AUSTRALIAN RAIL INDUSTRY
STANDARDS ORGANISATION

eRidables

TECHNICAL Paper

Section 1 Executive Summary

Lithium-ion batteries pose fire hazards unlike traditional passenger belongings. They can ignite suddenly, release intense heat within seconds, emit toxic flammable gases, and resist extinguishing. Train incidents worldwide show these events can threaten passenger safety, assets, and service continuity within minutes. Fires from e-bikes or e-scooters are especially severe, producing faster heat release, higher toxic emissions, and greater fire spread risk than either personal belongings or conventional arson, leading to significantly more dangerous consequences.

The growing number and severity of incidents in Australia have served as a catalyst to enable proactive analysis of the emerging risk.

Incidents from lithium-ion battery powered e-ridables (e-scooters, e-bikes) carried on passenger trains requires the examination of the hazards and practical strategies for transport operators, regulators, and emergency responders to best address the emerging hazard.

Beyond e-rideables, it is appreciated that lithium batteries are embedded in everyday passenger devices such as phones, laptops, and power banks. Their ubiquity, combined with the confined environment of train carriages, makes the risk persistent and complex.

This technical paper from Fire Life Safety (FLS) working group, a subgroup of the ARISO Safety and Operations Standing Committee, outlines why these fires challenge the current arrangements and hazard controls for passenger trains.

Key hazards examined in the paper are:

- Rapid fire growth rate: Internal faults can quickly escalate to thermal runaway. Even without an explosion, vented battery gases are highly flammable and ignite easily.
- Much larger fires: e-rideables can produce far greater fire size and peak heat release rates than current Fire & Life Safety provisions anticipate.
- Toxic gas release: Lithium-ion fires emit hazardous gases, notably HF, which is far more toxic per dose than CO, CO_2, or HCN from conventional fires.
- Deflagration and Projectiles: Thermal runaway can cause cell rupture with jet flames and hot components becoming dangerous projectiles.
- Suppression difficulty: Early fire growth leaves little response time, and standard firefighting equipment is often ineffective. Cascading between cells can be delayed, meaning fires may appear extinguished but reignite hours later.

Current arrangements do not address the increased fire size of eRidable battery fires and the consequence change in risk profile that may result in severe injuries or fatalities, major service disruption, asset loss, reputational damage, and regulatory scrutiny.

Section 2 Technical Paper e-Ridable Fire & Life Safety on Passenger Trains

Purpose:

This technical paper is based upon published peer-reviewed papers, identifies and raises awareness of the novel FLS challenges posed by e-ridable batteries when on passenger trains. Other sources of lithium-ion batteries are not considered in the paper because they are considered much smaller hazards compared to the large batteries on e-ridables, as detailed in the appendix.

Audience:

This paper is aimed at non-technical audiences from public transport operators, safety and risk managers, standards bodies, emergency services, rollingstock manufacturers, and regulatory authorities.

Background:

On Saturday, 15 March 2025, an e-scooter in the last carriage of a suburban passenger train caught on fire. This was the first confirmed Australian train fire caused by battery thermal runaway from an e-rideable device. The train was in service with passengers onboard. While no injuries were recorded, publicly available footage shows that the fire was substantial.

The widespread use of e-rideables such as e-scooters and e-bikes introduces severe new fire risks that differ fundamentally from those posed by traditional belongings or train materials. Existing FLS standards for public transport did not anticipate these hazards, leaving critical gaps in protection for passengers, crew, and assets.

Even with proposed bans or restrictions on e-rideables, the risk remains significant. Enforcement is difficult, and passengers often carry detached batteries onboard while leaving the e-ridable at stations. As a result, battery hazards persist independently of any ban of e-ridables albeit at a reduced exposure.

The Melbourne incident highlights the urgent need for a comprehensive review of safety strategies and emergency response protocols. Reliance on prohibitions alone will not adequately protect against the fire risks posed by batteries in the passenger rail environment.

Section 3 E-Ridable fire incidents on-board trains and stations

Large e-ridable fires on trains and stations have not been high frequency events. But a limited number of incidents with potential for high consequences have been identified to have occurred including:

- 2021 e-scooter smoke event, Parsons Green station UK, e-scooter removed from train to platform after releasing smoke but no fire onboard;
- 2022 e-scooter fire on Barcelona Metro train, Spain;
- 2023 e-bike fire on Toronto Metro train, Canada;
- 2024 e-bike fire, Sutton station UK, Fire on platform, not onboard train; and
- 2025 e-bike fire, Melbourne Australia.

3.1.1 Battery Fire Causes

The primary event leading to a battery fire is thermal runaway. Thermal runaway is defined as a battery fault/exposure (typically causing an internal short circuit within a cell) leading to uncontrolled exothermic heating of cell.

Causes of thermal runaway for batteries include:

- Overcharging (or Battery Management System faults resulting in overcharging) – This is the most prevalent cause of thermal runaway for e-ridables.
- Mechanical damage/puncture.
- External short circuit or high loads.
- Exposure to external fire/heat.
- User modifications to battery systems.

Experimental[i] findings demonstrate that the risk and severity of thermal runaway events in lithium-ion batteries are greater during charging, particularly at high charge rates and states of charge (SOC). Overcharging and faulty battery management systems elevate internal temperatures and incidence of lithium plating, accelerating material degradation and promoting internal short circuits. Thermal runaway onset and mechanical strain escalate more rapidly at higher SOCs, making fully or near-fully charged batteries intrinsically more vulnerable to severe failures compared to mostly discharged batteries.

3.1.2 e-Ridable Fire Characteristics

e-Ridable fires are much larger than the design requirements of modern trains and estimated to be similar to fire sizes measured in recent international research projects on e-ridables.

In this regard, the following are two particularly relevant recent studies:

1. one conducted by IFAB in Germany in late 2022[ii] focused on e-bikes on trains,
2. the second, published in March 2025[iii] prepared by researchers at Underwriters Laboratory (UL) Fire Safety Research Institute (FSRI) in the US, focused on large rubber tyred e-scooters.

In the IFAB study, the researchers tested a generic e-bike as well as generic e-bike with travel bag. The battery capacity of the bikes was 660 Wh and the motor was 250 W / 48 V. In one test, the peak Heat Release Rate (HRR) exceeded 1 MW, and in the other it exceeded 500 kW.
On completion of their study, IFAB recommended a HRR curve for an e-bike that peaks at 900 kW, 45 seconds after ignition.

Table 1: Table of Thermal Runaway Fire Metrics for e-Ridables from IFAB & UL testing:

Device Type	Battery Capacity	Thermal Runaway Peak HRR	Flame Height	Total Energy Released	Peak HRR Growth Time
eScooter (UL results)	~1.2 kWh	400 kW (overheating) to 1.6 MW (overcharging)	0.9–2.1 m	~40–60 MJ	13 seconds
eBike (IFAB results)	400–700 Wh	400–1000 kW	Up to ~2 m	20–35 MJ	Seconds to minutes

Despite these already compelling numbers, it has been shown that the intensity in terms of the peak HRR of any fire involving a lithium-ion battery is proprtional[iv] with the capacity of the battery. What this means is that with demand for increased power and range, the capacity of these batteries will continue to grow – as will the resulting fire risk.

This quantitative data confirms that battery thermal runaway fires in e-ridables are characterized by rapid onset and intense heat release, with megawatt-level fires combined with jet-flaming and substantial flame heights. Charging practices, battery state-of-charge, chemical composition and manufacturing quality critically influence thermal runaway risk and severity.

To put this size of ignition source into perspective, the European rolling stock fire safety standard EN45545-1 describes five different ignition models for rolling stock fires. The largest of these model ('type 5') peaks at 150 kW. Similarly, 1 kg of crumpled newspaper, what historically would be considered a large ignition source for rollingstock has a peak of around 150 kW. Similarly, CSIRO's 900 g timber crib is used in AS 7529.3 *Australian Railway Rolling Stock - Fire Safety – Passenger*, for testing seats because it is considered a very large ignition source, with a peak heat release rate of around 250 kW.

This shows that e-ridables produce a much larger fire than that which rolling stock is typically designed to accommodate. It is possible that previous and current rollingstock materials' reaction to fire standards have not been validated to reliably prevent fire spread beyond the immediate area of ignition source (which could possibly lead to carriage flashover) for this new, significantly larger ignition source.

3.1.3 Toxicity of Gases

Research highlights battery failures generate a variety of toxic gases, which pose serious health risks, especially in the confined environments of a railway carriage.
Key findings from peer-reviewed studies[v] [vi]include:

Hydrofluoric acid (HF) emissions: Thermal runaway fires in lithium-ion batteries emit large amounts of HF gas as a primary toxic component. Quantitative measurements show HF emissions can range from about 20 to 200 milligrams per watt-hour (mg/Wh) of battery energy capacity, depending on battery chemistry and state of charge. HF is highly corrosive and toxic, with severe respiratory hazards.

Additional Hazardous Gases: Carbon monoxide (CO), hydrocarbons, and other noxious gases are also emitted during thermal runaway, posing asphyxiation and poisoning risks in fire incidents.

In summary, research conclusively shows that thermal runaway battery fires release significant toxic gases, primarily HF and related fluorine compounds, which constitute a serious inhalation hazard beyond fire and heat. These findings underscore the necessity for emergency protocols to consider toxic gas exposure risk to mitigate toxic emissions during thermal failure.

3.1.4 Fire Suppression

Most suppression research focuses on small-scale cell or module-level tests; fewer studies exist on large pack scale fires. Effectiveness varies with battery design, state of charge, and fire scenario.

Technical Advisory Note 9 (*Lithium-ion Batteries: Portable Fire Extinguishers and Fire Blankets*) of the *Fire Protection Association Australia* reports that "it is noted that there is currently no Australian test rating that specifically addresses the unique hazards associated with lithium-ion batteries, separate from the general electrical fire test classifications. This gap is of concern given the distinct risks posed by lithium-ion batteries, including thermal runaway, off-gassing and the potential for explosion".

Fixed fire suppression systems are not installed to any Australian passenger rollingstock interiors. Emergency services would currently consider their options in suppressing a battery fire on board.

There are currently portable extinguishers for battery fires sold in Australia but are not currently installed on Australian passenger trains. Application of extinguishers on e-Ridable fires needs further consideration and is impacted by the following:

1. Specific portable extinguishers are most typically water type extinguishers (tested to AS 1841.1 for class A cellulosic type fires), which have additives to the water to promote “encapsulation” of battery cells. They are typically > 90% water. The additives are typically vermiculite or other materials to promote formation of a sticky wet encapsulation around the target battery cell.
2. There is currently no Australian standard extinguisher class or performance test for battery fires. They are not tested for application to battery fires, only Class A cellulosic fires.
3. Overseas battery extinguisher tests do not appear to reasonably represent the shielding and possible fire conditions of e-ridable fires on board trains. These extinguishers are likely to be less effective for real e-ridable fires on trains than indicated in these tests.
4. Deployment of battery extinguisher at close range to a fire on board is likely to expose crew to significant hazards and may negatively impact the primary response strategy of safe evacuation at nearest station as quickly as possible.
5. Water based extinguishers on trains can introduce other electrical hazards.

Research and standards (NFPA 855:2023, FM Global, Fire protection Research foundation etc) conclude or specify that high density sprinklers/deluge/water spray is the most effective means of suppression.

Suppression systems specifically designed for battery fires in train interiors still require further research.

3.1.5 Flammability of vented Gases

Research into the flammability of gases emitted during battery thermal runaway shows these gases pose significant combustion and explosion hazards. For clarity this is a separate outcome to the non-explosive defragmentation of the battery itself. The main findings from multiple scientific studies include:

Gas Composition and Flammability Limits[vii]: Thermal runaway events release a mixture of gases, including hydrogen (H2), carbon monoxide (CO), hydrocarbons (e.g., ethylene, methane), and volatile organic compounds from electrolyte decomposition. These gases are flammable and, in enclosed spaces, can accumulate to explosive concentrations. Studies report the lower flammability limit (LFL) of these gases around 8% volumetric concentration ± 1.8%, while the upper flammability limit (UFL) can vary broadly between 30% to 60%, depending on battery chemistry and gas mix. More research is required to understand the hazard in the confines of a train carriage.

Explosion Hazards[viii]: Experimental work, including large-scale controlled tests in confined volumes simulating residential garages, confirms that thermal runaway gases can accumulate and lead to prompt or delayed ignition with explosive deflagrations. More research is required to understand the hazard in the confines of a train carriage.

Impact of Battery Chemistry: Different lithium-ion chemistries (e.g., NMC - nickel manganese cobalt vs LFP - lithium iron phosphate) influence the volume and characteristics of off-gas and fire behaviour. Higher nickel content batteries tend to produce greater mass loss and flammable gases, increasing the risk explosion.

Gas Generation Rates: The normalized gas production rate during thermal runaway has been observed to be consistent at about 0.1 mol per Ah of battery capacity, indicating gas generation scales with battery size. Longer jetting durations and higher gas volumes increase the likelihood of combustible atmosphere formation.

Research emphasizes the importance of understanding flammability limits and gas release profiles to design proper ventilation, fire detection, and explosion mitigation systems but there is no research yet available for the confines of a train carriage.

Overall, the literature confirms that the flammable fumes and gases generated during thermal runaway pose a real fire and explosion hazard, and their characteristics must be carefully considered in hazard mitigation.

3.2 Discussion

Acknowledging that the Fire Safety Research Institute (FSRI) e-rideable test data is illustrating a maximum and nearly instantaneous energy release. Further testing is currently underway for a range of battery sizes by the FRNSW – Fire Research Team.

It was reported that in measuring the energy release rate, the calorimetry instrumentation was operating at or beyond its response limit. Such an observation from fire testing is profound as measuring the HRR to its peak is the foundation to FLS design.

A particular concern here is that the FSRI HRR curves are only measuring what they can, and the complete energy release may be underestimated.

From that HRR foundation, the conventional approach is to sequence the timing for FLS systems to detect early, alert and to avoid occupant injury or death. FLS, as a time response parameter is embedded in compliance and approval standards for transportation modes, most significantly underground train networks, as it affects virtually all the designed systems.

The e-rideables at our current knowledge level, violates the FLS time response of the following systems:

i. material classifications;
ii. fire detection and response;
iii. escape to safety time; and
iv. the time to ultimately the tenability limit for safety of humans.

FLS systems are constructed for sequential sub events to occur along timeline that is responsive to the threat so as to enable safeguarding responses. Occupant safety in a FLS design is typically expressed as: Required Safe Egress Time (RSET) and it must be less than the available safe egress time (Drysdale 2011)[ix]. The requirement being the time for a person to escape must be less than the Available Safe Egress Time (ASET) to occupants.

The requirement can be summarised as –

$$\text{RSET} \leq \text{ASET}$$

The minimal time of the RSET was decomposed by (Marchant 1976), and (Nelson and Mowrer 2002) and presented on the left of the following equation.

$$t_{det} + t_{del} + t_{rs} \leq t_u$$

Where:

t_{det} = the time component from the fire initiation to when the fire is detected.
t_{del} = the delay time from the fire being detected to when escape begins.
t_{rs} = the time for people to move to a place of relative safety.
t_u = ASET - the time for the fire to produce untenable conditions.

The evidence from e-ridable fire events is that t_{rs} ,the time to move to relative safety, is the only viable safety measure available. Detection time, and the escape delay are near zero due to the proximity of occupants being near to the fire. And this is obviously subject to human factors that may work against reducing the escape time to a necessary low value. The t_{rs} is also impacted by the characteristics of underground train operations, enclosed carriages, sensory lag (headphones etc). Importantly, '*relative safety*', in the underground sense, has a train in a fire event proceeding to the next station, possibly two minutes or more before any available active fire suppression occurs, should it be a viable action. The *relative safety* is being eroded by the 'next station' time delay. The hazardous conditions that develop with ASET (t_u) mean the untenable conditions are given a further two minutes. When the tenability limit is exceeds the design limit, the FLS design fails its objective.

In conclusion then the FLS requirement is difficult to achieve in a carriage fire for lithium batteries of a certain size because:

- There is no available detection system for a failed battery to fire scenario. The fire development is far too quick, and the failure sequences would be expected to occur faster than detection/verification/alarm sequence can occur to counteract the hazard.
- The time to alert and warn occupants is unviable because the detection system of 1) initiates the necessary warning too late compared to the development of the hazards.
- The movement of passengers to a place of relative safety may be difficult during peak hours and on congested trains.
- Train doors may be locked and immediate escape not possible. Effective evacuation can only occur at a station if the train can continue to the next station where escape occurs.
- There is no available fire suppression system for a failed battery-to fire scenario, noting that suppression systems act to limit growth rate and avoid the peak HRR.

In summary then for lithium battery fires of a certain size in a passenger train carriage the conditions are such that RSET>ASET and there is potentially no mitigations available. From the search and review of the cited papers it is apparent that more research is required in the specific context of a passenger train in all its configurations.

The tenability of conditions in a battery fire on board needs further investigation as the train carriage is a fixed volume and at times densely populated. The smoke and toxics from batteries off gassing and defragmentation deviate from a typical point source fire in conventional FLS design. The University of Queensland (UQ) has planned battery fire tests to quantify the risks associated with smoke toxicity and jet flame projection in confined rail environments that needs to be expanded to consider the carriage design and construction.

3.3 Conclusion

Emergency planning for lithium-ion battery fires, such as those from e-ridables and passenger devices on trains, must prioritize addressing the rapid onset, intense heat release, toxic smoke, and difficulty of extinguishing these fires, especially within the confined, enclosed, and occupied environment of passenger trains.

e-Ridables produce larger, faster growing, more toxic fires that in terms of risk for passengers leads to:

- Untenable conditions develop too quickly for successful escape.
- Onboard fire protection measures are defeated by the very high HRR. Passengers and asset are at high risk.
- Greater smoke hazard during the period where the train moves to the next station to evacuate amplified due to being more toxic.
- Potential for flashover fire, particularly on the oldest of Australia's passenger fleets where the whole carriage can become inflamed.

The next technical paper planned by the FLS Development Group is to consider FLS measures and considerations for battery fires on passenger trains.

As highlighted by this paper, the following further technical studies are recommended by the Working Group:

- Characterising the size of battery and type that challenges the FLS arrangements on a passenger train.
- Collection of data characterising the battery failure, smoke generation and fire HRR to validate fire engineering modelling used when approving station and rollingstock FLS measures.
- Undertake full size experiments to collect the data to inform the tenability challenges of fires on passenger trains from battery failure and fires.
- Research the detection devices that could identify battery failure onset.
- Undertake full size experiments of the fire protection measures taken in design and construction of rollingstock.

Section 4 Appendices

Table 2: Examples of typical Li-Ion device battery capacities, estimated fire peak HRR and charging voltage/current/power

Device type	Typical Li-ion Battery capacity and voltage		Estimated Fire peak HRR (kW)	Charging voltage, current and power		
	Capacity (Wh)	Voltage (V)		Charging Voltage (V)	Charging current (Amps)	Charging power supply (Watts)
Smart phone	8–18 Wh	3.7 V	~ 5–10 kW	5 V	1–2 A	5–10 W (25–45 W for fast charging)
Laptop	50–100 Wh	7.4–14.8 V	~20–35 kW	10–20 V	2–4 A	45–65 W (some larger laptops may be up to 100 W)

NOTE 1:
The above ranges are “typical ranges” only – some devices may operate outside these ranges.
NOTE 2:
Most laptops stay within a 100 Wh battery limit as this is typically the limit permitted to be taken as carry on luggage in passenger airflights.
NOTE 3:
The Estimated fire peak HRR (kW) has been estimated applying the correlation between battery pack electrical capacity and fire peak HRR provided by Sun et.al and RISE. This is a rough correlation only and actual fire peak HRR for battery packs may vary significantly dependent on specific details of battery pack design.

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[iii] Fleischmann, C., Weinschenk, C., Madrzykowski, D., Schraiber, A., Gaudet, B., (2025) *Quantifying the Fire Hazard from Li-Ion Battery Fires Caused by Thermal Runaway in E-scooters*, Fire Technology, March 2025,

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