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Lithium-ion battery FIRE RISK

Lithium-ion batteries have penetrated all levels of our society, and the speed of this adoption has exceeded our knowledge of the associated risks and hazards.

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A firefighter uses a thermal imaging camera to measure the temperature of the battery of a burnt electric car.

Lithium-ion batteries (LiBs) were first commercialised in 1991 in camcorders, followed rapidly by their use in mobile phones and laptops. They are best known today as the battery used in electric vehicles (EVs) and light electric vehicles (LEVs). Although LiBs are here to stay, with worldwide production increasing at a rapid pace to meet present and future demand, they must be kept and used correctly, and be manufactured to a high standard to remain safe.

E-bike and e-scooter risks

The type of electric vehicles (EVs) killing and injuring people are mainly LEVs (e-bikes and e-scooters) due to thermal runaway during home charging. When a LiB is overcharged, chemical reactions occur that produce a mixture of toxic and explosive gases, and heat. Heat speeds up these chemical reactions, generating more gas and heat. Thermal runaway is when these reactions become self-sustaining. LEV fires and explosions, often due to poor quality imports and unsafe practices in their use, are on the increase. The number of injuries in London, the worst affected area, is on course to be more than four times higher this year than in 2020[1]. In fact, the London Fire Brigade is dealing with a residential fire every two days caused by an e-bike or e-scooter[2].

The EVs killing and injuring people are mainly LEVs – e-bikes and e-scooters - due to thermal runaway during charging in homes.

Even small LiBs can generate very large quantities of vapour cloud (see panel), causing jet-like flames and/or an explosion[3]. LEV fires develop very quickly, often trapping people in their burning homes: and some fires have killed entire families[4]. Statistics suggest that if an LEV goes into thermal runaway in your home, you have a 7.8% chance of being killed, and a 64% chance of being hospitalised[5].

Simple guidelines can keep LEV users safe:

- Never buy an LEV (or any LiB-containing device) that has to be turned off when fully charged. All LiBs should have battery management systems that stop overcharging automatically.
- Do not charge LEVs indoors.

If you absolutely have no choice but to charge indoors:

- Do not charge when you are asleep or away from the building.
- Do not charge anywhere where there is material that can burn.
- Do not charge in an escape route.
- If there is popping, hissing or smoke, do not attempt to deal with it. Leave immediately, alert other occupants, and phone the fire brigade.

Electric vehicle risk

There are high-profile incidents involving LiBs in EVs, specifically passenger car fires and explosions[6]. Statistics from EV Firesafe, an organisation funded by the Australian Defence Ministry, reveals that as of April 2023, there had been only 375 verified incidents and 62 to be confirmed out of an estimated global total of 17 million[4]. This equates to an 0.002% risk of an EV catching fire, 20 times lower than an internal combustion engine vehicle. There have been four deaths, however these occurred following road traffic collisions or other accidents.

As of April 2022 there had been 18 verified e-bus fires[7], the highest profile of which were in London[8] and Paris[9]. These resulted in the entire e-bus fleets being taken out of service. There have been at least three fires in German e-bus depots that destroyed vehicles, causing significant damage[10].

There have also been explosions involving EVs, but statistics are very limited. These explosions fall into two types: explosion of the actual battery, and also following venting of the vapour cloud from the battery and it exploding externally to the vehicle. EV Firesafe record about five per cent of all EV incidents involved in a vapour cloud explosion[4].

There are no globally accepted methods of dealing with EV fires, and it is generally acknowledged they are extremely challenging, if not impossible, to extinguish.

Extinguishing a fire

The cells in an EV battery pack are typically enclosed in a steel case, protected underneath by a metal plate and covered by the seats, chassis and windows of the vehicle. Unless the case is severely compromised (for example, by an accident) any cells in thermal runaway are completely inaccessible to water. Eventually, the vapour cloud vents from the pack, but does so at high pressure and typically through a narrow orifice, producing rocket-like flames if ignited immediately and preventing access to water.

There are no globally accepted methods of dealing with EV fires, and it is generally acknowledged they are challenging to extinguish, and demand very large quantities of water. However, encouraging data about new equipment and procedures to control EV fires is emerging.

The choice of extinguisher for any LiB device from e-scooters and up is critical. In general, any suppression system that extinguishes flames but does not stop thermal runaway and thermal propagation (heat from one cell causing an adjacent cell to go into thermal runaway) flips the hazard from fire to explosion. This was exemplified with terrible effect by the explosion of a battery energy system in Arizona in 2019[11]. At present no lithium-ion extinguisher is endorsed by independent government bodies and water remains the best of bad options.

EVs have reignited hours, days or even weeks after the initial incident[12]. This raises concerns for the vehicle recovery industry, including questions of liability following handover of an 'extinguished' EV.

Concerns over EV fires have highlighted the need for clear guidelines, codes and standards for EVs in car parks and enclosed spaces. About 17% of EV fires and explosions occur during or within one hour after charging[4], focusing attention more on EV parking and, particularly, the provision of EV charging points in the built environment. This prompted the UK Government to commission Arup to produce *Interim guidance to support parking electric* *vehicles and installing electric vehicle chargepoints in covered car parks* (still in preparation).

All current passenger vehicles, irrespective of fuel type, pose an increased risk in car parks as they contain far greater amounts of plastic fire load and are wider and longer than when the current regulations governing car park design were introduced in the 1990s[13]. However, the hazard of vapour cloud explosion is specific to EVs and currently often overlooked[14].

Thermal stability and ageing

There is very limited research on the effect of ageing and use on EV batteries, not least because of the costs involved. It is generally believed the capacity of an EV battery decreases in a linear way (irreversible capacity loss) with time (calendar ageing) and use. When the remaining maximum capacity reaches 80%, the pack is no longer suitable for use in an EV. However, it can still store a significant amount of energy and has value. At this point, the pack should be removed, defective modules replaced and the pack itself or its modules employed in a second-life application, such as in a LiB energy storage system for supporting the national grid[15].

When the remaining maximum capacity reaches 50-60%, the ageing process accelerates ('the knee'), or new ageing reactions are initiated and the battery is deemed unsafe and should be sent for materials recovery.

7.8%

If an LEV goes into thermal runaway in your home, you have a 7.8% chance of being killed and a 64% chance of being hospitalised.

0.002%

There is an 0.002% risk of an EV catching fire – 20 times lower than for an internal combustion engine vehicle.

Repeated fast charging of EVs is also likely to destabilise the batteries as it can cause lithium metal plating. The plated lithium reacts exothermically with the organic solvent, producing gases including hydrogen and hydrofluoric acid, the latter then attacks the cathode materials. This reduces the onset temperature for thermal runaway and, during thermal runaway, causes stronger exothermic reactions and more violent destruction of the cells. As lithium-ions are repeatedly removed from the electrolyte through normal use, even using the EV

Why do LiBs catch fire and explode?

Thermal runaway leads to fire and explosion. If a lithium-ion cell is abused, for example by heating, overcharging, overdischarging, crushing or penetration, or if contaminants or defects have been introduced during manufacturing, the protective layer (the solid electrolyte interphase (SEI)) can become damaged and the exothermic, heat-producing chemical processes commence.

Once the exothermic processes become self-sustaining and the heat produced cannot be dissipated, the temperature of the cell increases. At some point one of the many chemical reactions triggers a vertical increase in temperature and the cell is in thermal runaway. The blast caps on cylindrical and prismatic cells vent and pouch cells burst. The vented gases comprise primarily hydrogen (up to 50%), carbon monoxide, carbon dioxide and small chain gases such as methane, ethane and ethene. They also contain hydrofluoric and hydrochloric acid gases and hydrogen cyanide.

The gases take small droplets of organic solvent with them that give the resultant vapour cloud the appearance of smoke or steam. If the vapour cloud ignites immediately, it produces long, flare-like flames due to the large volume of gas produced, which is released under high pressure. If ignition is delayed, a vapour cloud explosion can occur[1].

within the manufacturer's specification may result in the concentration of lithium-ions dropping below some minimum and causing plating[16]. This has been associated with the 'knee'.

But it may not necessarily be the failure of the LiB that is responsible for initiating thermal runaway. Other aged parts can compromise safety. For example, when a second-hand Nissan Leaf pack went into thermal runaway after having been transported through a rainstorm, the cause was identified as worn seals around the battery case allowing water ingress.

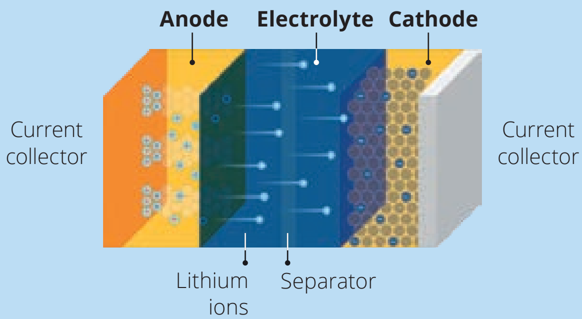
As garages other than the original manufacturers' service depots start to maintain older EVs, they may have insufficient detailed knowledge of the risks and hazards associated with LiBs to maintain the vehicles safely. Currently, this would not be helped by the refusal of manufacturers to allow access to the information stored in the battery management systems (BMS) of the battery packs.

Finally, new pack topographies (the way lithium-ion cells are assembled to make a battery pack) may offer new risks and hazards. While the energy density of lithium-ion cells has reached a maximum, and the space available for the pack has also reached a maximum, there are innovations in chemistry and pack topology that are either already or nearly in production, with major implications for increased energy density at cell and pack level.

Lithium-ion battery energy storage systems (LiBESS)

LiBESS are ideal for storing energy from intermittent generators such as wind turbines and solar arrays. They have extremely rapid response times and provide a range of support services to national grids. This is from peak shaving (balancing the energy available through the national grid and providing extra electricity during high demand) to frequency regulation and arbitrage (trading on the energy market). However, there have been up to 60 fires and explosions globally involving LiBESS since 2012, more than 50 since 2018, including an explosion in Arizona that severely injured four firefighters[11], and an explosion in Beijing that killed two firefighters and required 235 firefighters and 47 fire vehicles to extinguish[17].

The anatomy of a battery



As with EVs, the cells in thermal runaway are generally inaccessible, so LiBESS incidents are extremely challenging. Increasingly, the perception is that thermal runaway in LiBESS cannot be stopped and LiBESS containers should be left to burn, with firefighters taking a defensive strategy, cooling surrounding containers to prevent fire spread. This strategy is even more relevant for cabinet-based LiBESS. Cabinets, unlike walk-in containers with battery modules on both sides of an aisle, have virtually no free space. Modules are slotted in and densely-packed, giving far higher energy densities than containers.

Even if firefighters do not attempt to fight the fire in a cabinet or container, the volume of water required is still extremely large. The explosion and fire of a small LiBESS in Belgium in 2017 required 1.4 million litres of water to contain.

The Country Fire Authority in Victoria, Australia is one organisation leading the way in LiBESS safety, and recommends tanks containing at least 288,000 litres of water on a LiBESS site, or sufficient water to provide a flow of 20 litres per second for four hours (whichever is the greater) to contain any fire in the LiBESS.

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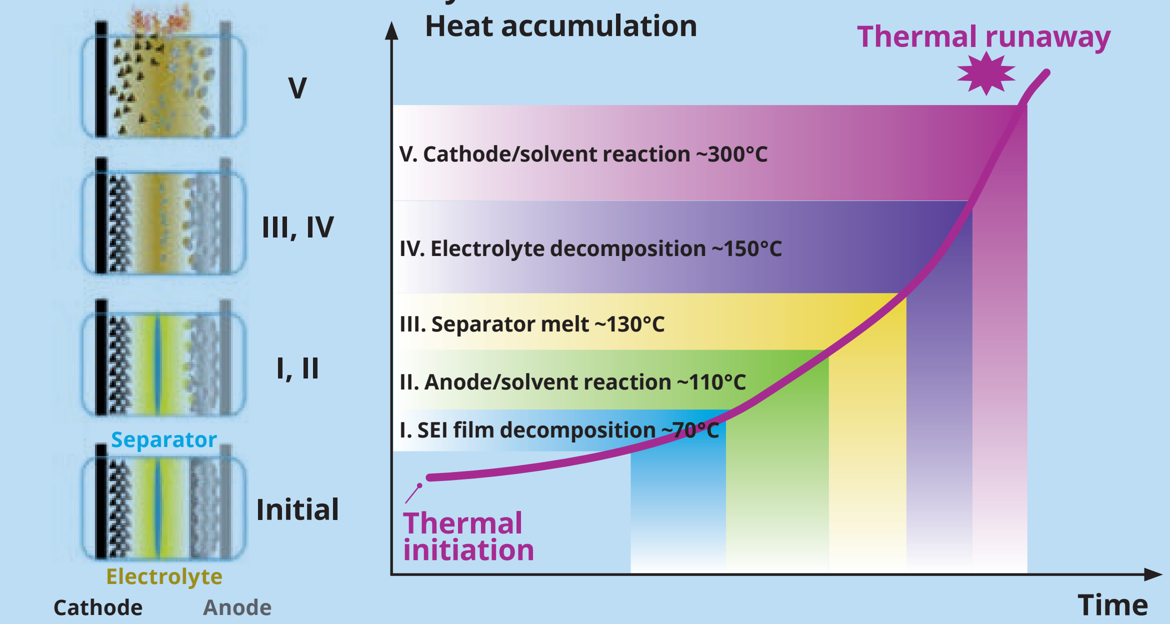
Battery storage systems are increasing in use, with a variety of applications. LiBESS are being installed in basements and on

The route to thermal runaway



roofs of buildings, as well as in multi-storey offices. Globally, three lithium-ion uninterruptable power supplies have caused major fires in office blocks in recent years[18].

Domestic LiBESS are used to store energy from solar panels and to exploit cheap, off-peak electricity, as well as grouping domestic systems to provide support to national grids via 'virtual power plants'[19]. There have been several fires involving DLiBESS and many recalls of commercial systems[20]. A very worrying aspect of DLiBESS is the trade in second-hand EV battery packs, sometimes damaged, with people cannibalising them for the modules to make their own systems. There have been fires involving these in Australia, Poland and the UK.

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