Lithium-Ion Battery Safety:
Navigating Risks in a Rapidly Evolving Technology

Michigan Safety Conference

Emergency Management &
Fire Safety Division

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Introduction

Mike Snyder; PE, CSP, CFEI
VP, Operational Risk Management
Mike.Snyder@dekra.com
https://www.linkedin.com/in/safetysnyder

About **DEKRA**

Established in 1925 to ensure road safety in connection with rapidly developing mobility, today DEKRA stands for safety on the road, at work, and at home and offers a broad service portfolio, including qualified and independent expert services in more than 60 countries.

DEKRA Consulting & Training Services

- DEKRA has **over three decades of experience** partnering with organizations across to address safety challenges with solutions that are effective, pragmatic, and address local and global regulations.

- **Pillars of DEKRA Process Safety:**
  - Process Safety Management
  - Process Safety Training
  - Process Safety Academy
  - Process Safety Consulting

Scope Process Safety Consulting:

Risk Assessment of Hazardous Processes

Process Safety Management (PSM)

Organizational Process Safety (OPS) Assessment

Major Accidents Legislation Compliance Services

Chemical Reaction Hazards and Overpressure Protection

Functional Safety Consulting

Explosion Protection Consulting

Process Safety Incident Investigation

We have served over 5,000 clients, among them the world's leading corporations across multiple industries.

- **Automotive**
- **Chemicals**
- **Food and Beverage**
- **Oil & Gas**
- **Mining**
- **Energy**
- **Transportation**
- **Utilities**
- **Pharmaceuticals**
- **Petrochemicals**
- **Agriculture**
- **Manufacturing**
- **Engineering**

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Outline

1. Overview of Li-ion Battery Utilization & Challenges
2. Li-ion Battery Basics
3. Anatomy of a Li-ion Battery Thermal Runaway
4. Prevention, Preparedness, & Response
   RAGAGEP, Emerging Best Practices, & Continued Opportunities
5. Summary & References

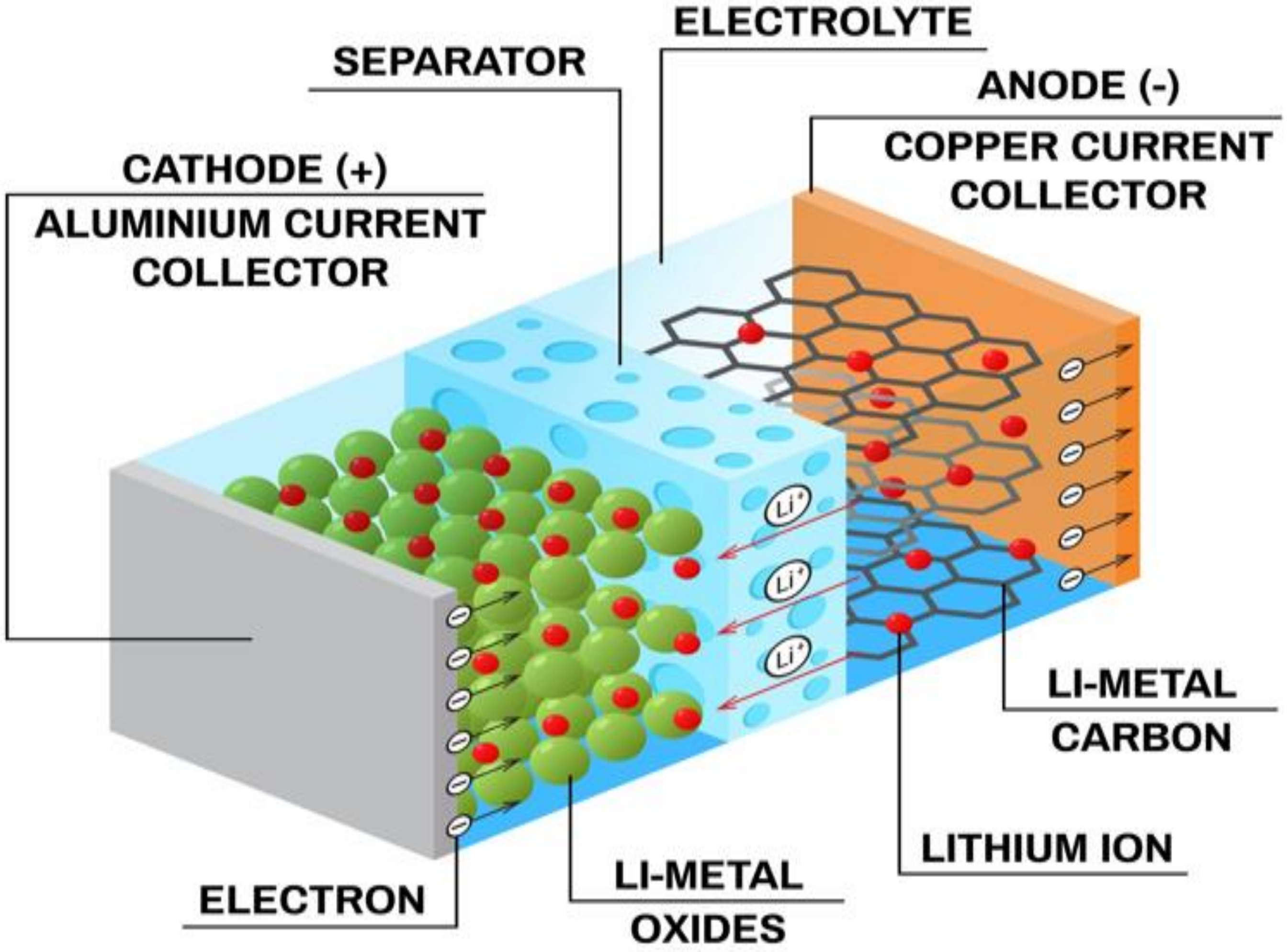
Guiding Principles: Risk Factors

1. What is the State of Charge?
2. What is the Battery (Cathode) Chemistry?
3. What is the Battery Size?
4. What is the Quality of Area Ventilation?

Li-ion Battery Utilization & Challenges

- **3 Utilization Platforms**
  - Portable Consumer Applications (several Wh)
  - Electric Vehicles (10 kWh to 100 kWh)
  - Energy Storage Systems (MWh)
- **Rapid Improvement & Innovation**
- **Limited Consensus Standards & Regulation, but Rapidly Developing**
- **Thermal Runaway & Fire Events Occurring**
  - Challenging Events & Emerging Public Scrutiny

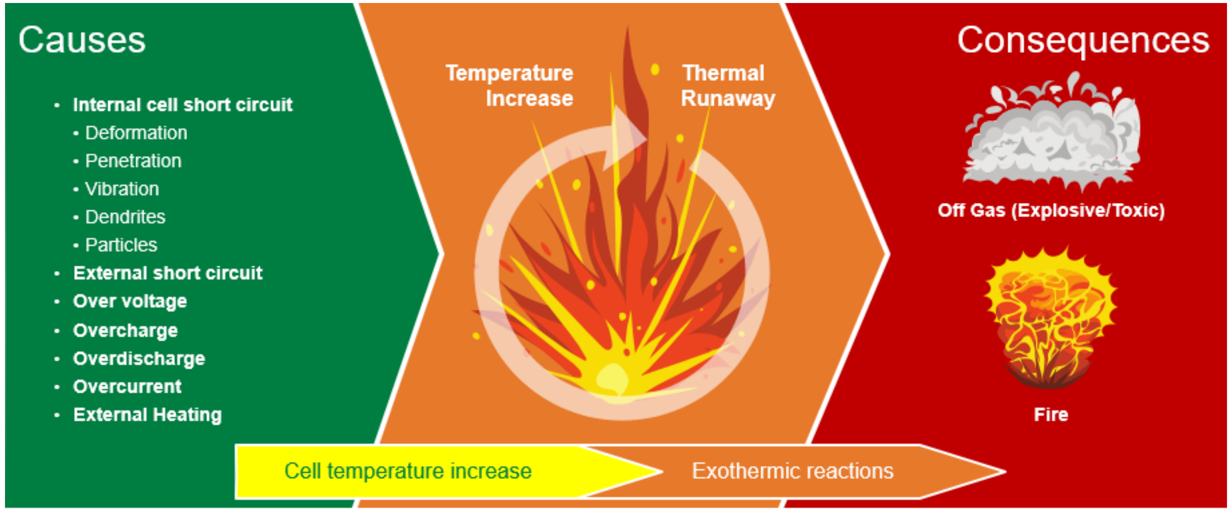
Li-ion Battery Nomenclature (Discharge)

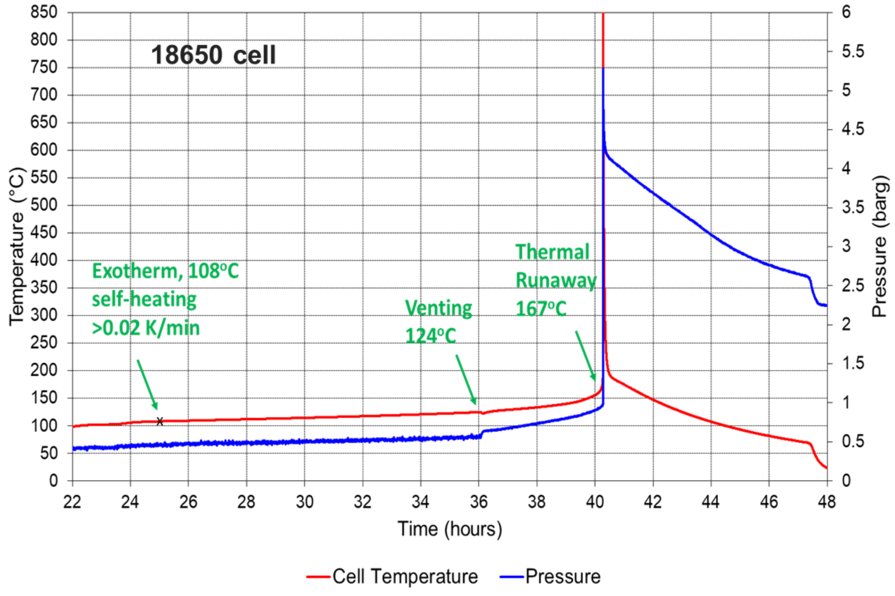


Li-ion Battery Nomenclature

- **Building Blocks**
  - Cells (Cylindrical, Prismatic, Pouch)
  - Modules
  - Packs
- **Battery Management Systems**
- **Thermal Management Systems**
- **Primary versus Secondary Cells**
- **Capacity (Wh) and State of Charge (SOC)**
  - Relationship of Capacity and SOC to Hazard
- **Solid Electrolyte Interphase (SEI)**
- **No “Free” Metallic Lithium in Battery**

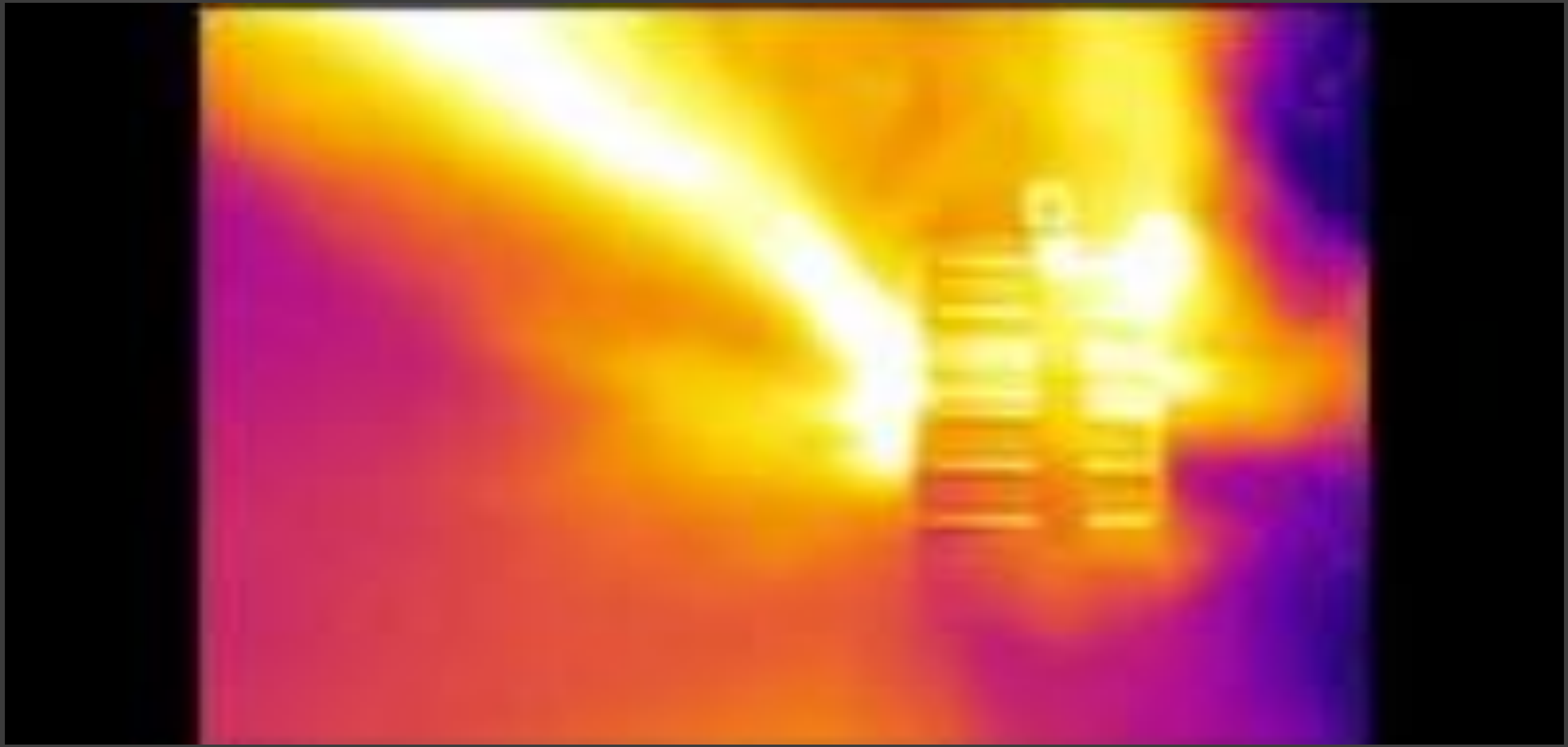
Anatomy of a Li-ion Battery Thermal Runaway





- **View through Abuse Mechanisms**
  - Mechanical
  - Electrical
  - Thermal
- **Manufacturing through Lifecycle Evaluation**
- **Each Mechanism results in "Short Circuit"**
- **Battery Components Have Specific Thermal Sensitivities**
  - Chemistry Dependent
- **Current Electrolytes Present Challenges**
  - Ignitable Liquids (Organic Carbonates)
  - Decomposition into HF ($LiPF_6$)
- **Reignition & Stranded Energy Challenges**

Thermal Imaging of a Li-Ion Battery Thermal Runaway



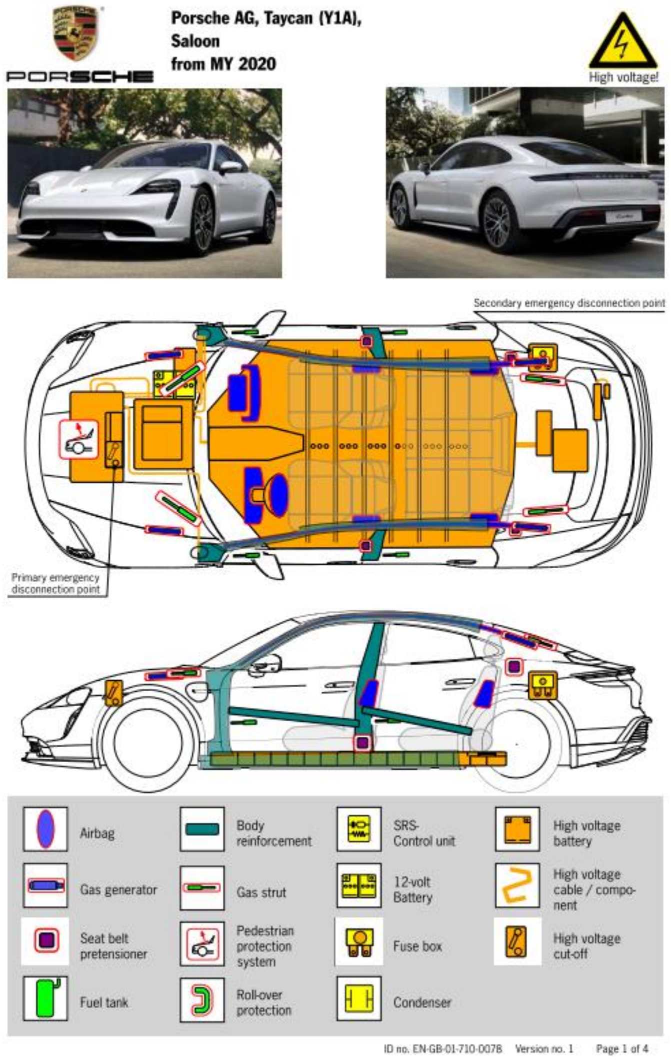
Courtesy: George Bilmyer
https://www.youtube.com/@Batteryman1952

The Context of Li-Ion Thermal Runaway in a Structure

Courtesy: Fire Safety Research Institute (11/2022)

Fatal Explosion Underground Parking Garage: April 2, 2025 – Madrid, Spain

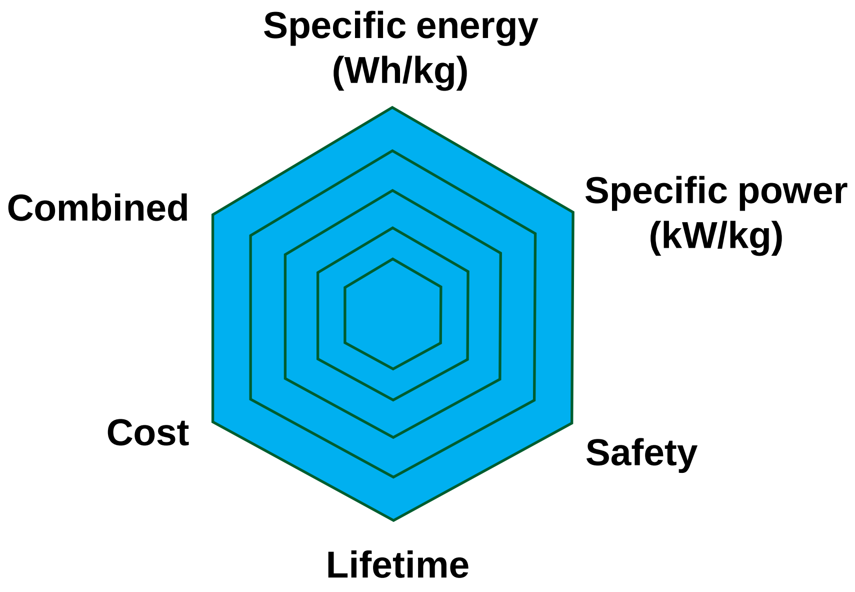
- **Collision of Porsche Taycan (EV) into Parked Car**
- **Vehicle Battery Went into Thermal Runaway**
- **Large Gas Evolution in Confined Area**
  - 13,000 liters of Hydrogen
  - 15,000 liters of Carbon Monoxide
  - Hydrogen Fluoride
- **Explosion Occurred**
  - **2 Firefighter Fatalities**
  - **15 Firefighter Injuries from Smoke Inhalation**
- **Brief Video Case Study Review:**
  - https://youtu.be/fxVucc2fX-w?si=q3_PaQLsriNTw6uU



Prevention & Preparedness Strategies

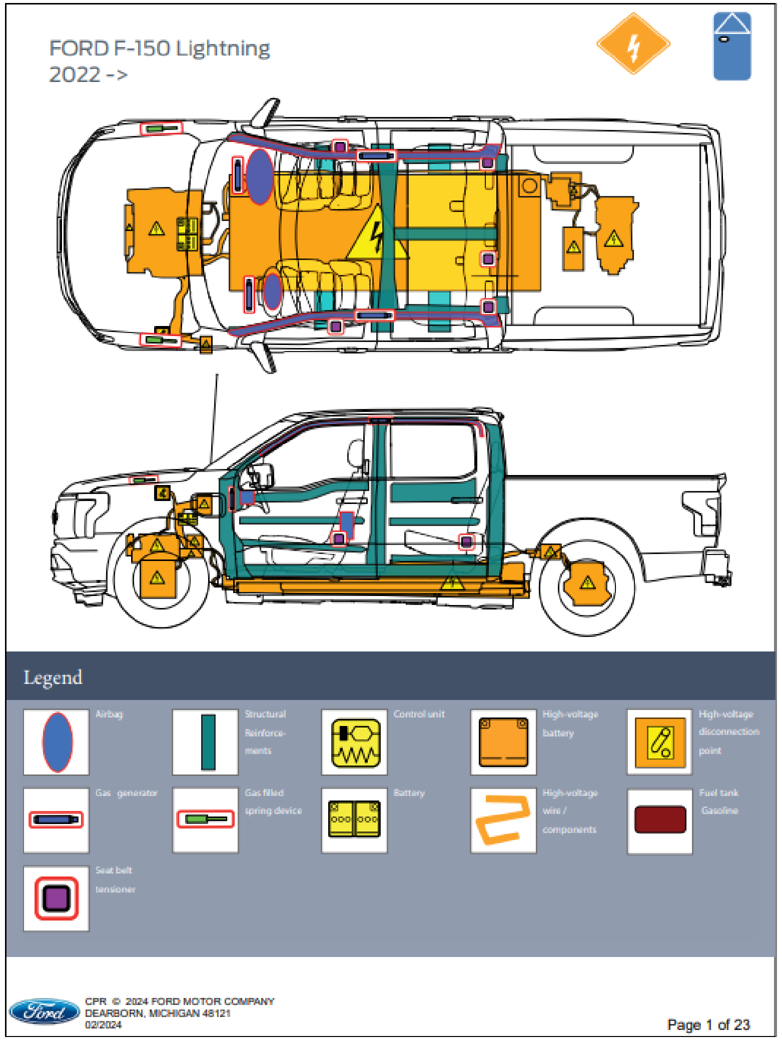
- **Thermal Runaway: A Lifecycle Consideration**
  - Battery Design
  - Battery Manufacturing Quality Assurance
  - Operational Abuses – Battery Management Systems
  - End of Life Processing
- **In Search of Optimization**
  - **Specific Energy**
  - **Specific Power**
  - **Safety**
  - **Cost**
  - **Reliability**

The perfect cathode



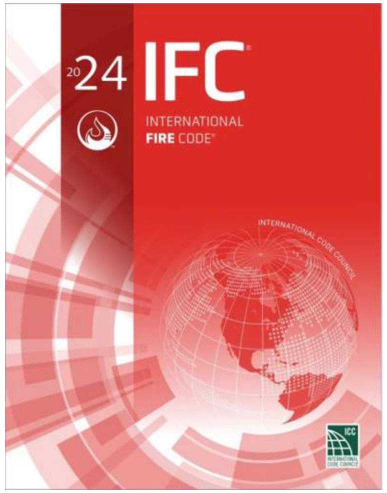
Status of RAGAGEP

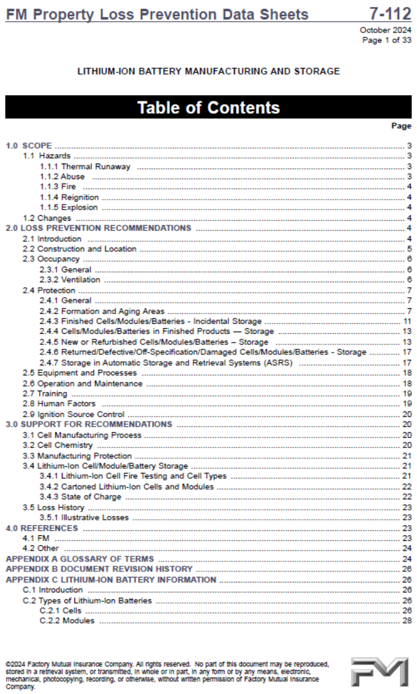
- **A Rapidly Changing Landscape**
- **Battery Manufacturing & Transport Requirements**
- **Storage Requirements**
  - Generally, at Lower SOC
  - Extensive Testing Programs Underway
- **Vehicle Platforms**
  - High Risk Platforms for Abuse Mechanisms
  - Vehicle Rescue Cards
- **Energy Storage Systems**
- NFPA 855 (2023)
  - International Building & Fire Code (2024)
  - Unique Response Considerations
  - Fire Safety Research Institute – Fire Service Training for Li-ion ESS



Updates to International Fire Code (2024)

- **Permits & Fire Safety Plans**
  - **Section 105.5.29:** Operational Permit for Battery Use/Storage greater than 15 cubic feet
- **Storage Requirements**
  - **Section 320:** Li-ion and Lithium Metal Battery General Requirements
  - **Section 320.4:** Specific Storage Scenarios (Reduced for <30% SOC)
- **Automatic Sprinkler Systems**
  - **Section 903.2:** Specifies when Sprinkler Systems must be installed
  - **Section 903.3.1.1.3:** Special Requirements for Design
- **Fire Alarm & Detection Systems**
- **Powered Micromobility Devices**
  - **Section 322: Micromobility Device Li-ion Requirements**
- **New FM Global Resource (Datasheet 7-112)**
  - FM Datasheet 7-112 (October 2024) Li-Ion Battery Manufacturing & Storage





FM Property Loss Prevention Data Sheets 7-112

October 2024
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LITHIUM-ION BATTERY MANUFACTURING AND STORAGE

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Emergency Response Considerations

- **3 Unique Utilization Platforms:**
  - Consumer Goods Use & Storage
  - Electric Vehicles
  - Energy Storage Systems (ESS)
- **Isolation and Contain to Unit of Origin Strategies**
- **Water Represents Today's Best Practice**
  - Protects Adjacent Combustibles
  - Copious Amounts
  - Limited Ability to Stop Runaway
- **SOC and Thermal Runaway Risks**
- **Detection & Thermal Imaging**
- **EV Rescue Cards**
- **Specific Challenges for ESS Facilities**

NEWS › LOCAL NEWS

Fire departments prepare for electric car battery fires; can take 10 times more water to put out than gas engines

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

July 29, 2020

FSRI releases new report investigating near-miss lithium-ion battery energy storage system explosion.

MORRIS

Nearly 100 Tons of Lithium Batteries Involved in Large Morris Industrial Fire

Published June 29, 2021 • Updated on June 29, 2021 at 5:37 pm

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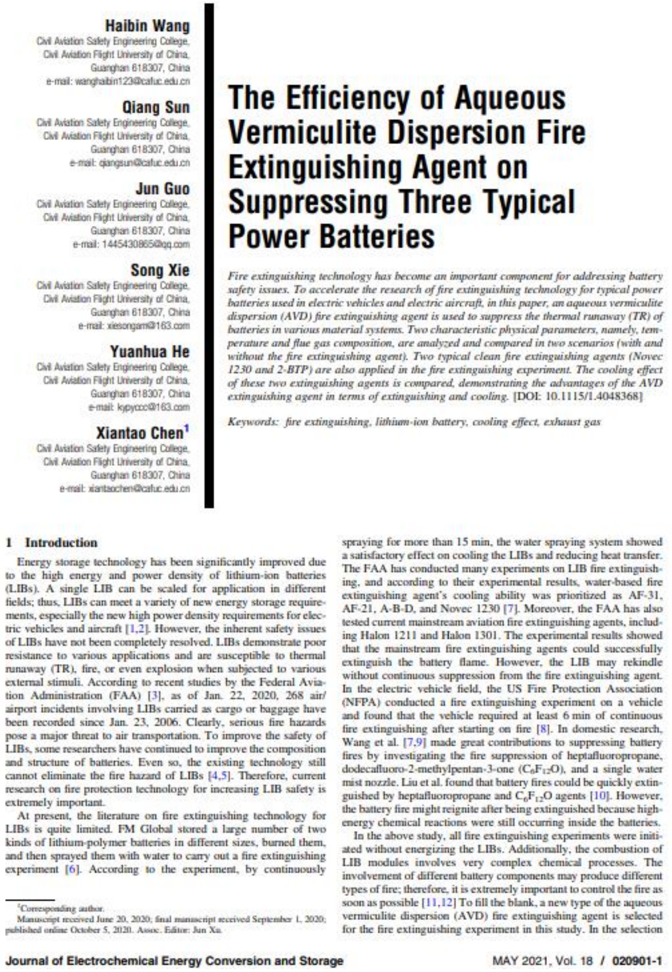
Emergency Response: Emerging Considerations

- **Encapsulation Using Recycled Glass**
- **Control Using Vermiculite Solutions**
- **Fire Exposure Containment Blankets**
- **Direct Water Injection into Battery Packs**



Haibin Wang
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: wanghaibin123@cafuc.edu.cn

Qiang Sun
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: qiangsun@cafuc.edu.cn

Jun Guo
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: 1445430865@qq.com

Song Xie
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: xiesongam@163.com

Yuanhua He
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: kypyccc@163.com

Xiantao Chen[1]
Civil Aviation Safety Engineering College,
Civil Aviation Flight University of China,
Guanghan 618307, China
e-mail: xiantaochen@cafuc.edu.cn

The Efficiency of Aqueous Vermiculite Dispersion Fire Extinguishing Agent on Suppressing Three Typical Power Batteries

Fire extinguishing technology has become an important component for addressing battery safety issues. To accelerate the research of fire extinguishing technology for typical power batteries used in electric vehicles and electric aircraft, in this paper, an aqueous vermiculite dispersion (AVD) fire extinguishing agent is used to suppress the thermal runaway (TR) of batteries in various material systems. Two characteristic physical parameters, namely, temperature and flue gas composition, are analyzed and compared in two scenarios (with and without the fire extinguishing agent). Two typical clean fire extinguishing agents (Novec 1230 and 2-BTP) are also applied in the fire extinguishing experiment. The cooling effect of these two extinguishing agents is compared, demonstrating the advantages of the AVD extinguishing agent in terms of extinguishing and cooling. [DOI: 10.1115/1.4048368]

Keywords: fire extinguishing, lithium-ion battery, cooling effect, exhaust gas

1 Introduction

Energy storage technology has been significantly improved due to the high energy and power density of lithium-ion batteries (LIBs). A single LIB can be scaled for application in different fields; thus, LIBs can meet a variety of new energy storage requirements, especially the new high power density requirements for electric vehicles and aircraft [1,2]. However, the inherent safety issues of LIBs have not been completely resolved. LIBs demonstrate poor resistance to various applications and are susceptible to thermal runaway (TR), fire, or even explosion when subjected to various external stimuli. According to recent studies by the Federal Aviation Administration (FAA) [3], as of Jan. 22, 2020, 268 air/airport incidents involving LIBs carried as cargo or baggage have been recorded since Jan. 23, 2006. Clearly, serious fire hazards pose a major threat to air transportation. To improve the safety of LIBs, some researchers have continued to improve the composition and structure of batteries. Even so, the existing technology still cannot eliminate the fire hazard of LIBs [4,5]. Therefore, current research on fire protection technology for increasing LIB safety is extremely important.

At present, the literature on fire extinguishing technology for LIBs is quite limited. FM Global stored a large number of two kinds of lithium-polymer batteries in different sizes, burned them, and then sprayed them with water to carry out a fire extinguishing experiment [6]. According to the experiment, by continuously spraying for more than 15 min, the water spraying system showed a satisfactory effect on cooling the LIBs and reducing heat transfer. The FAA has conducted many experiments on LIB fire extinguishing, and according to their experimental results, water-based fire extinguishing agent's cooling ability was prioritized as AF-31, AF-21, A-B-D, and Novec 1230 [7]. Moreover, the FAA has also tested current mainstream aviation fire extinguishing agents, including Halon 1211 and Halon 1301. The experimental results showed that the mainstream fire extinguishing agents could successfully extinguish the battery flame. However, the LIB may rekindle without continuous suppression from the fire extinguishing agent. In the electric vehicle field, the US Fire Protection Association (NFPA) conducted a fire extinguishing experiment on a vehicle and found that the vehicle required at least 6 min of continuous fire extinguishing after starting on fire [8]. In domestic research, Wang et al. [7,9] made great contributions to suppressing battery fires by investigating the fire suppression of heptafluoropropane, dodecafluoro-2-methylpentan-3-one ($C_6F_{12}O$), and a single water mist nozzle. Liu et al. found that battery fires could be quickly extinguished by heptafluoropropane and $C_6F_{12}O$ agents [10]. However, the battery fire might reignite after being extinguished because high-energy chemical reactions were still occurring inside the batteries.

In the above study, all fire extinguishing experiments were initiated without energizing the LIBs. Additionally, the combustion of LIB modules involves very complex chemical processes. The involvement of different battery components may produce different types of fire; therefore, it is extremely important to control the fire as soon as possible [11,12] To fill the blank, a new type of the aqueous vermiculite dispersion (AVD) fire extinguishing agent is selected for the fire extinguishing experiment in this study. In the selection

[1]Corresponding author.

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Peer Reviewed Testing Programs are a <u>Critical Factor</u> to Advance this Technology!

Examples of Significant Li-Ion Events

- **Surprise, AZ (April 19, 2019)**
  - Battery Energy Storage System
  - Flammable Gas Explosion with 4 Firefighter Injuries
  - Impetusus for NFPA 855
- **Waste & Recycling Facilities (Numerous)**
  - Reported Fires rose from 290 (2017) to 373 (2023)
  - Increasing Fires traceable to Improper LiB disposal
  - Detection & Initial Automated Response Capabilities
- **Hand/Maintenance Tool Storage/Charging Operations**
  - Generally Simplistic Battery Management Systems
  - Many Damage Mechanisms
  - New Code Requirements Limiting Battery Capacity & Requiring Automatic Sprinkler Systems

Source: Ryan Fogelman, rfogelman@firerover.com

Mayor Adams Announces Plan to Combat Lithium-Ion Battery Fires, Promote Safe Electric Micromobility Usage

March 20, 2023

Watch the video here at https://www.youtube.com/live/4dbqoBQ5Btg?feature=share

STOPPING FIRES BEFORE THEY SPREAD

Lithium-ion batteries can be found in everything from laptops and cell phones to musical greeting cards and electric toothbrushes. When damaged or crushed, these batteries can catch fire, creating a hazard in recycling facilities, transfer stations and landfills. To combat risks posed by batteries that may end up in our facilities, we have invested in automated fire suppression technology that quickly detects hotspots and remotely contains and extinguishes the fire. **This technology has been installed in nearly half our recycling facilities and at nearly 40 landfills and transfer stations as of 2023.** In 2024, we aim to continue expanding the number of [illegible]s in which this technology is installed.

Safety Tips & Precautions for Li-Ion Battery Consumer Use

ALWAYS:

- **Purchase & use Devices Certified by a US NRTL, such as UL.**
- **Follow Manufacturer’s Instructions for Charging and Storage.**
- **Use Correct Battery, Cord, and Power Adaptor.**
- **Remove Damaged Li-Ion Batteries to Isolated, Outdoor Areas.**
- **Dispose/Recycle at Authorized Recycling Centers.**

NEVER:

- **Use Aftermarket (or Generic) Batteries or Chargers.**
- **Overcharge or Leave Battery Charging Overnight.**
- **Charge a Battery/Device Under a Pillow, On a Bed, or near a Sofa.**
- **Block a Primary Exit Route In or Out of a Room.**

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Conclusions

- **Li-ion Batteries will be a Significant Contributor to Alternative Energy Management Strategy**
- **Thermal Runaway (& Fire) Represent Significant Hazards**
  - Viewed through Abuse Mechanisms
- **Rapid Development of Regulatory Standards & RAGAGEP**
- **Development of Battery Chemistry to Deliver Improved Operational Efficiency & Safety**
- **Additional Emergency Response & Loss Control Testing Programs are Necessary**
- **More Awareness & Technical Training for All Stakeholders is Needed**

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Thank You!

Mike Snyder PE, CSP, CFPS

Vice President, Operational Risk Mgmt.

Email: mike.snyder@dekra.com

LinkedIn