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Fire safety concerns with lithium-ion batteries

In collaboration with:



CROSS Topic Paper

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Region: CROSS-UK



Figure 1: A row of electric scooters for rent on a city street

Who should read this Paper?

- Owners and occupiers of facilities where lithium-ion battery technology may be prevalent, or planned for the future
- Local authorities, building control bodies, developers, building surveyors, architects, structural engineers, fire engineers, facilities managers and maintenance organisations
- Fire and rescue services, and all other first responders including the police and ambulance service

Overview

This Topic Paper draws attention to the fire and explosion hazards associated with the use of lithium-ion batteries within the built environment, whether in handheld devices, electric vehicles or energy storage systems.

It draws on publicly available guidance and research, as well as confidential reporting experience from the UK about both battery powered devices and Battery Energy Storage Systems (BESS).

Introduction

Lithium-ion batteries, integral to modern technology, pose significant fire hazards due to a phenomenon called thermal runaway. This self-sustaining reaction can lead to large scale fires or explosions and is triggered by factors like overcharging, short circuiting, and overheating.

These fires are challenging to control as the batteries are often inaccessible to suppressants, and they produce flammable and toxic vapours, can reignite due to residual heat, and react violently with common extinguishing agents.

To mitigate these risks, measures such as the use of a battery management system (BMS), installation of gas and fire detection and suppression systems, safe storage and disposal practices, adequate ventilation, regular inspection and maintenance, and proper emergency procedures are vital.

By understanding these risks and implementing appropriate measures, the likelihood and impact of such fires can be reduced, improving both the safety of people and the environment.

Background

Lithium-ion batteries are widely used in various devices and applications, such as smartphones, laptops, micromobility devices, electric vehicles and Battery Energy Storage Systems (BESS). They offer many advantages, such as high energy density, long lifespan, and perceived environmental friendliness.

However, lithium-ion batteries also pose significant fire and explosion hazards in the built environment that all stakeholders need to be aware of and prepared for.

All battery technologies require a certain amount of energy to initiate their chemical reactions. However, lithium-ion batteries, with their high energy density, can generate a significant amount of heat in a small space, leading to thermal instability and potentially explosive failure.

When the heat generated by a lithium-ion battery cell exceeds its ability to dissipate it, a process known as thermal runaway occurs. This can cause a chain reaction, leading to rapid overheating, gas production, and potentially violent destruction. Thermal runaway in one cell can trigger a chain reaction, causing other cells to fail and intensify the fire. The combination of high energy density, reactive chemicals, thermal propagation, and potential hydrogen production makes lithium battery fires extremely challenging to extinguish. Furthermore, extinguishment can lead to further gas production.

While other battery chemistries can also experience thermal runaway, lithium batteries are particularly vulnerable due to their high energy density. Despite ongoing research to improve safety, thermal runaway remains a potential risk, especially in large battery packs.

When assessing the severity of a fire, two key metrics are considered: 1. **peak heat output** and 2. **the rate of rise of heat output**. While both are important, the rate of rise is particularly critical, as a slower increase allows for intervention before peak temperatures are reached.

The heat release rates of car fires, for instance, have risen in recent years due to the increased use of plastic materials in vehicles. Modern vehicles often produce peak heat outputs of 4-5 Megawatts or more, compared to 3 Megawatts or less two decades ago. Large vehicles can generate even higher heat release rates, especially when carrying heavy loads.

The combination of higher heat release rates and the use of plastic fuel tanks has made firefighting more challenging, particularly in car parks where fires can spread rapidly. While lithium-ion battery packs may not significantly increase the total fuel load, their energy release rates are far more rapid. This can lead to explosive fire growth, reaching peak heat output quickly and spreading burning material, posing a serious risk to firefighters and bystanders.

The rapid rate of rise of heat output in lithium-ion battery fires is a major concern. It often means that the fire is at its peak intensity before firefighters can arrive, making it difficult to control and prevent further spread.

Despite concerns about lithium availability and other environmental impacts, lithium-ion batteries are currently the leading choice for applications such as electric vehicles due to their high energy density and performance. However, ongoing research into alternative chemistries may offer future solutions to address these challenges.

Hazards specific to EVs are confined and unconfined vapour cloud explosions. Confined vapour cloud explosions occur (i) when the battery explodes due to the very large volumes of gas produced during thermal runaway, or (ii) the gas vents into the passenger compartment and explodes. Unconfined vapour cloud explosions occur when the gas vents to the outside of the vehicle and explodes.

Lithium-ion battery fires are difficult to **detect**, **control** and **extinguish** for several reasons:

1. They can produce off gassing of flammable and toxic electrolyte vapours that can ignite or explode when exposed to air or oxygen
2. The inaccessibility of the cells to water and any suppressants
3. They can reignite after being extinguished due to the residual heat and energy in the battery cells
4. Due to the inaccessibility of the cells and the fact that thermal propagation does not require fire, while it may be possible to extinguish the external flames, this will not stop thermal propagation and hence the production of explosive gas, and the hazard switches from fire to explosion

Readers are encouraged to review the work of the **Science of Battery Safety (SafeBatt) project from The Faraday Institution**>. The project is a collaboration of seven universities (University College London, University of Oxford, King's College London, Newcastle University, University of Sheffield, University of Warwick and University of Cambridge) as well as industrial partners, investigating the science of battery safety.

The SafeBatt project's goals are to:

1. Understand failure events through state of the art instrumentation, imaging and high speed techniques
2. Understand the safety signatures of degraded cells and investigate how materials properties cause safety concerns or varied safety signatures
3. Demonstrate detection methods and mitigation strategies
4. Determine the toxicity of cell fires and runoff, and the composition and behaviour of the vapour cloud
5. Develop an initial model of thermal runaway, cell to cell propagation and reaction pathways, using data to parametrise the models
6. Give a clear point of access for industry and government bodies seeking knowledge and engagement on battery safety related issues

In 2020, a team at Newcastle University were responsible for highlighting the previously unknown hazard of vapour cloud explosion from lithium-ion batteries in thermal runaway (Figure 2).

As described above, when overheated, crushed, or overcharged, gases can be produced in lithium-ion cells and in certain circumstances their temperature can increase very suddenly. This results in the venting of a vapour cloud that includes hydrogen, carbon monoxide, carbon dioxide and very small drops of the organic solvents used in the cells. First responders had previously mistaken these clouds for steam or smoke, but their composition means that they create the potential for a vapour cloud explosion, which can be more damaging than the initial fire. The SafeBatt project's output can be [accessed on their website](#)>.



Figure 2: potentially explosive vapour cloud emitted by module in thermal runaway

Safety measures

It is vital to adopt appropriate measures to prevent and mitigate lithium-ion battery fires. Some of these measures include:

- Using a battery management system (BMS) that monitors and regulates the voltage, current, and temperature of the battery cells and prevents overcharging or over discharging
- Installing fire detection and suppression systems that can quickly identify and isolate the affected battery cells and apply suitable extinguishing agents
- Implementing safe storage and disposal practices that avoid stacking or crushing the batteries and separate them from other flammable materials. This is particularly relevant for batteries in handheld devices
- Providing adequate ventilation and fire barriers that prevent the accumulation of flammable vapours and limit the spread of fire to other areas
- Conducting regular inspection and maintenance of the batteries and their associated equipment to detect any signs of damage or deterioration
- Following robust emergency procedures that ensure the safety of personnel and property in case of a fire incident

CROSS Safety Reports

CROSS Safety Report 1058, Fire safety risks with lithium-ion batteries> published in March 2022 describes the thermal runaway phenomenon in detail.



Figure 3: Flare-like flame, approximately 3 metres long, resulting from nail penetration of a lithium-ion battery electric vehicle module

This Safety Report also described the increasing use of domestic lithium-ion Battery Energy Storage Systems (DLiBESS) in the UK. These systems are becoming increasingly popular for “behind the meter” storage. They store electricity when supply is cheap and use it when prices are higher, helping to optimise time of use (TOU) billing. Additionally, they are used to store renewable energy from photovoltaic (PV) arrays for domestic or commercial use. The worry is exacerbated by the rise in the second hand market for these batteries, which are routinely sold on the internet for DIY projects by members of the public.

The Safety Report asserts that designers should ensure that a competent fire safety engineer is consulted in projects that involve battery systems; and that fire engineers should stay up to date with the latest research developments in the field of battery systems and inform other members of the design team and clients about the potential risks arising when employing novel, unregulated technologies. The Report also states that authorities having jurisdiction should carefully review proposals that employ novel, unregulated technologies so that any potential risks can be acknowledged and addressed.

Another **CROSS Safety Report 1166, Battery Energy Storage System concerns**> is about a specific BESS which was built and commissioned in 2018. The reporter asserts that the application of Approved Document B (ADB) in England to meet the functional requirements of Building Regulations is not always sufficient, and that BESS should be considered as ‘complex’ situations.

In the reporter’s view, the technology in relation to BESS is changing and evolving rapidly and could potentially outpace current fire safety guidance or legislation. The Report considers three aspects of fire safety design in relation to BESS - emergency water supply, signage, and detection and alarm. The Safety Report suggests that designers should engage with the fire and rescue service early in the design process of BESS, as they are unlikely to be categorised as a ‘common building situation’.

The Report also recommends that the fire and rescue service should attempt to provide guidance on the design specifications for emergency water supplies within the appropriate jurisdiction; and that operators of BESS should consider the necessity of producing an emergency response plan for first responders, review the process of detecting a fire and alarming the emergency services, and ensure that safety signage complies with **The Electricity, Safety, Quality and Continuity Regulations 2002**>.

Available guidance

In 2023, a document called **Need to Know Guide RE2: Lithium-ion Battery Use and Storage**>¹ was published by the Fire Protection Association (FPA) and endorsed by the British Automatic Fire Sprinkler Association (BAFSA). This document provides detailed information on the hazards associated with lithium-ion batteries, including the risk of fire or explosion due to thermal runaway.

The guide outlines various risk control recommendations for the safe use and storage of lithium-ion batteries, emphasising the importance of fire safety considerations, manual control of small fires, storage guidelines, and procedures for dealing with damaged or defective cells. Key points from the document include:

1. The hazards associated with lithium-ion batteries, such as thermal runaway leading to fire or explosion
2. Different styles of lithium-ion rechargeable batteries and their structural properties affecting robustness
3. The risks of gases emitted during thermal runaway, including flammable and toxic gases
4. Highest risk of fire during charging and when batteries are damaged
5. Recommendations for general use, including purchasing from reputable sources, proper storage, and handling
6. Guidelines for manual control of small fires, including the use of Aqueous Vermiculite Dispersion (AVD) fire extinguishers
7. Storage recommendations based on sprinkler protection and fire control strategies
8. Procedures for dealing with damaged or defective cells, including compliance with regulations for safe shipping
9. Importance of fire risk assessments, staff training, and emergency procedures related to lithium-ion batteries

These points highlight the critical importance of understanding and managing the risks associated with lithium-ion batteries to ensure safety in various settings where these batteries are used or stored.

Also in 2023, The Office for Zero Emission Vehicles (OZEV) published **interim guidance**^{>2} to support the parking and charging of electric vehicles (EVs) in covered car parks. Authored by Arup, this guidance aims to provide information on fire safety considerations when installing EV charge points in covered car parks. Key points include:

1. Risk assessment: before installing EV charge points in a covered car park, a thorough fire risk assessment should be conducted to identify potential hazards and risks
2. Fire safety measures: adequate fire safety measures should be in place, including fire detection and suppression systems, emergency exits, and clear signage
3. Separation: EV charge points should be located a safe distance from other flammable materials and structures
4. Ventilation: adequate ventilation should be provided to ensure proper airflow and prevent the buildup of smoke and fumes
5. Charging infrastructure: the charging infrastructure should be installed and maintained in accordance with relevant standards and regulations
6. Training: staff should be trained on fire safety procedures and the proper use of fire extinguishers



Figure 4: Image of a multi-jet sprinkler system test undertaken by the City of London corporation. © City of London Corporation Fire Safety Department (with permission)

The OZEV guidance provides useful information for building owners, managers, and EV charging operators who are considering installing EV charge points in covered car parks.

In 2020, the Fire Industry Association produced a document entitled **Guidance on lithium-ion battery fires**^{>3} prepared by their lithium-ion battery special interest group (SIG). The guidance covers various aspects related to lithium-ion batteries, including terms and definitions, battery types, fire issues, fire solutions, post fire management, and references.

Last updated in 2023, the **NHS Estates Technical Bulletin (NETB/2023/2)**^{>4} highlights the risks associated with electrical batteries in the healthcare estate. These risks primarily stem from the potential for battery fires, which can be severe and difficult to extinguish.

Recommendations from the bulletin include:

1. Risk assessment: conduct regular risk assessments to identify potential hazards associated with electrical batteries in the NHS estate
2. Safe handling and storage: implement procedures for the safe handling, charging, and storage of electrical batteries



Figure 5: A Lithium-Ion Battery

3. Staff training: provide staff with training on the safe use and management of electrical batteries
4. Regular inspections: conduct regular inspections of electrical equipment and batteries to identify and address any potential safety issues
5. Emergency preparedness: develop and implement emergency plans for dealing with battery fires and other incidents involving electrical equipment

In January 2023, the Office for Product Safety & Standards (OPSS) published **A Study on the Safety of Second-life Batteries in Battery Energy Storage Systems**>. This comprehensive document provides an overview of the market for second life batteries. It reviews the hazards for lithium-ion batteries and the risks specific to second-life batteries, with a description of gateway testing and other mitigating measures.

More recently, in December 2024 the Office for Product Safety & Standards in conjunction with the Department for Business and Trade **published statutory guidelines**> to assist businesses in producing safe lithium-ion batteries for use in e-bikes. These statutory guidelines set out the safety mechanisms that lithium-ion batteries for e-bikes must contain to address the risk of thermal runaway.

Summary

Lithium-ion batteries, while essential to modern technology, present significant fire hazards due to thermal runaway. This self-sustaining reaction, which can lead to large scale fires or explosions, is challenging to control due to the production of flammable and toxic vapours, potential reignition, and violent reactions with common extinguishing agents.

However, these risks can be managed by implementing safety measures such as the use of a battery management system (BMS), installation of fire detection and suppression systems, safe storage and disposal practices, adequate ventilation, regular inspection and maintenance, and proper emergency procedures.

Through a comprehensive understanding of these hazards and the implementation of appropriate safety measures, it is possible to significantly reduce the likelihood and impact of such fires.

It is critically important that those with responsibilities for designing, constructing and managing aspects of the built environment, keep their knowledge of this evolving technology up to date.

References

1. Fire Protection Association, **Lithium-ion battery use and storage, RE2>**, 2023
2. Office for Zero Emission Vehicles (OZEV), **T0194- Covered car parks, fire safety guidance for electric vehicles>**, Ove Arup & Partners Limited, 2023
3. Fire Industry Association, **Guidance on Li-ion battery fires>**, 2020
4. NHS Estates, **Technical Bulletin (NETB/2023/2): Risks of electrical batteries for the NHS Estate, PRN00713, 2023>**

Related CROSS content

- **CROSS Safety Report 1058, Fire safety risks with lithium-ion batteries>**
- **CROSS Safety Report 1166, Battery Energy Storage System concerns>**
- **CROSS Safety Report 1007, Fire protection to car park steel frame>**

Other reading

- Paul A. Christensen, Paul A. Anderson, Gavin D.J. Harper, Simon M. Lambert, Wojciech Mrozik, Mohammad Ali Rajaeifar, Malcolm S. Wise, Oliver Heidrich, **Risk management over the life cycle of lithium-ion batteries in electric vehicles**, Renewable and Sustainable Energy Reviews, **Volume 148, 2021,111240>**, ISSN 1364-0321
- Grunde Jomaas & Sameed Khan, **Burning Misconceptions: The truth about EV fires, Burning Matters blog series, [online]>**.
- Office for Product Safety & Standards, **A Study on the Safety of Second-life Batteries in (domestic) Battery Energy Storage Systems>** Final Report, 2023

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