Damage and contamination caused by Lithium Ion vehicle Fires

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Abstract

The sale of electric vehicles has seen the exponential rise in fires, increasing deaths and unusually expensive damage. Westminster Council in London has banned storage of LEV in buildings*, but the true cost of damage and health consequence has yet to be assessed. The risk is now extended to include LiBESS, Lithium ion Battery Electrical Storage Systems used to store solar energy. The paper reviews contingency planning, insurance liabilities, Health and Safety of contractors and occupiers of the building and of course stakeholders such as employers, employees, residents, leaseholders and property owners.

The following issues are considered within the parameters of this document.

A scooter in the open or car in underground car park the event cannot be controlled.

1. Causation

1.1. The fires can be caused by human actions of abuse, overcharging, heat, crush, puncture and penetration .The concern is fires can start hours or days after use or damage. The fires are known to cause structural damage, contamination, and result in toxic residue. The causation of fires is “Thermal runaway” where heat is produced exponentially. The graphite and Metal oxide poles within the battery overheat to breech the safety barrier of the Solid Electrolyte Interface or SEI. This allows the heat to penetrate into the organic solvent component within the battery. Once the chain of events has started it cannot be stopped.

Submerging an “*at risk*” EV saw explosive fire days later.

2. Risk Management

The normal route of risk management is identifying the risk and hazard and instal controls and response and perhaps issue PPE. Fire alarms, sprinklers, security and training would normally provide warning but with LI fires and explosions they are uncontrolled and give little or no warning. The events cannot be controlled, and the effects of heat and explosion and uncontrolled and changeable air pathways mean whole buildings and occupants can be affected. A new approach to risk management and contingency planning is required. With civil unrest possibly increasing these vehicles could become the weapon of choice.

3. Contingency Planning

The fires are generated by thermal runaway and can be unstoppable and unlike most other fires there are currently no effective ways of extinguishing them which have been validated*.

***Tests have shown normally accepted results of the following fire suppressant systems fail :**

- Liquid N2 single module*
- F500*
- Coldcut cobra*
- Water*

3.1. Electric vehicles have been emersed in water filled skips and explode days or weeks after a warning event*.

3.2. With no effective means of controlling a fire or secondary damage the location of the Lithium-Ion source is a major concern*.

3.3. With the massive volumes of smoke and vapour the source of ignition can be impossible to identify or find in closed environments*.

3.4. Professional PPE is usually unsuitable and additional protection is required for Cobalt vapours.

3.5. The risk is possibly uncontrollable once inside a building and various options are used.

3.6. Placement in basements is considered such as an underground car park but the heat and the lighter than air high volume gas vapour cloud, will see stack effect rise through the building. Wherever the location of LEVs, or LiBESS, heat and air pathways will see contamination and damage spread.

3.7. Purpose made storage units such as Metrostore can limit damage but there are of course limitations.

3.8. Fire stops are usually relied upon between floors, but we have seen Grenfell and other properties where perhaps systems are more a legal requirement than operational.

3.9. Smoke vents can provide risk reduction, but as explosive vapour clouds move vertically through tall buildings could they become additional sources of danger and secondary damage?

3.10. Contingency planners may be currently faced with unknown risks and hazards from possibly foreseeable events. These will require expert input to provide plans which revolve around buildings, locations of risk and hazard and available resources.

3.11. Contingency planning for LI events in buildings should follow typical CBRN event planning which encompasses defence of the building and protection of occupants. Building Forensics with experience in this field provide site specific guidance utilising installed engineering controls and or temporary auxiliary equipment. The effectiveness of risk reduction, damage mitigation and disruption, will often depend on speed of responsive action.

Building Forensics provide detailed assessments much in line with terrorist CBRN response planning. Note Asterix denotes data taken form Professor Paul Christensen. Fire safety conference 16/05/2023.

4. Thermal runaway consequences*

The following list of events follow thermal runaway in LEVS, EVs and LiBESS:

4.1. Loud hissing or screaming as hot and expanding gases escape through vents.
4.2. Heavy black smoke comprising of heavy metals and nano particles.
4.3. White smoke and vapour cloud possibly explosive within 12 minutes
4.4. Very large quantities of smoke
4.5. Highly directional flames burning between 1000c and 2000c
4.6. Rocket type flames shooting out igniting anything combustible nearby.
4.7. Spalling of concrete as water within the concrete boils and bursts the surface substrate*.
4.8. Explosion

4.9. Wide spread of toxic contamination on surfaces and in the air.

4.10. Cathode material ejected as black smoke of toxic heavy metal nanoparticles.

4.11. Stranded electrical energy (potential to electrocute)

5. The components of the fire

Fires involving lithium-ion batteries can release several dangerous substances. Here are the key hazardous residues and byproducts from such fires:

5.1. **Toxic Gases**: During combustion, lithium-ion batteries can emit a variety of toxic gases. These include carbon monoxide (CO), hydrogen fluoride (HF), and phosphorus oxides. Hydrogen fluoride, in particular, is highly corrosive and toxic, and can pose significant health risks when inhaled or when it comes into contact with skin.

5.2. **Metal Particles and Compounds**: Lithium-ion battery fires can also release particles of metals such as lithium, aluminium, and cobalt, along with other compounds found in the battery. These metals can be toxic and pose environmental and health risks, especially when they accumulate in living organisms.

5.3. **Volatile Organic Compounds (VOCs)**: VOCs such as benzene and toluene may be released during a fire. These compounds are harmful to human health and can contribute to air pollution.

5.4. **Particulate Matter**: The combustion process can produce fine particulate matter that can be inhaled deeply into the lungs, potentially causing respiratory issues. The highest risk are the smaller particulates or NANO particles, and these can remain airborne for days and weeks buoyed by Brownian motion and secondary aerosolisation.

The combination of these substances can make Lithium-ion battery fires particularly hazardous, requiring careful handling and appropriate safety measures during and after an incident. This includes suitable PPE which is not standard issue even for normal hazmat situations.

6. The chemical composition of fire residue and risk factors

6.1. The residue from lithium-ion battery fires can be highly corrosive. One of the primary corrosive substances produced in such fires is hydrogen fluoride (HF). When Lithium-ion batteries burn, the fluoride-containing compounds in the battery's electrolyte can decompose and release hydrogen fluoride. This gas is not only toxic but also highly corrosive to metals, glass, and human tissue. It can cause severe damage to the respiratory system if inhaled and can burn skin on contact. More importantly HF can penetrate skin and tissue and burn skeletal bones.

6.2. Additionally, other corrosive substances, are released even prior to ignition include but not limited to:
   - 6.2.1. Hydrogen (ca 30-50%)
   - 6.2.2. Carbon Monoxide
   - 6.2.3. Carbon Dioxide
   - 6.2.4. Hydrogen fluoride
   - 6.2.5. Hydrogen chloride
   - 6.2.6. Hydrogen cyanide
   - 6.2.7. Small droplets of the organic solvents
   - 6.2.8. Ethane,
   - 6.2.9. Methane and other hydrocarbons
   - 6.2.10. Sulphur and nitrogen oxides

7. Human Health

Human exposure to smoke, vapours or particulates and residue is a health risk and hazard with specific concerns regarding:

7.1. Cobalt and vapours
7.2. Hydrofluoric Acid
7.3. Heavy metals
7.4. Nano Particles
7.5. Unknown combustion materials

These contaminates together with other carbon soot particulates and nano particles can result in both respiratory and dermal exposure with ranging symptoms and acute or chronic response depending on individual immune response, severity and period of exposure.

8. Electrical conductivity and corrosion issues

8.1. Hydrogen fluoride (HF) itself is a gas at room temperature and does not form soot particles. However, the soot and other residues produced in a lithium-ion battery fire can contain various metallic compounds and elements from the battery's materials, such as lithium, cobalt, and nickel. These elements and their compounds can be electrically conductive as well as specific health hazards.

8.2. If soot particles from a fire incorporate these metallic elements, they can exhibit some level of electrical conductivity. This can be particularly problematic in electronic environments where such conductive soot could potentially cause short circuits or other electrical failures if it deposits on electronic components. It's important to handle cleanup carefully to prevent such conductive residues from causing further damage in sensitive environments.

8.3. Apart from the acids and toxins chlorides can be expected to form and these conductive particles will cause corrosion and failure in metalized finishes, electronic equipment and even penetrate concrete to affect re bars, possibly resulting in concrete cancer or spalling.

8.4. These corrosive elements can penetrate substrates and act over long period resulting in long tail damage and insurance claims.

Exposure Routes

While smoke and vapours and risk of explosion should see all, including responders withdraw from the fire scene, the heat will cause stack effect and carry contamination upwards and though air pathways. While the initial heavy smoke and soot's may see some contamination move downwards as it is heavier than air. The stack effect and movement of warm or hot contaminated air will also see hazardous contamination from the ignition moving upwards vertically and horizontally to areas possibly far away from the source.

9. Primary and Secondary Damage

The initial smoke and subsequent fire, explosion may show recognisable damage, and this is primary damage.
The subsequent damage of corrosion and discolouration and spread of odour and contamination is recognised as secondary and usually preventable damage. Prevention of secondary damage requires contingency planning and prompt action.

10. Insurance and Claim management.

It may be in all stakeholder's best interest to identify the scope of damage as soon as practically possible. This would or should see auxiliary controls put in place to prevent secondary damage and more importantly mitigate the primary damage by engineering controls , critical barriers, neutralising and or dilution protocols. This management control may be extremely important to mitigate claim costs for whoever may or may not pay.

11. Health and Safety CoSHH

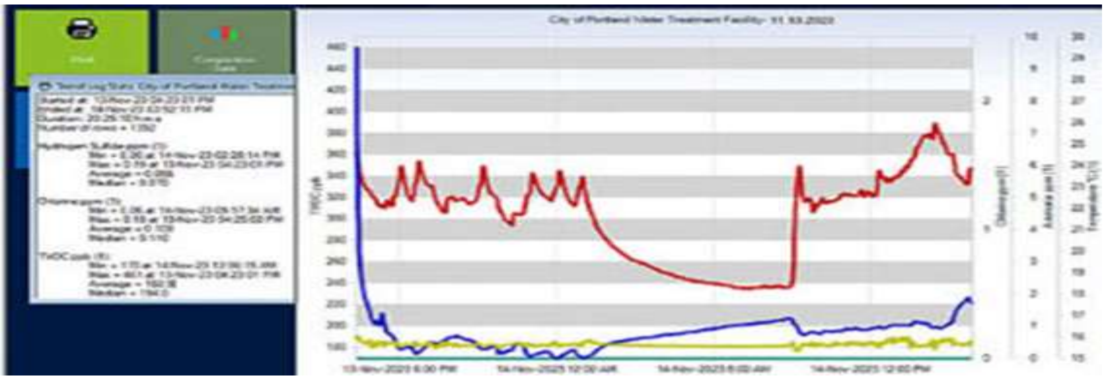
The health and safety professional will usually rely on EH40 or occupational exposure standards of individual chemicals. The EH40 identifies these chemicals and provided Occupational Exposure Levels (OELs) and various information on Time Weighted Averages, (TWA). In the case of a Lithium Ion fire there are so many differing chemicals that are mixed and EH40 cannot identify the risk or hazard of synergistic values. The Health and Safety executive will however state "Must be reduced to lowest practical levels regardless of cost.

These laws and issues revolve around workplace exposure and while offices may be considered a workplace, homes are domestic dwellings and therefore not applicable excepting to contractors.
The absence of exposure standards for chemical compounds and mixes should simply be addressed with removal a to lowest practical level.

12. Measurement

The contamination and preventable secondary damage caused by Lithium Ion fires requires very specialist equipment and an understanding of chemical analysis and air pathways. Areas not assessed may see future failure of substrates, electrical and computer systems. While legislation such as CoSHH and guidance by Health and Safety Executive may not currently provide adequate guidance the basic parameter of risk assessment does provide the need for evidence of data driven assessments.
The following are simplistic real time assessments for immediate risk assessments to initiate controls but we also provide detailed GCMS reports too.

Data Driven Assessments



Live monitoring VOCs

A real time assessment of airborne fine particulate spread of smoke to risk assess spread of toxic chemicals.

13. Mitigation

While the fire and explosion residue may require detailed cleaning and source removal, the initial response should be mitigation and risk reduction by neutralising and concentration reduction. This will halt or reduce secondary damage and may include a mix of chemical and air management systems. Building Forensics have these in stock for response issues.

Random Chemical distribution systems

Typical tools for isolation

14. PPE

Due to risk issues of varying fire and explosion residue PPE must be suitable.

The selection of PPE will of course depend on risk and hazard assessments with suitable training. While Level A may be initially used by emergency services, Level B as shown with powered positive pressure suits will normally be a minimum requirement to protect both skin and respiratory system. Building Forensics carry stock of these or own use.

15. Conclusion

Lithium-Ion batteries are currently a high risk if or when malfunctioning and contingency planning is essential to manage the risk. These risks include building and occupants with potential financial implications for insurers, Leaseholders various stakeholders and employers and residents too. Building Forensics with experience in CBRn defence, disaster recovery and business continuity can assist in developing contingency and response planning.

End

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