Understanding and Managing Hazards of Li-Ion Battery Systems

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AGENDA

- **Overview of Li-ion Battery Utilization & Challenges**
- **Li-ion Battery Basics**
- **Anatomy of a Li-ion Battery Thermal Runaway**
- **Prevention, Preparedness, & Response**
  Emerging Best Practices, & Continued Opportunities
- **Summary & References**

Li-ion Battery Utilization & Challenges

3 typical ranges of usage

- 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 Never-Ending Hall of Shame

Application	Country	Year	Incident description
Energy	Australia	2021	Fire of Geelong 450MWh storage plant after initial testing
Automotive	USA	2021	Recall of 69000 electric vehicles due to faulty LG Chem batteries
Marine	Norway	2019	Hybrid-battery ferry on fire due to coolant leaking
Computer	Global	2019	Apple recalls a "limited number" of Mid2015 MacBook Pros because the battery may overheat and pose a fire safety risk.
Automotive	UK	2018	i-Pace suddenly on fire while parked.
Energy	Various	2017	Battery fires in large grid-connected systems
Automotive	USA	2016	Electric car suddenly on fire while parked.
Aerospace	USA	2013	Sudden failure in auxiliary units of Dreamliner 787.
Automotive	USA	2011	Chevy Volt on fire weeks after crash test.
Aerospace	South Korea	2011	Crash B744 Jeju due to cargo on fire - 2 fatalities
Aerospace	UAE	2010	Crash B747-400F Dubai due to cargo fire - 2 fatalities
Computer	Japan	2006	Sudden failure of batteries powering notebooks.
Aerospace	USA	2006	Accident DC8 Lithium-Ion Philadelphia
Cell phone	Finland	2003	Sudden failure in batteries of mobile phones.

Table 1: Some battery fire events – from Diaz & al[8]

- **Battery fires occur in many industrial sectors and in everyday objects: in cargo, on boats, in planes, in cell phones, laptops or electric vehicles.**
- **The American Consumer Product Safety Commission (CPSC) reported 25,000 battery fire incidents in more than 400 consumer products between 2012 and 2017**

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Li-ion Battery Never-Ending Hall of Shame

Fire at Victorian Big Battery site near Geelong (Australia) on July 29, 2021. The fire broke out during testing of a battery megapack.

Credit: Fire Rescue Victoria

Li-ion Battery Never-Ending Hall of Shame

Li-ion Battery Never-Ending Hall of Shame

Pas-de-Calais : le four d'un crématorium explose à cause d'un téléphone portable oublié dans un cercueil

Par La Provence

La cause de cette explosion n'est autre que la batterie au lithium d'un téléphone portable qui se serait retrouvé dans le cercueil. *PHOTO ILLUSTRATION DR*

0 0 0 0 0 | 0 Partages

L'idée pourrait presque faire sourire mais cela aurait pu avoir de graves conséquences. Au mois de juillet, l'un des deux fours du crématorium de Vendin-lès-Béthune (Pas-de-Calais) a explosé alors qu'une cérémonie se tenait à proximité, révèle aujourd'hui **La Voix du Nord**. S'il n'y a heureusement pas eu de blessé, le four est toutefois hors d'usage et les travaux de réparation ont été estimés à 90 000€.

La cause de cette explosion n'est autre que la batterie au lithium d'un téléphone portable qui se serait retrouvé dans le cercueil. Une fois à l'intérieur du four et soumise à une température de 1 100 degrés, celle-ci aurait rapidement gonflé jusqu'à exploser. "*Il en va de la responsabilité des pompes funèbres de s'assurer qu'il n'y a que le défunt dans le cercueil*", peste Frédéric Ivain, le directeur du crématorium, auprès de nos confrères.

- **Crematory Oven explosion**
- **Due to mobile phone battery**
- **90k€ damage**

Li-ion Battery Incidents : Database

Stationary Energy Storage Failure Events

This table tracks utility and C&I scale energy storage failure events with publicly available information.

Note: Missing values in this table reflect unknowns.

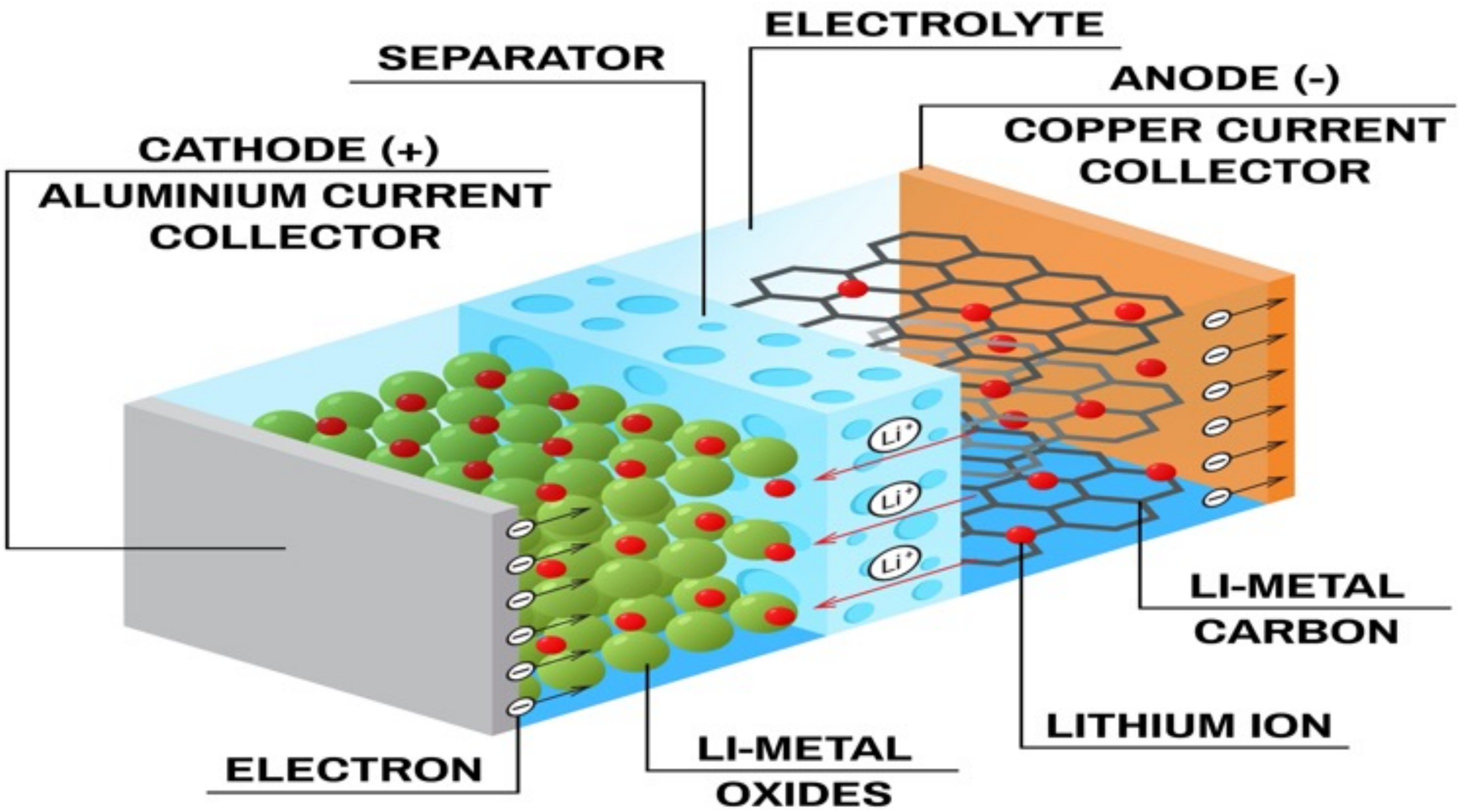
Show 10 entries

Search:

Location	Energy (MWh)	Power (MW)	Application	Installation	Event Date	System Age (yr)	State During Accident
US, AZ, Chandler	40	10		Substation	18 April 2022	3	Operational
US, CA, Valley Center	560	140		Substation	5 April 2022	0.2	Operational
Longjing, Taichung City, Taiwan	1	1	Solar Integration	Power Plant	30 March 2022	2	Operational
US, CA, Moss Landing	400	100	Solar Integration	Power Plant	13 February 2022	1	Operational
South Korea, Gunwi-gun, Gyeongsangbuk-do	1.5	0.45	Solar integration	Remote	17 January 2022	3	Operation. Fully charged
South Korea, Nam-gu, Ulsan	50	10	Peak Load Reduction	Urban	12 January 2022	2	Operational
US, CA, Moss Landing	1,200	300	Solar Integration	Power Plant	4 September 2021	0.8	
Australia, Victoria, Geelong	450	300	Grid Stability	Rural	30 July 2021	0	Construction, Commissioning

https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

Li-ion Battery Nomenclature (Discharge)



Li-ion Battery Nomenclature

Li-ion is a generic term, covering

Several types of battery chemistries
Several formats for various applications

Different from the Lithium metal Primary battery

Building Blocks

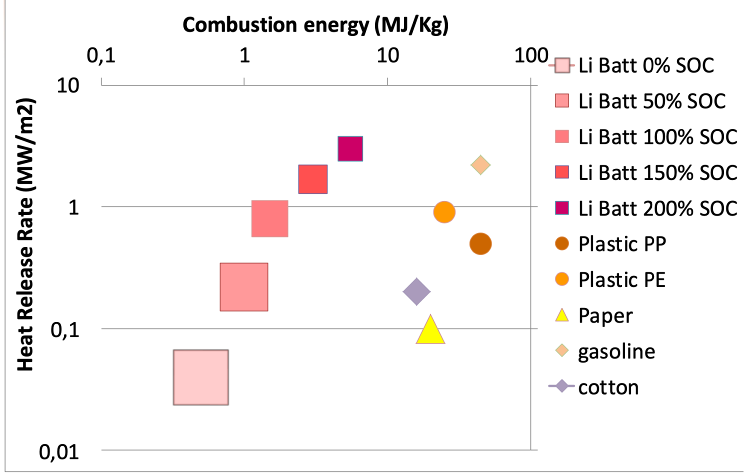
Cells (Cylindrical, Prismatic, Pouch)
Modules
Packs

Battery Management Systems (BMS)

Capacity (Wh) and State of Charge (SOC)

Relationship of Capacity and SOC to Hazard

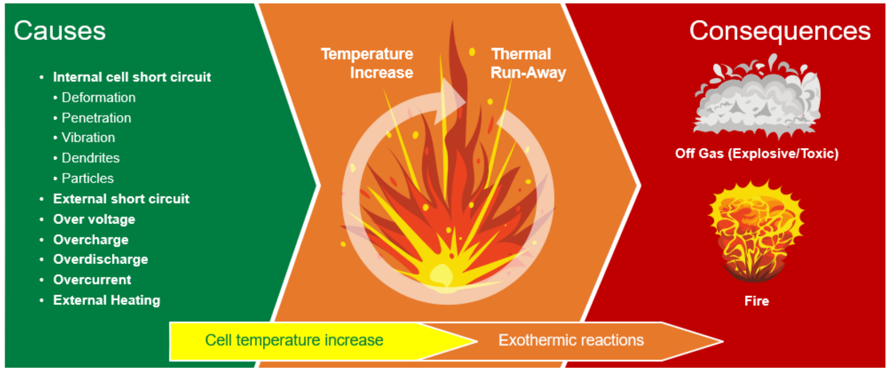
Solid Electrolyte Interphase (SEI)

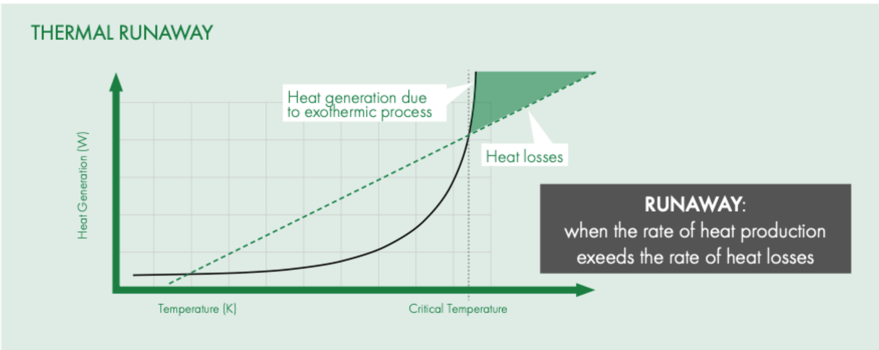


Comparison based on maximal combustion energy from Li-ion cells

Source : RECHARGE

Anatomy of a Li-ion Battery Thermal Runaway





View through Abuse Mechanisms

- Mechanical
- Electrical
- Thermal

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 ($LiPF_6$)

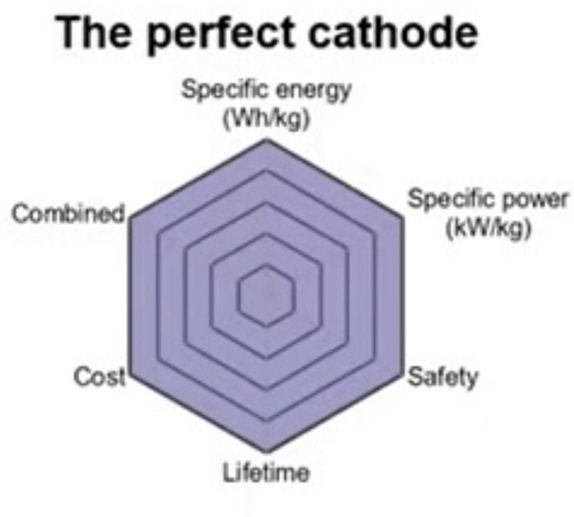
Prevention & Preparedness Strategies

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



Status of Best Practices

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 (2020)
- International Building & Fire Code
- Unique Response Considerations
- Fire Safety Research Institute – Training for Li-ion ESS
- GESIP Guide D’intervention Systèmes de Stockage d’Energie

Leistung	Lithiummetallbatterie (UN 3090)	Lithiumionenbatterie (UN 3480)
gering	≤ 2 g Li je Batterie 	≤ 100 Wh je Batterie 
mittel	> 2 g Li je Batterie und ≤ 12 kg brutto je Batterie 	> 100 Wh je Batterie und ≤ 12 kg brutto je Batterie 
hoch	> 2 g Li je Batterie und > 12 kg brutto je Batterie 	> 100 Wh je Batterie und/oder > 12 kg brutto je Batterie 

Tentative Interim Amendment

NFPA® 855

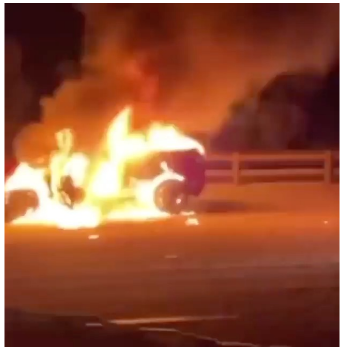
Standard for the Installation of Stationary Energy Storage Systems

2020 Edition

Emergency Response Considerations

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

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

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Emergency Response : Water or Salted Water ?

Emballement d'une batterie au lithium dans une usine automobile

ARIA 46083 – 29/12/2014 – Viry-Chatillon (91)

Naf 29.10 : Construction de véhicules automobiles

Une batterie lithium-ion est à l'origine d'un violent départ de feu dans une usine automobile. Suite au constat par un opérateur de la hausse anormale de température de la batterie au moment de sa mise en place sur son moyen d'essai, la batterie a été transportée dans une zone sécurisée et immergée dans un grand volume d'eau prévu à cet effet. Cette immersion a généré une détonation sourde et un violent départ de feu qui n'a fait aucun blessé. Les 40 employés évacuent les lieux.

L'analyse de l'accident montre que le circuit de refroidissement par eau de la batterie accidentée présentait un défaut d'étanchéité. À la mise en eau, un court-circuit interne a engendré un emballement thermique sur une ou plusieurs cellules. En parallèle, l'eau d'immersion était chargée en sel afin d'accroître la décharge de la batterie noyée. Il semblerait que l'eau salée ait amplifié le phénomène d'emballement thermique et généré un fort dégagement d'hydrogène à l'origine de la détonation et de l'inflammation de vapeurs à la surface de l'eau. Par ailleurs aucun dégagement de fluorure d'hydrogène n'a été constaté.

H_2 explosion

Source : BARPI review of Li-Ion incidents – Jan 2022

Emergency Response: Future Considerations

Encapsulation Using Recycled Glass

Control Using Vermiculite Solutions

Fire Exposure Containment Blankets

https://youtu.be/x_uLL-wCues

Direct Water Injection into Battery Packs

Peer Reviewed Testing Programs are a Critical Factor to Advance those technologies !

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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

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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

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

Avoid battery abuse &
Manage fire consequences

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Some further references

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DEKRA would be delighted to discuss further any battery related question