



# SFPE

## Engineering Solutions Symposium

Progress with Li-Ion Battery Fire Safety: Engineering Solutions to Mobility and Storage Hazards

June 4-6, 2024

Phoenix, Arizona

**Venue Location:** DoubleTree Resort by Hilton Paradise Valley – Scottsdale, 5401 N. Scottsdale Rd., Scottsdale, Arizona, 85250, USA

<p><b>Badge Pick Up</b>          Tuesday: 8:00 a.m. – 12:30 p.m. (for 1-day or 3-day registration passes only)          Wednesday: 8:00 a.m. – 12:30 p.m.</p>	<p><b>Expo Hours</b>          Tuesday: 12:30 – 1:30 p.m. &amp; 3 – 3:30 p.m.          Wednesday: 12:30 – 1:30 p.m. &amp; 3 – 3:30 p.m. &amp; 5:45 – 7:00 p.m.</p>
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<b>Tuesday June 4</b>	
9:00 - 9:15 a.m.	<p><b>Welcome and Introductions</b>            Chris Jelenewicz, PE, FSFPE, SFPE CEO &amp; Symposium Chair: Adam Barowy</p>
<p style="text-align: center;"><b>THERMAL RUNAWAY HAZARD FUNDAMENTALS</b>            Moderated by Ofodike Ezekoye, PhD, PE</p>	
9:15 – 9:45 a.m.	<p><b>Battery and ESS Structures</b>            Sean Yang, Senior Research Engineer, UL Solutions</p> <p><i>The presentation touches on the structures of cells of different chemistries, including lithium iron phosphate (LFP) and nickel manganese cobalt (NMC) as well as the battery module structures based on the testing experience. The presentation will not reveal specific designs, however, share the general structures that are used in the industry in order to enhance the understanding of batteries of fire protection engineers.</i></p>
9:45 – 10:15 a.m.	<p><b>Early Detection of Li-Ion Battery Thermal Runaway Using Commercial Diagnostic Technologies</b>            Loraine Torres-Castro, PhD, Sandia National Laboratories</p> <p><i>The rate of electric vehicle (EV) adoption has grown exponentially, largely driven by technological advancements, consumer demand, and global initiatives to reduce carbon emissions. As a result, it is imperative to understand the state of stability of the cells inside an EV battery pack. That understanding will enable the warning of or</i></p>



	<p><i>prevention of catastrophic failures that can lead to serious injury or, even, loss of life. This presentation will discuss the use of rapid electrochemical impedance spectroscopy (EIS) coupled with gas sensing technology as diagnostics to monitor cells and packs for failure markers during thermal and electrical abuse. These failure markers correspond to the onset of unstable conditions and could become part of a BMS or be applied to interrogate batteries in an unknown state. Identifying diagnostic tools that pinpoint failure markers with ample time to intervene is crucial for minimizing the consequences of failure.</i></p>
10:15 – 10:30 a.m.	<b>Morning Break</b>
10:30 – 11:00 a.m.	<p><b>Thermal Runaway and Its Causes</b> Lucy Buannic, PhD, Senior Scientist, Exponent</p> <p><i>When a battery cell goes into thermal runaway, it is often too late to reverse the course of action and stop the exothermic reaction from happening. Understanding how a battery gets triggered into thermal runaway will help us better prevent and avoid such uncontrollable and catastrophic outcomes. This presentation will review the various types of battery use, abuse and causes that can lead to a thermal runaway and provide some options on how to mitigate them.</i></p>
11:00 – 11:30 a.m.	<p><b>Understanding, predicting and mitigating cell-to-cell cascading failure in lithium-ion battery modules</b> John Hewson, PhD, Sandia National Laboratories</p> <p><i>In large-scale batter-based energy storage systems, a large number of cells are combined together to create a larger-scale storage capability. While the heat release of a single cell will be relatively modest, if thermal runaway occurs and cascades throughout the system, the heat release will be orders of magnitude greater. This presentation will give an overview of some of the phenomena observed in cascading failure of lithium-ion batteries. Then we discuss what it takes to predict cascading propagation and how safer systems might be designed.</i></p>
11:30 a.m. – 12:00 p.m.	<p><b>Aerosol emissions during li-ion battery failure</b> Vinay Premnath, Director of Research, Energy Storage Safety, UL Research Institutes</p> <p><i>Lithium-ion batteries can experience failure in the form of thermal runaway due to internal defects and also, when subjected to off-nominal operating conditions. Such failure events can result in the significant release of hazardous gaseous and particulate emissions, posing a severe risk to human health and the environment. This presentation will focus on emissions released during such failure events.</i></p>
12:00 – 12:30 p.m.	<p><b>Gas Production and Characterization During Lithium-ion Cell Thermal Runaway</b> Ofodike Ezekoye, PhD, PE</p> <p><i>Cell characteristics such as cell chemistry, capacity, and state of charge all influence the gases produced during thermal runaway of lithium-ion cells. Literature data and measured gas composition during thermal runaway will be reported for a range of cell chemistries, capacities, and states of charge. Correlations for these properties will be provided. The impact of generated gases on fire and explosion properties of vented systems will be detailed. Simple models for characterizing the overall</i></p>

	<i>flammability and flame propagation processes for these gas compositions will be discussed.</i>
12:30 – 1:30 p.m.	Lunch
<b>CODES AND STANDARDS</b> Moderated by Robert Marshall	
1:30 – 2:00 p.m.	<b>Existing Challenges with Emerging Trends</b> Robert Marshall
2:00 – 2:30 p.m.	<b>ESS Permit Review</b> Robert Marshall
2:30 – 3:00 p.m.	<b>Current ESS Safety Codes and Standards</b> Matthew Paiss, Technical Advisor, Pacific Northwest National Laboratory  <i>The presentation will cover the current status of the key codes &amp; standards relating to ESS. This will include NFPA 855, UL 9540/9540A, and the International Fire/Residential Codes. We will look at the topics under consideration by the technical committees for the next editions, as well as research being conducted to support gaps in the code language.</i>
3:00 – 3:30 p.m.	Afternoon Break
3:30 – 4:00 p.m.	<b>Future ESS Requirements</b> William E Koffel, PE, FSFPE, SASHE, Koffel Associates, Inc., Director of the Online FPE Undergraduate Program, University of Maryland  <i>Codes and standards related to Energy Storage Systems (ESS), Electric Vehicle (EV) regulations, and micro mobility and transportation regulations are essential for ensuring the safety, reliability, and interoperability of these technologies. Regulations and standards for ESS are continually evolving to accommodate technological advancements and safety considerations. Staying updated with local and national regulatory bodies is crucial for all safety professionals involved in the energy storage, EV, and micro mobility sectors. The starting point regarding codes and standards will be the requirements in the 2024 Edition of the International Fire Code and the 2023 Edition of NFPA 855. The session will provide an update regarding ICC Committee Actions on proposed changes to the International Fire Code and an update on NFPA 855, using the First Draft Report. If Public Comments on NFPA 855 are available prior to the session, key Public Comments will also be identified.</i>
4:00 – 4:30 p.m.	<b>Learning from events - the evolving state of EV and Battery Safety Regulations, Standards, and Practice</b> Brian Engle, Amphenol  <i>This presentation will describe the latest learnings from battery, xEV, and BESS field incidents and their influence on global regulations, industry standards, and recommended practices for manufacturers and the first responder community. Attendees will gain an understanding of the safety challenges from battery failures, including the influence of arc flash and vapor cloud explosion incidents, with background on the risks from flammable and hazardous gas release. This new knowledge is now driving changes to regulatory and standards framework and subsequent guidelines not only for best practice design, but also improvements in</i>

	<i>procedure and methodology for dealing with battery failure for best possible outcomes.</i>
4:30 – 5:00 p.m.	<p><b>Strategies and Best Practices for Mitigating Lithium-Ion Battery Fires in Micro-Mobility Devices</b></p> <p>Jeffrey Fecteau, CBO, UL Solutions</p> <p><i>A brief overview of lithium-ion battery hazards to include; environmental factors, charging concerns, internal short circuits, manufacturing defects, aging and misuse.</i></p>
<b>Wednesday June 5</b>	
9:00 - 9:15 a.m.	<p><b>Welcome and Introductions</b></p> <p>Chris Jelenewicz, PE, FSFPE, SFPE CEO &amp; Symposium Chair: Adam Barowy</p>
9:15 – 9:45 a.m.	<p><b>Keynote</b></p> <p><b>Lithium-Ion Battery Fires: Challenges from Different Perspectives</b></p> <p>Dr. Lori Moore-Merrell, U.S. Fire Administrator</p> <p><i>Li-ion batteries and emerging alternatives constitute a significant component of the drive to reduce emissions worldwide. These are necessary and emerging technologies intended to reduce our dependence on fossil fuels, yet they can introduce new risks to our communities and to firefighters. Without complete research and regulation, these risks will continue. One of the major challenges to fully understanding the scope and scale of the LIO battery fires is that we do not have sufficient data on the number of related fire incidents in the nation. Therefore, the United States Fire Administration is working to change that scenario. Incident data and ongoing research are imperative to identifying proven safety and suppression practices and implementing lasting solutions.</i></p>
9:45 – 10:00 a.m.	<p><b>Grand Challenges in Energy &amp; Infrastructure: Acting on Global Research, Education, &amp; Outreach Priorities</b></p> <p>Noah Ryder, PhD, PE, Representing SFPE Foundation</p> <p><i>In July 2023, following 18 months of intensive working group meetings, the SFPE Foundation's Grand Challenges Initiative Energy &amp; Infrastructure Working Group published its <a href="#">white paper</a> outlining a 10-year plan for coordinated strategic investment in research, education, and outreach. This presentation will highlight some of the areas where our 34+ academic, industry, and research partners know fire engineers can contribute to tackling global challenges in energy and infrastructure, including with respect to emergent energy generation, storage, and distribution technologies. Moving forward, we can marshal our collective resources to make progress in these key areas.</i></p>
<b>BULK STORAGE OF BATTERY PRODUCTS</b>	
Moderated by Phil Friday, PE	
10:00 – 10:30 a.m.	<p><b>Large-Scale Sprinklered Fire Testing of Lithium-ion Battery Cells in an ASRS Rack Storage Configuration</b></p> <p>Phil Friday, PE, FSFPE, The Reliable Automatic Sprinkler Co., Inc.</p>



	<p><i>This presentation will review the fundamental hazards associated with lithium-ion batteries and the history of large-scale sprinklered fire testing of lithium-ion batteries. It will then describe a project wherein a unique fire sprinkler protection scheme was tested at UL Solutions to assess its ability to mitigate cell-to-cell thermal runaway propagation in small format lithium-ion batteries at 100 percent state of charge within different rack storage configurations. The rack storage configurations were representative of Automatic Storage and Retrieval System (ASRS) racks found in the formation, aging, and testing areas of the battery manufacturing facilities. Each test involved thousands of cylindrical cells (18650 form factor) in plastic trays in different rack configurations. The array of cells was forced into thermal runaway, and the performance of the sprinkler protection scheme was assessed.</i></p>
10:30 – 10:45 a.m.	Morning Break
10:45 – 11:15 a.m.	<p><b>Review of Storage Guidelines, Handling and Testing from Batteries to Final Products</b> Christina Francis, PE, FSFPE, CFPS, Sr. Staff Fire &amp; Regulatory Specialist, Tesla</p> <p><i>Review of storage guidelines, handling and testing from batteries to final products.</i></p>
11:15 – 11:45 a.m.	<p><b>Development of Loss Prevention Recommendation for Lithium-Ion Battery Manufacturing and Storage</b> Benjamin Ditch, Principal Research Engineer &amp; Stephanie Thomas, Senior Staff Engineering Specialist, FM Global</p> <p><i>In today's work, the use of lithium-ion batteries continues to grow significantly. The increased use has led to greater quantities of li-ion batteries being manufactured and stored to keep up with demand. However, hazard evaluation within the manufacturing process and fire protection guidance within the lithium-ion battery industry has lagged. This presentation will walk through the hazards associated with the main steps of the li-ion cell manufacturing process and fire protection approaches to mitigate the hazards. We will also discuss the continued fire testing efforts to enhance our understanding of the hazard and needed protection approaches.</i></p>
11:45 a.m. – 12:30 p.m.	<p><b>Q&amp;A / Panel Discussion</b> Panelists: Phil Friday, PE, FSFPE, Christina Francis, PE, FSFPE, CFPS, Benjamin Ditch, Stephanie Thomas Moderated by: Victoria Hutchison</p>
12:30 – 1:30 p.m.	Networking Lunch & Exhibits
12:30 – 1:30 p.m.	<i>Grand Challenges Initiative: Energy &amp; Infrastructure Planning Session (Invitation only for SFPE Foundation GCI Partners)</i>
<p><b>HAZARDS OF DEPLOYED PRODUCTS – Electric Vehicles and Micro-mobility</b> Moderated by Sean DeCrane</p>	
1:30 – 2:00 p.m.	Topic: Case Study Session. Invited Speaker: Lee Walker
2:00 – 2:30 p.m.	<p><b>FSRI Experimental Investigation of EV Fires</b> Nathaniel Sauer, PhD, UL Research Institutes Fire Safety Research Institute</p>

	<p><i>Vehicles are a necessity of the modern world; we rely on them heavily for transportation needs and we park them in and near our homes. As electric vehicles become more commonplace, understanding how vehicle fire hazards are evolving is more important than ever. The Fire Safety Research Institute (FSRI) has begun a multi-year effort to investigate the hazards associated with internal combustion engine and electric vehicle fires. FSRI gathered data during experiments to address hazards including heat release rate, heat flux to adjacent surfaces, and occupational exposure risks. Preliminary findings are outlined in this work.</i></p>
2:30 – 3:00 p.m.	<p><b>EV Fires &amp; Fire Protection</b> Victoria Hutchison, Senior Research Project Manager, Fire Protection Research Foundation</p> <p><i>As the penetration of electric vehicles into the global vehicle market continues, there are a number of downstream fire safety considerations that must be considered – from the unique hazards presented at the manufacturing and assembly plants, to marine transport of EVs, safe placement of EV charging infrastructure, protection of EVs in parking structures and fire response considerations. The latest research findings from the Fire Protection Research Foundation and guidance for the vast fire protection challenges presented throughout the EV lifecycle will be presented.</i></p>
3:00 – 3:30 p.m.	Afternoon Break
3:30 – 4:00 p.m.	<p><b>Fire and Explosion Hazards of Lithium-Ion Battery-Powered E-Mobility Products</b> Benjamin Gaudet, PE, Lead R&amp;D Engineer, UL Solutions</p> <p><i>This presentation will introduce the prevalence of, reasons behind, and descriptions of the fire and explosion hazards generated by e-mobility devices powered by lithium-ion batteries. Trends related to the amount and rapid growth rate of thermal runaway incidents related to e-mobility and consumer products will be discussed. This presentation will also describe projects conducted by a partnership between UL Solutions and UL Fire Safety Research Institute that investigated fire and explosion hazards of e-mobility devices in a residential setting. The findings and conclusions of these projects will be discussed.</i></p>
4:00 – 4:30 p.m.	<p><b>UL 1487: A Standards Approach to Consumer Product Lithium-Ion Battery Containment</b> Benjamin Gaudet, PE, Lead R&amp;D Engineer, UL Solutions &amp; Joshua Dinaburg, PE, Fire Test Specialist, CSA Group</p> <p><i>This presentation will discuss the recent and ongoing development of UL 1487: Standard for Battery Containment Enclosures. The presentation will discuss the rising incident rate for consumer product lithium-ion battery thermal runaway events - including in the space of e-mobility - and how UL 1487 was initiated to assess products designed to store and contain lithium-ion batteries and the consumer devices they power. The engineering approaches behind the standard and its intended scope will also be discussed.</i></p>
4:30 – 5:00 p.m.	<p><b>Electric Vehicle &amp; Micro-mobility Firefighting Considerations</b> Patrick Durham, Stached Training</p>



	<i>This presentation will provide essential insights into the challenges combating fires involving micro-mobility devices and electric vehicles (EVs). From understanding lithium-ion battery hazards to tactical response strategies, participants will gain actionable knowledge for safer and more effective firefighting operations in modern transportation contexts.</i>
5:00 – 5:45 p.m.	<b>Q&amp;A / Panel Discussion with Afternoon Session Speakers</b> Panelists: Lee Walker, Nathaniel Sauer, PhD, Victoria Hutchison, Benjamin Gaudet, PE, Joshua Dinaburg, PE, Patrick Durham Moderated by: Sean DeCrane
5:45 – 7:00 p.m.	Networking Reception
<b>Thursday June 6</b>	
<b>HAZARDS OF DEPLOYED PRODUCTS – ESS</b> Moderated by Paul Hayes	
8:30 – 9:00 a.m.	<b>Case Study - Low Level Failure and Emergency Response in a Unclear Event</b> Paul Hayes, VP of Energy Infrastructure, Hiller  <i>What happens when the BMS and gas detection register a failed cell and an event, but there is no fire and no imminent explosion? A five-day response and evaluation to minimize risk and protect the evaluation team and SME's. The approach and lessons learned.</i>
9:00 – 9:30 a.m.	<b>ESS: Fire Service Response - Tactical Considerations</b> Sean DeCrane, Director, Health and Safety, IAFF  <i>The presentation will provide a short overview of recent research projects partnered by the International Association of Fire Fighters, UL Solutions, and the UL Fire Safety Research Institute under a working agreement with the US Department of Energy. The presenter will review lessons learned and share the Fire Service Tactical Considerations developed by the project panel.</i>
9:30 – 10:00 a.m.	<b>ESS Engineering Practices – Design using 9540A</b> Noah Ryder, PhD, PE, Chief Operating Officer, Fire & Risk Alliance, LLC.  <i>This presentation will discuss how UL9540A and full-scale test data can be utilized to inform product safety, ensure safe site design, and support the fire service and development of emergency response plans.</i>
10:00 – 10:15 a.m.	Morning Break
10:15 – 10:45 a.m.	<b>Battery Energy Storage System Hazard Assessment: Modeling and Scaleup</b> Dong Zeng, PhD, FM Global  <i>The increased utilization of lithium-ion batteries (LIB) in battery energy storage systems (BESS) for utility-scale renewable energy generation has drawn attention to better understanding the associated fire and explosion hazards. These hazards are attributable to the heat and flammable gases released during LIB thermal runaway (TR). The energy released from cells that undergo TR causes inter-cell thermal</i>

	<p><i>runaway propagation (TRP). Fire and sensible heat generation from the TRP of a module can trigger inter-module TRP and, ultimately, large-scale fire or explosion. Hazard assessments are critical to the prevention and protection of such incidents, and numerical modeling is a key tool in developing such assessments. For this purpose, FM Global has conducted a systematic experimental study spanning LIB cells, modules, and multi-module LIB units using NMC/graphite pouch-type cells with a capacity of 63 Ah. A novel cell thermal runaway modeling approach based on single-cell TR experiments was developed and applied to predict module-level fire hazards, with the final objective of predicting unit-level fire and explosion hazards. This presentation will discuss the experimental findings and the progress of modeling.</i></p>
10:45 – 11:15 a.m.	<p><b>Battery Energy Storage Systems: Lessons from the FDNY and Beyond</b> Nick Petrakis, PE, FPE, Energy Safety Response Group</p> <p><i>An insight into the creation of NYC's first adoption of safety requirements for Battery Energy Storage Systems: 3RCNY 608-01. This presentation will describe the challenges and lessons learned from creating and enforcing standards for the safe installation of Battery Energy Storage Systems in the densely populated urban environment of New York City.</i></p>
11:15 – 11:45 a.m.	<p><b>Applicability and Limitations of Existing Methodologies for Protecting ESS Enclosures against Explosions</b> Jens Conzen, Dipl.-Ing., EUR ING, MSc, MBA, Vice President &amp; Anil Kapahi, Director, RDT&amp;E, Jensen Hughes</p> <p><i>Similar to other product designs, the development of an Energy Storage System (ESS) aims to fulfill various performance objectives concerning its functionality and safety. Key requirements, like maintaining optimal temperatures for operating batteries and other ESS components to minimize overall cooling costs, lead to intricate and congested geometries in ESS designs. Moreover, the creation of hot and cold aisles within air-cooled BESS introduces additional compartmentalization, posing challenges in explosion control. Other design considerations, including fire safety and protection against water ingress, also emphasize the need for increased compartmentalization, adding complexity to the explosion control design. The release of flammable battery gas during thermal runaway in this confined environment with congestion created by the obstructions within the enclosure poses a challenging explosion control design problem, drawing significant attention from the fire protection community. One of the methods of mitigation prescribed by NFPA 855 is deflagration venting, according to NFPA 68. Both prescriptive and performance-based methodologies will be discussed, emphasizing their applicability and limitations on modern ESS enclosure designs.</i></p>
11:45 a.m. – 12:45 p.m.	Lunch
<b>HAZARDS OF DEPLOYED PRODUCTS – ESS cont.</b> Moderated by Paul Hayes	
12:45 – 1:30 p.m.	<p><b>Q&amp;A / Panel Discussion with Morning Session Speakers</b> Panelists: Paul Hayes, Sean DeCrane, Noah Ryder, Dong Zeng, Nick Petrakis, Jens Conzen, Anil Kapahi Moderated by: Christina Francis</p>



<p>1:30 – 2:00 p.m.</p>	<p><b>I Have The UL9540A Data, Now What?</b>  Veronica Goldsmith, PE, Arup</p> <p><i>Full-scale fire testing is essential to understand the thermal runaway, fire, and explosion hazards of the LIBs and BESSs. However, engineers must interpret and manipulate that data to inform design. Proper use of the testing data and an understanding of its limitations are critical for the design and operation of BESSs. Examples of how data can be interpreted to inform risk assessments will be presented in an effort to bridge the knowledge gaps between stakeholders, industry, and engineers.</i></p>
<p>2:00 – 2:45 p.m.</p>	<p><b>Panel Discussion: What's Are the Next Steps in Li-ion Battery Fire Safety?</b>  Panelists: Phil Friday, Sean DeCrane, Paul Hayes, Adam Barowy  Moderated by: Victoria Hutchison</p> <p><i>In this session, a panel of experts comprised of the Symposium session leads for each topic will review the latest advancements, research, challenges, and next steps in ensuring the fire safety of lithium-ion batteries across various applications.</i></p>

Questions? Email us at [education@sfpe.org](mailto:education@sfpe.org).

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