

This is the first issue of the Recommended Practice* for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, *UL RP 9540A.

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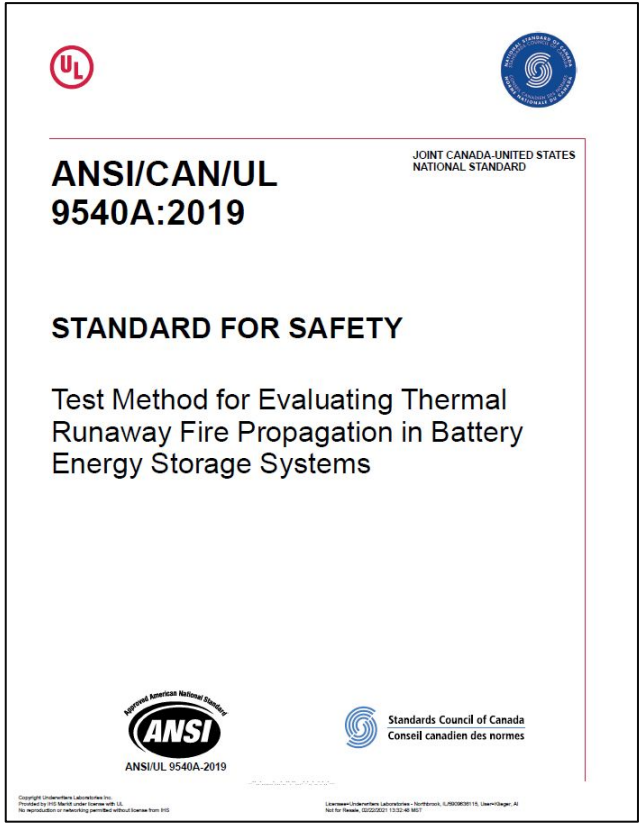
DRAFT

Hazard research
improved test methods



JOINT CANADA-UNITED STATES NATIONAL STANDARD

ANSI/CAN/UL 9540A:2019

STANDARD FOR SAFETY

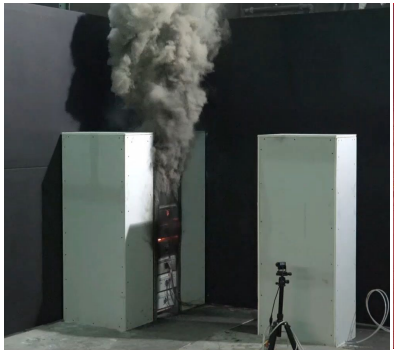
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

ANSI/UL 9540A-2019

Standards Council of Canada
Conseil canadien des normes

UL 9540A, Standard Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems





Cell

- T_{vent}
- $T_{ThermalRunaway}$
- Gas composition
- LFL, S_U, P_{Max}

Module

- Thermal runaway propagation
- Gas release rate
- Heat release rate
- Deflagration hazards

Unit

- Thermal runaway propagation
- Gas release rate
- Heat release rate
- Deflagration hazards

Installation

- Thermal runaway propagation
- Gas release rate
- Heat release rate
- Deflagration hazards
- Role of fire protection systems

Energy system explosion – April 2019

2 MW/2.16 MWh lithium-ion battery ESS

- Very Early Smoke Detection Apparatus (VESDA) smoke detector system
- Novec 1230 total flooding clean agent suppression
- Four firefighters (Peoria hazmat team) seriously injured
- Four firefighters (Surprise E304) held overnight for suspected exposure to hydrogen cyanide (HCN)

Source: Report: Four Firefighters Injured In Lithium-Ion Battery Energy Storage System Explosion - Arizona | The Fire Safety Research Institute (FSRI), part of UL Research Institutes

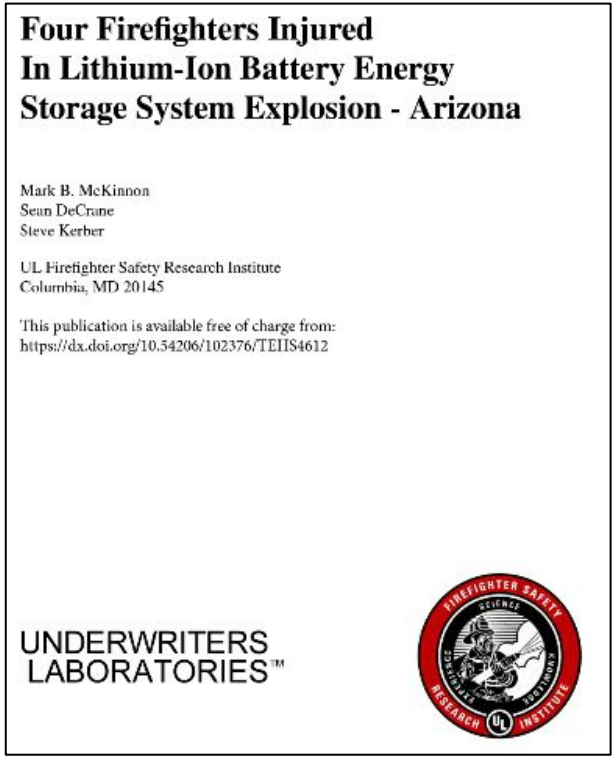
Source: Report: Four Firefighters Injured In Lithium-Ion Battery Energy Storage System Explosion - Arizona | The Fire Safety Research Institute (FSRI), part of UL Research Institutes

Contributing factors

- The ESS did not have deflagration venting panels (NFPA 68) or adequate ventilation to prevent the accumulation of flammable gases (NFPA 69).
- The total flooding clean agent suppression system likely contributed to the deflagration.

Recommendations

- Lithium-ion battery ESSs should incorporate adequate explosion prevention protection as required by consensus standards in coordination with the emergency operations plan.
- Research that includes full-scale testing should be conducted to determine the most effective fire suppression and explosion prevention systems for lithium-ion battery ESSs.


Four Firefighters Injured
In Lithium-Ion Battery Energy
Storage System Explosion - Arizona

Mark B. McKinnon
Sean DeCrane
Steve Kerber

UL Firefighter Safety Research Institute
Columbia, MD 20145

This publication is available free of charge from:
https://dx.doi.org/10.54206/102376/TEIIS4612

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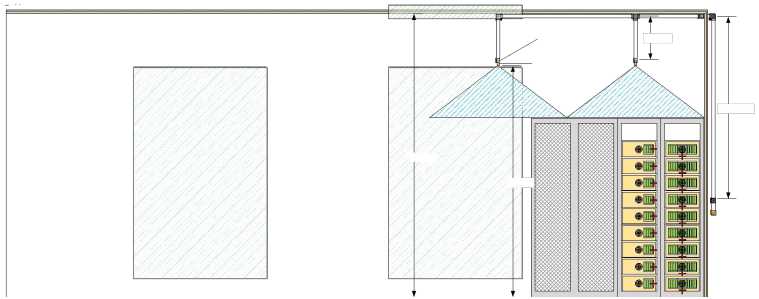
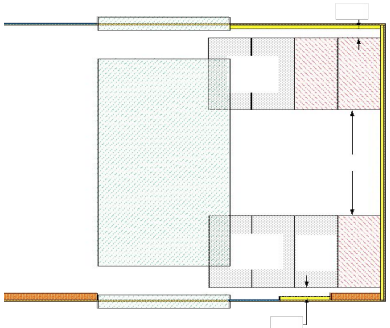
Installation-level container tests





FIRE RESEARCH AND DEVELOPMENT TECHNICAL REPORT

UL 9540A Installation Level Tests with Outdoor Lithium-ion Energy Storage System Mockups

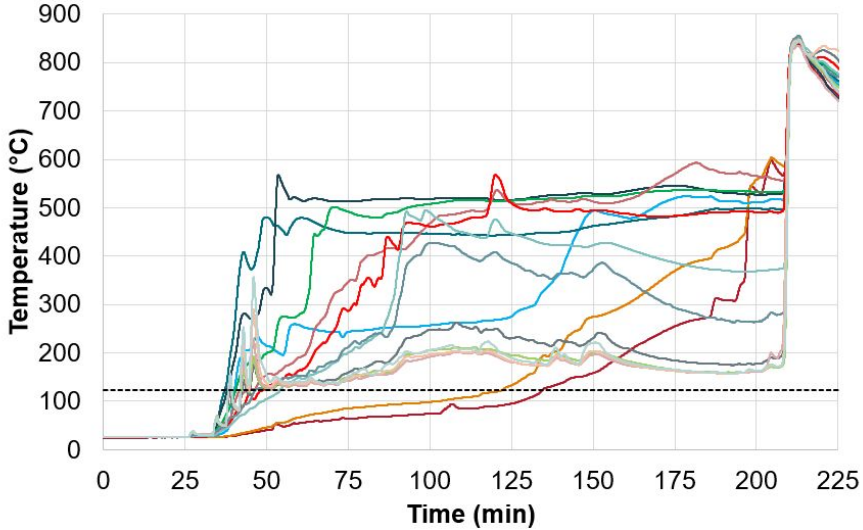
April 12, 2021

Adam Barowy
Alex Klieger
Jack Regan
Mark McKinnon, Ph.D., P.E.

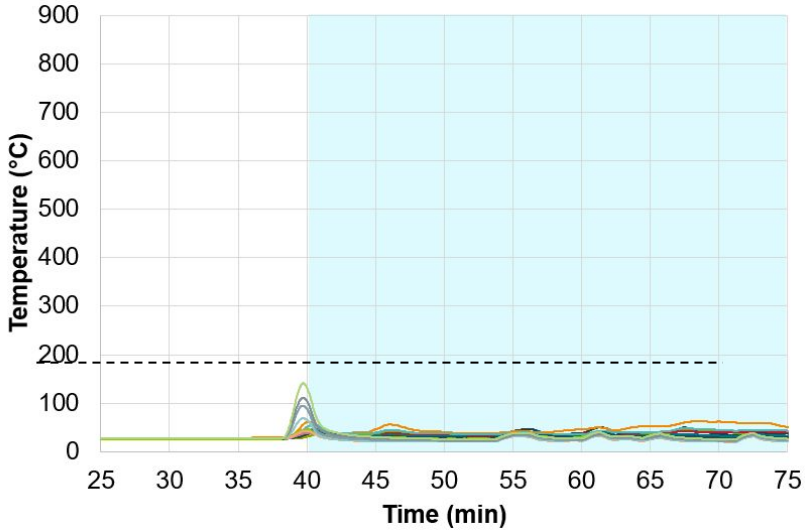
Empowering Trust®

Key findings: Water spray suppression system

The water spray suppression system prevented unit-to-unit propagation and cooled wall surfaces adjacent to the initiating ESS unit, which had limited effectiveness in preventing module-to-module thermal runaway propagation.



Rear wall without water spray



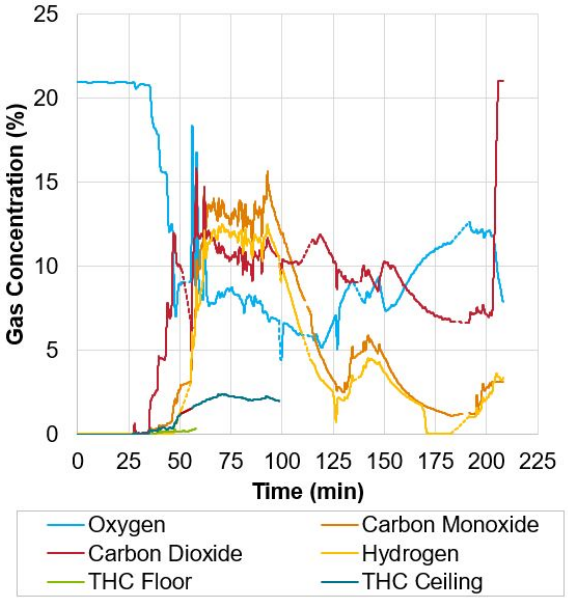
Rear wall with water spray

Source: UL Solutions R&D

Key findings: Flammability and toxicity hazards

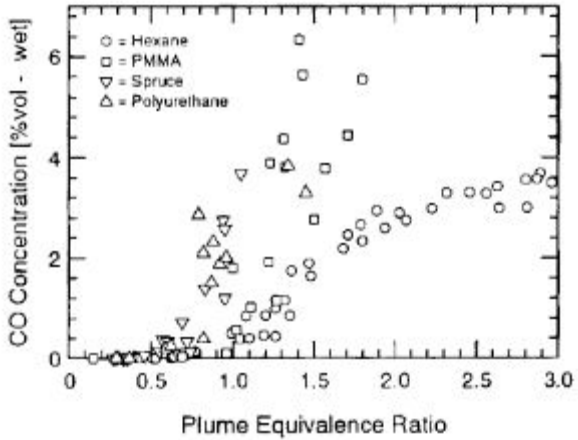
Propagating thermal runaway events generate more severe flammability and toxicity hazards than typical room and content fires. Note: The IDLH* for CO is 1,200 ppm (0.12 v%).

Test 1: Baseline



	Battery fire	Compartment fire
H_2	> 10%	0%
CO	12%-15%	6%
CO_2	10%	10%

Underventilated compartment fire



Gottuk, D, Beyler, C., Roby, R., Peatross, M., "Carbon Monoxide Production in Compartment Fires", J. of Fire Prot Eng. **4**, 4, 1992

*Immediately dangerous to life or health (IDLH)

Key findings: Deflagration protection

- The deflagration venting successfully vented overpressure, potentially preventing dangerous loss of integrity/rupture of the enclosure.
- Flames emitted from the deflagration vents indicate the need to site and orient the enclosure to mitigate secondary ignition/life safety hazards.
- Flammable gas mixtures at elevated temperatures in all demonstrations
- Ignition timing not predictable
- Gas accumulation not prevented by clean agent or water suppression

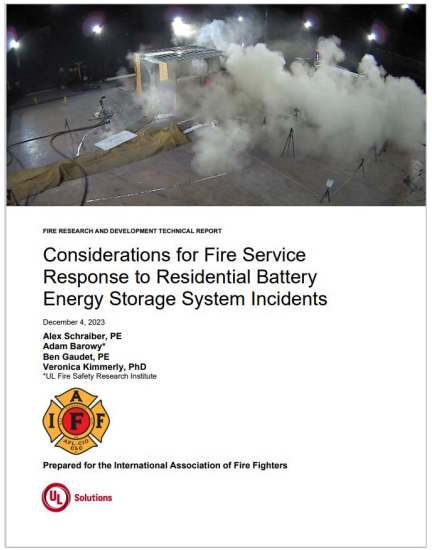
Residential fire risk: ESS field incidents

Sydney, Australia — February 2023
Source: Fire and Rescue NSW investigators determine a faulty lithium ion battery caused a villa fire at Epping - Epping - Fire and Rescue NSW

Residential ESS incident response

Impact of Li-ion residential ESS on incident response:

- Determine whether Li-ion battery gas impacts compartment fire dynamics.
- Develop size-up and tactical considerations for first responders to Li-ion residential energy storage system fire incidents.



FIRE RESEARCH AND DEVELOPMENT TECHNICAL REPORT

Considerations for Fire Service Response to Residential Battery Energy Storage System Incidents

December 4, 2023

Alex Schraiber, PE
Adam Barowy*
Ben Gaudet, PE
Veronica Kimmerly, PhD
*UL Fire Safety Research Institute

Prepared for the International Association of Fire Fighters

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U.S. DEPARTMENT OF ENERGY

IAFF ORGANIZED FEB 1918 AFL-CIO CLC

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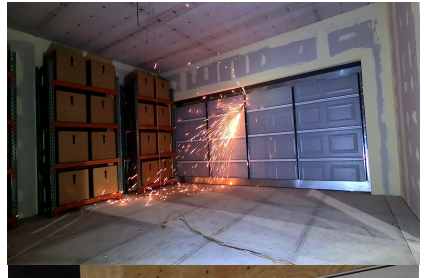
Disclaimer: The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States government.

Source: IAFF_DOE_ResidentialESSConsiderations_Final.pdf

Test setup

- Two-car attached garage (IRC R328.4) – Most common new construction and near electrical panel
- Three units; 17 kWh per unit (IRC R328.5)
- Pyrotechnics to simulate sparks from K-12 saw



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Fire service size-up and tactical considerations

An explosion hazard develops the instant batteries undergo thermal runaway and release gas without burning.

24:01 (TR + 03:31)

25:13 (TR + 04:43)

26:22 (TR + 05:52)

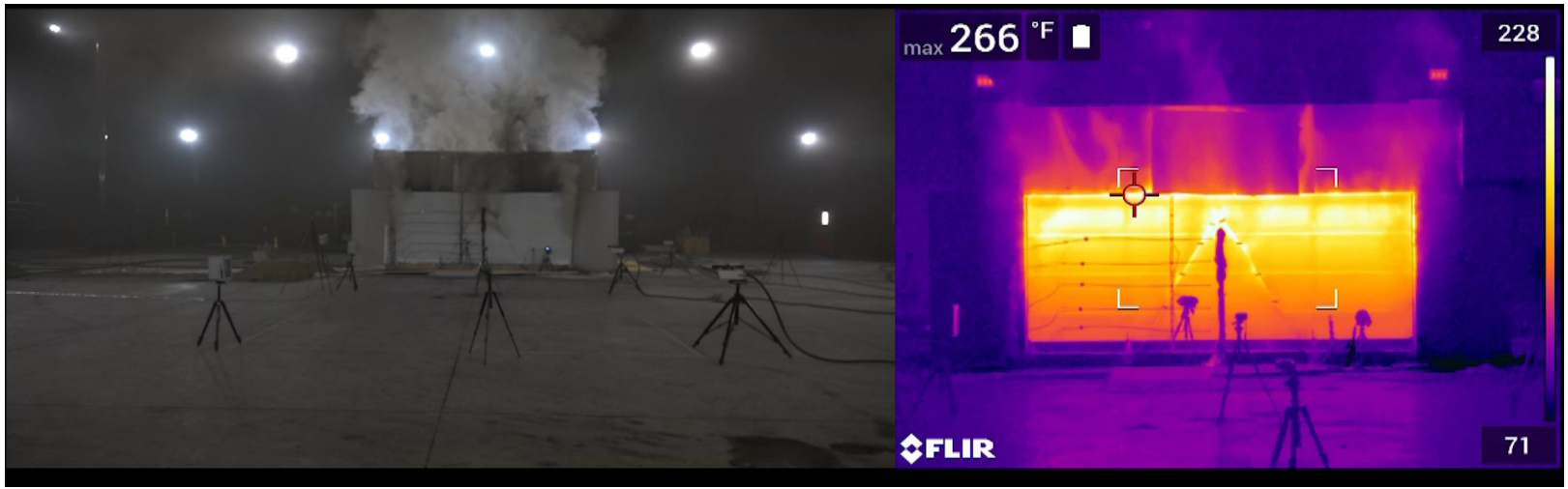
29:43 (TR + 09:13)

30:50 (TR + 10:20)

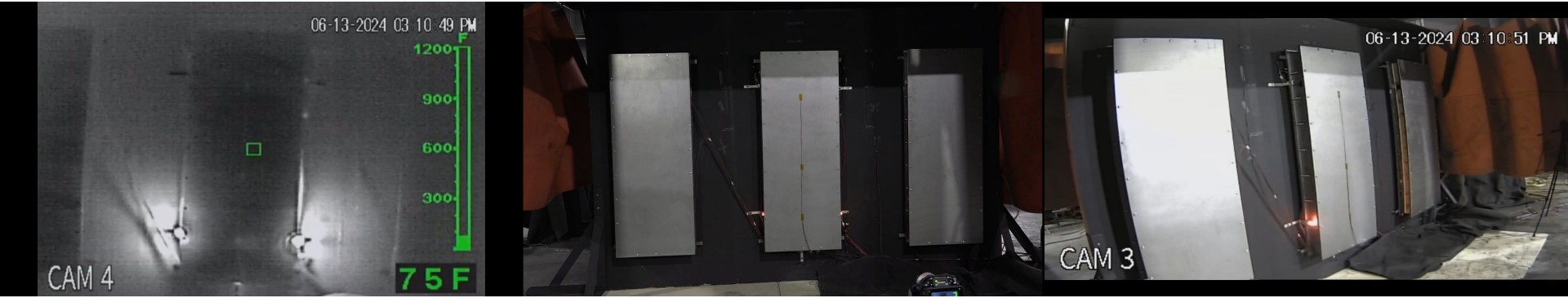
36:34 (TR + 16:04)

Fire service size-up and tactical considerations

Unburned battery gas readily ignites and can increase the flammability of the smoke in a ventilation-limited fire.



Publication of UL 9540B (2024)



- UL 9540B, Outline of Investigation for Large-Scale Fire Test for Residential Battery Energy Storage Systems
- Response to failure incidents, fire authority feedback and research testing
- Evaluates peak thermal stress by removing variation in ignition scenario
- Standardized fire safety performance for residential ESS developers
- Separates fire and explosion safety evaluations

What hazard research is coming next?

- ESS explosion testing
- EV fire testing

Explosion hazards: Field incidents

Liverpool, U.K. — September 2020

Photo courtesy of Merseyside Fire & Rescue Service Headquarters

Erie, Colorado, USA — April 2023

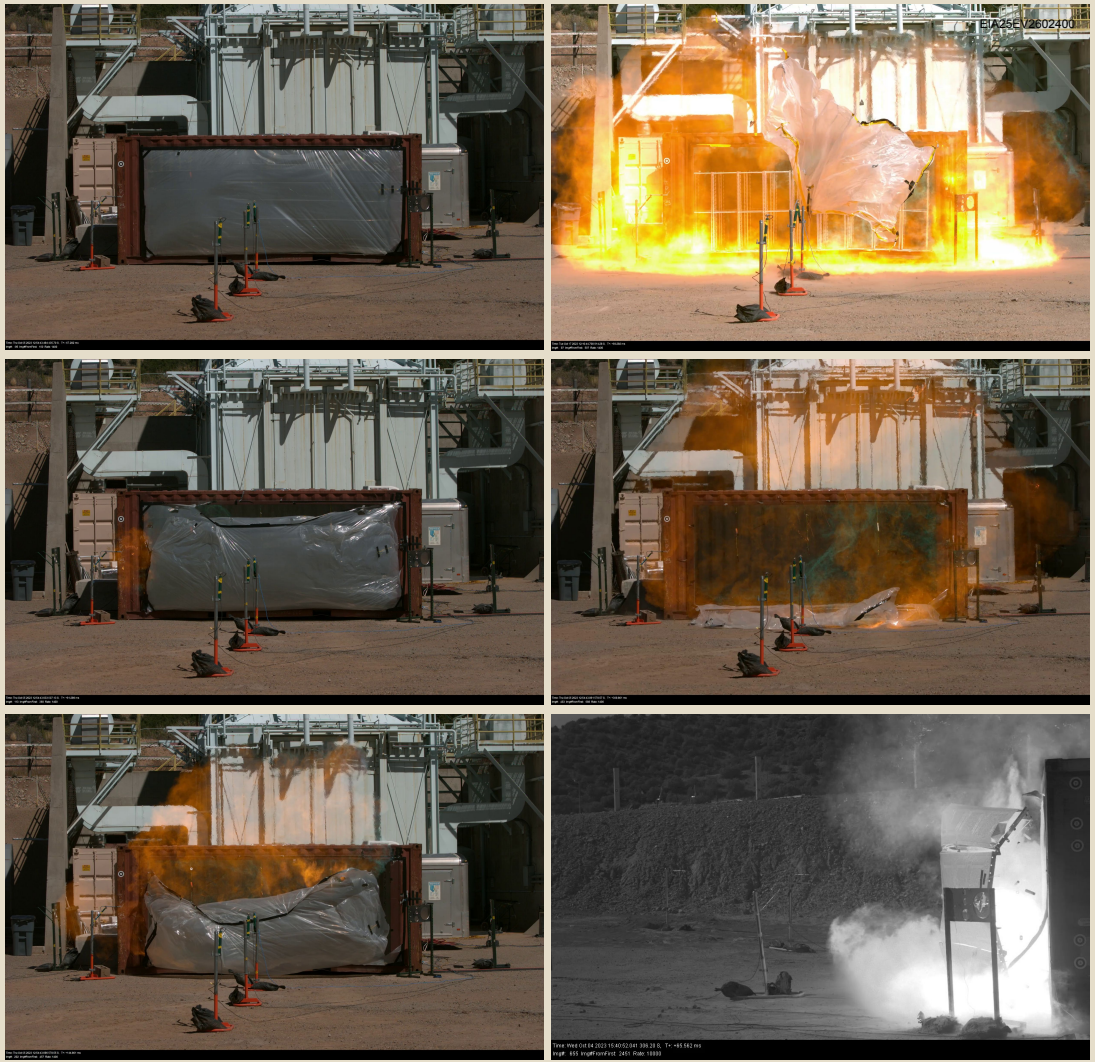
Video courtesy of Mountain View Fire Department

Outdoor testing: Representative garage

An explosion hazard is dependent on the release duration, quantity and flammability of thermal runaway gases.

Research collaboration: UL Research Institutes FSRI

Testing with Sandia National Laboratories



UL – Garage Explosive Testing

Test 4

Garage Door

October 4th, 2023

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SAND2024-03631O

Current standards and research focus: EVs and fire response

UL Research Institutes

FSRI

https://fsri.org/research/fire-safety-batteries-and-electric-vehicles

Summary

- Battery energy storage is a new technology, which necessitates new standard tests and response strategies to mitigate hazards.
- Further research is needed at all scales, especially full-scale testing, to develop appropriate test methods.
- Standards must keep up with the pace of battery technology development and innovation.

Thank you

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