Incidents Involving Electric Vehicles

GUIDELINE

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PROCEDURAL

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Review period

This AFAC guideline should be reviewed by the doctrine owner come 5 May, 2027.

Contents

About AFAC and AFAC Doctrine

AFAC

The Australasian Fire and Emergency Service Authorities Council (AFAC) is the Australian and New Zealand National Council for fire, emergency services and land management. It is a collaborative network of fire, emergency services and land management agencies that supports the sector to make communities safer and more resilient.

AFAC Doctrine

AFAC develops doctrine to support the practice of emergency management. The information in doctrine publications is evidence based and drawn from academic research and the collective expert knowledge of member agencies. Doctrine is regularly reviewed and represents the official AFAC view on a range of topics.

Doctrine does not mandate action; rather, it sets aspirational measures. Publishing nationally agreed views, shared approaches and common terminology enhances cooperation and collaboration within and between agencies and jurisdictions.

Types of AFAC Doctrine

AFAC Doctrine is classified as follows:

Capstone doctrine – includes publications, such as 'strategic intents', that are high-level accounts of the concepts of emergency management operations and service delivery. They describe the principles of what is practical, realistic and possible in terms of protecting life, property and the environment.

Fundamental doctrine – includes 'positions', which AFAC members are expected to support, as well as 'approaches' and some 'frameworks'. Fundamental doctrine may become agency or jurisdictional policy on a matter if adopted by individual services or jurisdictions.

Procedural doctrine – includes 'guidelines', some 'frameworks', and 'specifications'. AFAC members are expected to be aware of procedural doctrine. A guideline is an advisable course of action; a framework provides a linking of elements to create a supporting structure to a system, and specifications are a detailed description of a precise requirement to do something or build something.

Technical doctrine – includes 'technical notes', 'training material' and the *Australasian Inter-Service Incident Management System* (AIIMS). Technical doctrine provides guidance of a technical nature: the how to do something, or the technical meaning relative to a situation.

About this document

This publication is a procedural guideline.

Source of authority

AFAC National Council endorsed the AFAC guideline for *Incidents Involving Electric Vehicles* on 5 May 2022.

Purpose

This guideline provides operational advice to ensure the safety of emergency service personnel at incidents involving electric vehicles

Scope

This guideline provides a basic analysis of the role by taking into consideration the following areas:

- hazards and risks
- identification
- equipment and response safety considerations for fire, rescue, and other emergency response
- tactics.

Statement of engagement

This document has been prepared by the AFAC Alternative and Renewable Energy Technologies (ARET) Working Group for the Urban Operations Group. This has been developed in consultation with SES Operations Group, Rescue Technical Group, Community Safety Group, HAZMAT & CBRN Technical Group, Built Environment and Planning Technical Group and Fleet Technical Group.

AFAC also acknowledges the work of the external Alternate Energy Doctrine Working Group.

Audience

This guideline is intended for use by AFAC Members, notably Australian and New Zealand emergency service agencies and operational personnel. This guideline can also be used by vehicle recovery personnel, police, vehicle storage locations and other secondary responders.

Definitions, acronyms and key terms

Stranded energy: Any situation where electrical energy remains in a battery without an effective means to remove it. When the battery is damaged and the circuit is broken, the stored energy is unable to be removed, creating a hazard. There is no approved way outside of recycling to remove stranded energy.

Secondary ignition: A secondary ignition is a new failure in a cell occurring in a damaged battery due to the initial abuse event. Secondary ignition incidents can occur hours, days, or weeks after the initial failure and without warning. The term reignition is not a correct depiction of what has occurred as it infers that the initial incident was not completed.

Extreme fire behaviour: Highly flammable gases released during thermal runaway rapidly accumulate in compartments reaching upper explosive limits. When access is gained to these compartments, the gases transfer with the air track and are lowered to the explosive range where they can be ignited by arcing, short circuit or fire resulting in extreme fire behaviour (EFB).

Thermal check: Thermal checks are carried out by personnel using a thermal imaging camera to establish the area of greatest heat on the batteries outer casing. Temperature checks should be carried out regularly during cooling operations after cooling streams have been turned off.

Regenerative braking: During braking, the electric motor acts as a generator, using the energy to charge the battery, thereby recapturing energy.

Thermal runaway: A chain of chemical reactions within the cell where the rapid discharge of electrically charged ions moving from the cathode to the anode occurs. This rapid discharge results in an uncontrolled chain of exothermic chemical reactions leading to rapid temperature rises in the electrolyte and decomposition of the electrolyte leading to generation of flammable and toxic vapours.

Abbreviations

AC – Alternating current

BESS – Battery energy storage system

BEV – Battery electric vehicle

BMS – Battery management system

DC – Direct current

EFB – Extreme fire behaviour

EV – Electric vehicle

FCEV- Fuel cell electric vehicle

HEV – Hybrid electric vehicle

HV – High voltage

IC – Incident controller

ICE – Internal combustion engine

PHEV – Plug in hybrid electric vehicle

PPE – Personal protective equipment

SOC – State of charge

Introduction

The following content has been produced by the Alternative and Renewable Energy Technologies (ARET) Working Group. It is recommended that AFAC Member agencies alert their workforce to the potential risks and hazards presented by vehicles that use lithium-based batteries as a source of propulsion.

The presence of electric vehicles (EV) or plug in hybrid electric vehicles (HEV or PHEV) across Australia and New Zealand is increasing significantly. There are several industry, societal and governmental initiatives that are driving a transition from internal combustion engine (ICE) powered vehicles to electrically powered vehicles. Note that EV, HEV and PHEV are referred to throughout this document as 'EV'.

According to the Electric Vehicle Council (2022) Australians now have access to 30 passenger EV models with 65 variants, and it is expected that in the future, Australians will have access to 31 additional BEV models and six PHEV's from a range of 28 models. There are currently 291 public fast charging locations around Australia. State and federal government funding has been committed to co-fund the deployment of approximately 700 additional fast charging locations over the next 5 years, each with multiple charging bays. According to EVFireSAFE (2021) 's global research, supported by the Defence Science and Technology Group and Deakin University, there is a 0.0012% chance of a passenger EV battery catching fire.

EV manufacturers use a variety of types and brands of battery cells to store energy. The most common type of battery used is a lithium-ion (or Li-ion) battery, a type of rechargeable battery in which lithium-ions move from the negative electrode (anode) through an electrolyte to the positive electrode (cathode) during discharge, and back when charging.

The competition in the battery energy storage system market revolves around the intellectual property associated with battery chemistries, i.e. in the electrolyte and materials used for the anode and cathode. This presents varying levels of hazards and risks to first responders and emergency service personnel when attending incidents involving EVs. The battery chemistry may not be easily identifiable at an incident, requiring responders to take the highest precautions available. The cooling products used to manage battery temperatures are also identified as a hazard and usually involve glycol-based automotive coolants.

It is recommended that agencies allow for their incident reporting systems to capture data on events that either involve lithium-ion based batteries or have identified a lithium-ion based battery as the source of failure. Where appropriate and possible, fire investigators should identify the type of battery and failure. Agencies should undertake education for fire investigators to enable a thorough understanding of battery types, identification of a battery failure and thermal event, and the likelihood of the HV battery being the origin and cause of the EV fire. Where this cannot be achieved, fire investigators should consult with independent external experts where appropriate in line with agency procedures.

Electric vehicle categories

Electric vehicles currently fit into one of five categories:

Battery electric vehicles (BEV)

These vehicles do not contain an ICE and rely solely on a battery for stored energy to fuel the vehicles electric motors. These vehicles are charged from an external source and have other features for harvesting power while the vehicle is in motion such as regenerative braking.

These contain the largest batteries out of the group of EVs. BEV will not have an exhaust system and do not require a grill for cooling the ICE. They produce very little noise and can move without warning and without an occupant in the vehicle.

Plug in hybrid electric vehicle (PHEV)

These vehicles do contain an ICE and use a combination of stored energy from a battery and the ICE to drive the vehicle. The battery can be charged from an external source and has other features for harvesting power while the vehicle is in motion, such as regenerative braking and the ICE charging the battery while the electric motors work.

Batteries are often smaller and do not provide the range of a BEV alone, relying on the ICE.

Figure 1 Image source: Fire and Rescue NSW

Figure 2 Image source: ACT Fire and Rescue

Fuel cell electric vehicle (FCEV)

These vehicles are powered by hydrogen and only emit warm air and water vapour which may be present beneath the vehicle. FCEVs have a propulsion system like that of EVs. Hydrogen is used as stored energy and converted to electricity by the fuel cell. These vehicles have a small lithium-ion battery for storing electricity and fuelling the electric motors. These vehicles also have other features for harvesting power while the vehicle is in motion such as regenerative braking.

Non-plug in hybrid electric vehicle (HEV)

These are self-charging hybrid vehicles that have a smaller ICE with extra power supplied by electric motors, resulting in a smaller ICE. They have a battery big enough to power the electric motor for a short distance or at lower speeds. Along with providing assistance with propulsion the battery is also used to power auxiliary loads and reduce engine idling when the vehicle is stationary. These vehicles cannot be connected to an external charger and instead harvest energy from regenerative braking and the ICE.

Mild hybrids

These vehicles are also classified as HEV with many similar features. The difference is that the vehicle cannot be powered solely using electricity. Instead the battery supplements power for the vehicle and allows it to shut down when stopped. Mild hybrids employ the smallest batteries (typically around 48 VDC) of all EV's and may be located in a variety of positions in a vehicle.

Hazards

The likelihood of the following hazards being present when a cell fails is almost certain.

Thermal runaway

- Thermal runaway is a chain of chemical reactions within the cell where the rapid discharge of electrically charged ions moving from the cathode to the anode occurs. This rapid discharge results in an uncontrolled chain of exothermic chemical reactions leading to rapid temperature rises in the electrolyte and decomposition of the electrolyte leading to generation of flammable and toxic vapours.
- As the temperature rises, the pressure within the cell increases and activates the pressure-relief ports. This allows the release of the vapour to the atmosphere.
- The exterior temperature of the cell casing can reach temperatures of above 1000°C. The vapour may be ignited from contact with the hot cell cases or from burning packaging ignited by the hot cells.
- Thermal runaway can be propagated to adjacent cells by the heat from the exothermic thermal runaway reaction, and furthermore by fire.

Note: Fire is not the propagation mechanism for thermal runway, but if present provides for more rapid propagation.

Indications a thermal runaway is occurring may include:

- High velocity smoke (greyish in colour) or white coloured vapour emitting from the battery, battery casing or underside of the vehicle.
- A loud hissing noise (like a gas leak), popping or crackling sounds.
- Intense or uneven areas of heat may be evident on the battery surface. Use of a thermal imaging camera to monitor temperature is recommended.
- Jet-like flames emitting from the underside of the vehicle or at the battery vents.

Toxic and flammable gases and vapours

- Multiple toxic and flammable gases and vapours are released when lithium-ion batteries are involved in fire. Incident Commanders (IC) and personnel should be aware that hydrogen fluoride (HF), hydrogen cyanide (HCN), hydrogen chloride (HCl), and carbon monoxide (CO) may be present and pose the greatest risk of physical injury.
- Vapour cloud explosions (VCE) resulting in extreme fire behaviour is possible when access is gained to a

compartment and UEL's are lowered to fire gas ignition ranges and an ignition source is present resulting in explosive force.

- IC and personnel should be aware that the ignition of gases can occur rapidly and result in jet like flames, particularly from the floor pan or side of the vehicle.
- A build-up of vapour clouds in enclosed spaces is possible, which can result in an explosive hazard and lower visibility, making vehicle identification difficult.

High voltage (HV) electricity

- High voltage (HV) stored electricity is direct current (DC) and may be as high as 1000 Volts in EVs.
- HV cables will be orange in colour.

Note: Existing voltage detection devices may not detect the presence of DC voltage.

- Personnel are advised not to touch the service plug as indicated in some manufacturer emergency response guides. It poses the highest risk of electrocution because of its direct connection to the HV battery. Agencies may use the service plug if utilising an immobilisation 'emergency plug' product. Agency procedures are to be strictly adhered to in this instance.
- Damaged HV batteries can retain lethal levels of DC electricity, commonly referred to as stranded energy.
- Alternating current (AC) may be present where EVs are on charge.

Warning: Due to the high voltage hazard and risk of electrocution, **never** cut or pierce a sealed battery product enclosure or service plug.

Stranded energy

- Stranded energy is high voltage (HV) energy trapped in cells due to the circuit being damaged.
- After shutting down the HV system, EVs equipped with an inverter/converter to drive the electric motors will have capacitors that will take a minimum of 10 minutes to drain down.

Note: A cell cannot ever reach a state of total discharge as irreversible damage will be caused and render the cell unusable.

Secondary ignition

- Secondary ignition is a subsequent thermal runaway event resulting in fire which is not directly connected to the initial event but a result of the effects of that event. Secondary ignition can occur at any time without warning. i.e. this can be a short circuit due to a damaged separator or damage to the separator due to contaminants forming dendrite growth.
- This hazard can exist for over four weeks post extinguishment.

Hazardous materials

- Leaked electrolyte and toxic gases with a risk of serious respiratory illness or skin contamination can occur from the by-products of a thermal runaway event or leakage of electrolyte.
- White salt residue may be evident on the outside of damaged battery casings indicating remnants of evaporated electrolyte.
- These materials may contaminate personal protective equipment (PPE) and equipment including hoses.
- Hydrogen is a colourless, odourless, and tasteless gas. It cannot be odourised like other flammable gases.

Note: Electrolytes contain volatile hydrocarbon-based liquid and dissolved lithium salts. Spills are likely to evaporate rapidly, leaving a white salt residue. Evaporated electrolyte is flammable and will contain alkyl-carbonate compounds. Leaked electrolyte is colourless and characterised by a sweet odour. If an odour is obvious, evacuate or clear the surrounding area and ventilate the area. Breathing apparatus and structural PPE should be worn if on approach to these incidents.

Projectiles

- Cells may be released under pressure in some EV types. This is typically associated with EVs containing cylindrical cells.

Extreme fire behaviour (EFB)

- Ongoing research is occurring where flammable vapours reach upper explosive limits (UEL) in confined spaces.
- Vapour cloud explosions (VCE) are possible when access is gained to a compartment and UEL's are lowered to fire gas ignition ranges and an ignition source is present resulting in explosive force.

State of charge (SOC)

- Research shows that fire intensity is directly associated with SOC of a battery or cell. A vehicle battery with a SOC between 50 and 100%, or a car straight off charge, will behave more violently in a fire than a car with a battery below 30% SOC.
- It has been identified that EVs may be at a higher risk of experiencing a fire event whilst connected to a charger or having recently come off charge. Identify if the vehicle is, or was recently, connected to a charger at the commencement of an incident.

Unexpected movement of a vehicle

- An EV may move if not immobilised and/or stabilised.
- Wheel chocks should be placed as soon as practical to prevent unexpected movement of vehicle.
- EVs may not produce any sound prior to or during movement.
- Some EVs can move without a driver or occupant as a manufacturer's feature for parking purposes.

Risks

The consequence should a person interact with one of the hazards listed above is considered extreme, resulting in physical harm or death. A risk assessment should be completed by the IC, safety officer and other personnel.

Four main risks to workers include:

- Electrocution from exposure to HV components
- Impact injury from unexpected vehicle movement or projectiles
- Burns from exposure to corrosive vapours, gases or liquids, or extreme fire behaviour
- Respiratory illness from exposure to toxic vapours and gases

Reasonably practicable controls

The following are reasonably practicable controls that should be applied or considered by the IC and personnel at all incidents attended where damage has or may have occurred to an EV or battery.

Engineering

- Set appropriate exclusion zones.
- Immobilise the vehicle by placing chocks around the wheels.
- Disable the vehicle in accordance with manufacturer's emergency response guidance.
- Isolate the main switch board, especially if the vehicle is charging.

Administrative

- Identify the vehicle as an EV.
- Identify signage or other features of a charging station.
- Refer to the latest manufacturer emergency response guide or relevant safety sheet in the ANCAP RESCUE app or similar products.

Personal Protective Equipment

- Ensure self-contained breathing apparatus is worn, especially when white vapour or smoke is present.
- Wear structural firefighting ensemble if in vicinity of an EV involved in fire.
- Use electrical gloves and insulated tools in accordance with agency procedures.
- Chemical gloves may be required if spillage of electrolyte, coolant or other hazardous materials are present, in accordance with agency procedures.

Operations

Size- up and identification of electric vehicles

Information gathering is to form part of the initial scene assessment, size-up and risk assessment processes for any incident where lithium-based batteries are involved. This could include:

- Questioning occupants about vehicle type.
- Looking for QR codes on vehicle windscreen, inside driver's door pillar, fuel cap, under bonnet. If QR codes or badges are placed on the vehicle/windscreen, they could be compromised in a significant vehicle accident and not be identifiable.
- Signage or stickers on the number plate.
- Vehicle badging, such as 'hybrid', 'electric' or 'zero emission'.
- A blue hue around manufacturers branding which indicates environmentally friendly technology.

- The absence of an exhaust pipe or radiator grill.
- Searching the ANCAP RESCUE app, similar products or manufacturer's website for emergency response guides.
- It has been identified that EV's are at higher risk of a fire event whilst connected to a charger. Identify if the vehicle is or was recently connected to a charging station at the commencement of an incident.

Figure 3 Image source: Fire and Rescue NSW

Figure 4 Image source: Fire and Rescue NSW

Note: Not all of the above indicators may be present as different state legislation and nuances between manufacturers may differ. All should be assessed or identified during the scene assessment or 360 size up.

ANCAP RESCUE app can be downloaded to mobile devices free of charge, while access to manufacturer emergency response guide information can be found on their respective websites. Similar products may also provide assistance. These guides are comprehensive and may provide information about:

- location of high voltage cables
- location of batteries
- instructions for disabling the vehicle
- firefighting, extrication and rescue, HAZMAT
- towing instructions.

EVs have high voltage cabling connecting the battery to the motor. Whilst the cabling colour is standardised as orange, the location of these cables varies between vehicle makes and models.

Note: Do-it-yourself conversions of ICE to EV are starting to emerge. Conversions need to comply with the Australian Design Rules (ADRs) and the National Code of Practice for Light Vehicle Construction and Modification (VSB 14). The VSB14 guidelines include requirements for orange cabling and standard shut down procedures.

The location of the battery varies:

- For BEVs, the battery is usually under the floor pan of the vehicle or runs under the centre console and rear seats.
- For all other EVs, the battery can be in a variety of different locations in the vehicle. Use of the ANCAP RESCUE app or similar products, manufacturer emergency response guides or National Fire Protection Association (NFPA) guides should be used to establish the make and model of the vehicle to identify the battery location. For larger vehicles such as buses, trams, and trucks, the operator or owner of the vehicle may know the battery location, sometimes this can be in the roof of the vehicle.

In FCEV's, fuel cell location varies:

- In passenger vehicles, underneath the car where a fuel tank would usually be located.
- In buses, can be found on the roof.

Incidents where an EV battery has been damaged require the EV and battery to be inspected by a suitably qualified technician before the vehicle is used again. It is possible that second hand batteries may have sustained previous damage.

Note: If a thermal runaway event has occurred, it may be a long duration incident and may require significant resources to control. Previous incidents indicate that between 4,000 and 30,000 litres of water may be required for extinguishment and cooling, depending on the extent and quantity of damaged cells.

Approach and initial actions at all incidents involving an EV

- Position crew and appliance upwind at a 45-degree angle to the side of the vehicle to avoid the areas of highest risk (side, front and rear).
- Confirm the vehicle is an EV.
- As the parking brake is usually electronically controlled in EV, engage the parking brake before the 12V battery is disabled. Consider that disconnection of 12V system may disable some systems such as boot latch and drivers seat movement.
- Identify the owner and if possible, locate the fob key to prevent accidental operation of the vehicle remotely.
- Switch the vehicle off in accordance with the manufacturer's emergency response guide.
- Communicate with motorway operators and traffic commanders to inform them of the possibility of a long duration incident for planning purposes in traffic management and community notifications.
- Leaked electrolyte is colourless and characterised by a sweet or pungent odour. If an odour is obvious, evacuate or clear surrounding area and ventilate. It is flammable and corrosive/irritating to the eyes and skin. It is important that breathing apparatus and appropriate PPE is donned on approach to the vehicle.

- Consider using appropriate atmospheric monitoring equipment when establishing hot, warm and cold zones.
- Ventilate the vehicle cabin as a precaution to avoid build-up of explosive gases.
- Be aware that existing in-service AC voltage detection devices may not detect the presence of DC voltage.

Tactics and strategies

Collision incident not involving fire

- Do not touch the service plug. It poses the highest risk of electrocution because of its direct connection to the HV battery.
- If possible and safe to do so, immobilise and/or stabilise the vehicle as a matter of priority.
- Consider disconnecting the 12V DC battery in accordance with the manufacturer emergency response guide, **not using the service plug**.
- Be aware damaged HV batteries can retain lethal levels of DC electricity, commonly referred to as stranded energy.
- Due to the HV and electrocution risks, **never** cut or pierce a sealed battery product enclosure, cabling or service plug.
- Use a thermal imaging camera to assess battery temperature. If the battery is found to be at ambient temperature, and there is no increase in temperature then thermal runaway is unlikely.
- Advise the owner to have the vehicle inspected by a suitably qualified electrician as battery damage may not be immediately visible.

Firefighting

Note: Access for thermal checks using a thermal imaging camera on the battery casing will present a challenge for personnel where the battery is located on the underside of the vehicle. IC and personnel must be aware of the hazards of vapours, jet-like flames and hazardous materials in fireground run off when conducting thermal checks near damaged batteries.

Figure 5 Image source: Fire and Rescue NSW

An option may be to use a tow vehicle with a tilt tray to slightly lift the vehicle to provide access. AFAC Members are researching and testing solutions to identify safe methods for providing access. Further solutions will be provided when testing is complete.

- Structural firefighting ensemble including flash hood and self-contained breathing apparatus is the minimum PPE for any firefighting activities within proximity of the vehicle, or if any smoke/vapour is present, in line with the hierarchy of controls.
- Use of atmospheric monitoring to identify hazards in the environment is recommended.
- Conduct regular thermal checks with a thermal imaging camera during the firefighting and cooling process.
- Water is the recommended medium in Australia and New Zealand for extinguishing a lithium-ion battery involved in fire. Extinguishing strategies are to be established by the IC, with consideration that foam will not provide any additional extinguishing capability but may inhibit conducting thermal checks. Carbon dioxide and dry chemical powder extinguishers have no cooling effect and are deemed ineffective for controlling a battery involved in fire.
- Once the fire has been extinguished use a thermal imaging camera to identify hot spots on the outer casing of the battery and apply a pinpointed water stream on the hot spot. This can take some time.

Figure 6 Image source: Fire and Rescue NSW

Note: Sweeping a stream across the battery casing will not have the desired effect for cooling the battery cells affected by thermal runaway and preventing it from cascading to other cells in the module. A consistent, directed stream is required to penetrate the protective battery casing and module casing to provide adequate cooling to the cells.

- The recommended cooling process for a thermal runaway event is as follows:
  - Apply a direct pinpointed stream of water onto the identified hotspot for a minimum of 8 minutes.

- At the end of the 8 minutes minimum of cooling, undertake a thermal check after a minimum period of 10 minutes, to allow battery to drain.
- If any signs of above-ambient temperatures are identified through the TIC or areas on the battery casing which are dry, continue cooling.
- Once it is deemed the battery is at ambient temperature wait 60 minutes to conduct a final thermal check prior to handing over to either the owner, occupier or tow truck operator.

- Cooling is to continue until the battery casing either shows no further hot spots or the battery is at ambient, stable temperature.
- Secondary ignitions are a significant hazard and temperature monitoring is required immediately after knockdown and should continue until the battery temperature has reduced to an ambient, stable level.
- In the event the HV battery is on fire, it may be preferable to allow the fire to continue to burn until the battery is burned out if the situation allows.
- Contact specialist scientific/HAZMAT officers for advice in line with agency procedures.
- Use extreme caution when making initial entry to any compartment suspected of housing a battery to avoid a VCE or an EFB event through the ignition of flammable vapours/smoke within the compartment.
- Consider the management of water runoff taking into account the incident's proximity to waterways or environmental assets. If appropriate, contact the relative jurisdictional environmental protection authority for support and/or advice in line with agency procedures.
- If the incident involving the vehicle is in a rural or remote location, with limited access to extinguishing media and no potential for fire spread to exposures, consider containing the fire to the vehicle and allowing the fire to self-extinguish as a response strategy.
- If the vehicle is an FCEV, consider that identification of a fire may be difficult as hydrogen fires produce almost no radiant heat and no smoke, making it almost impossible to sense the presence of a fire. Use of a thermal imaging camera is integral at any incident where an FCEV is damaged. Allow venting of the cylinder and control any ignition sources if a temperature activated relief device is operating.

Salvage and Overhaul

- Consider run off as containing contaminated products of combustion and control as per agency procedures. Due to the large volumes of water hazardous products may be diluted significantly compared to an ICE vehicle fire.
- The use of chemical gloves and appropriate PPE is recommended in any post-fire handling of batteries due to the risk of injury from corrosive/caustic substances. Monitor material with a thermal imaging camera.
- In the event cells are scattered around the site, consider (if safe to do so) moving and submerging cells or battery modules in a suitable nonconductive container of clean water. Batteries can continue to burn and off gas while underwater so care should still be observed even after this action has taken place.
- Use a tool such as a long-handled shovel to move the cells or battery modules.

Note: Under no circumstances should salt or any other additive be introduced into the container of water, it is possible that through electrolysis from stranded energy, chlorine gas may be released.

Figure 7: Image source: Fire and Rescue NSW

Rescue

- The batteries in an EV are heavy. This can make the vehicle more prone to rolling unexpectedly if on its side. If the vehicle is on its side on arrival to the incident, stabilise the vehicle to prevent it rolling any further.
- When using stabilisation equipment, be careful to avoid puncturing the battery casing or coming into contact with orange cabling or damaged HV components.
- Be aware in the event of severe damage there is always potential for HV cabling or components to be exposed.
- Always visualise and expose the cutting area before starting, ensuring that there are no obstacles such as HV cabling or supplemental restraint system (SRS) components. Tunnelling through the boot, sill cuts and crushes may not be an option with EV, because of

the location of HV cabling and batteries. Refer to the ANCAP RESCUE app, similar products or manufacturer emergency response guide.

Vehicles in water and flood damaged vehicles

An EV that has been submerged in water, particularly salt water, has a higher risk of experiencing a battery short circuit, which may result in a battery fire. Any damaged HV battery also has the potential for a secondary ignition event.

- If accessible, turn off the vehicle's ignition but do not attempt any further disabling procedures while the vehicle is submerged. Any occupants should be assisted in accordance with normal rescue procedures.
- Identify that the vehicle contains a battery. Look for signage on number plate or other identifiers discussed in the identification section of this document.
- Due to the risk of a secondary ignition, ensure that the HV battery is stored in an open area at least 15 metres from any exposure.
- If unable to shut the vehicle down, first remove it from the water. Be prepared to respond to a fire. Raise the front of the vehicle to allow water to drain out of the vehicle and the HV battery pack.
- To avoid electric shock, **do not** come into contact with any HV electrical components or cabling.
- Do not cut, pierce, or touch damaged batteries. Refer to the ANCAP Rescue app, similar products, or manufacturers emergency response guides available online for further information.

Electric and hybrid vehicles can move at any time without warning. Advise the owner of the vehicle to:

- Not charge or use the vehicle until it has been inspected by a suitably qualified technician as water and dirt can cause short circuits in batteries and electrical components.
- Contact the sales point, service point, or manufacturer for advice.

Vehicle charging

- Locate and shut down the charging station power source before beginning firefighting operations. AC and DC electricity may be present.
- Be aware that EV incidents may happen at locations where non-compliant EV charging equipment may be encountered.
- Contact the local power distribution company to isolate an EV charging station if an emergency isolation switch cannot be identified. If the charging station or equipment is involved in the fire, treat the scene as a structure fire and take all normal precautions associated with electricity. An isolation switch should be installed within two metres of the unit as required by Australian Standard AS/NZS 3000 *Electrical Installations*. Confirmation of power isolation should be sought before approaching or applying water.
- Protect exposures from the fire until power is shutdown at the distribution board, do not direct any firefighting streams onto the EV until disconnected from the charger, or onto the charging equipment until the isolation switch has been activated.
- In the event of a collision involving a charging station, the same approach of shutting down power should be applied.
- Be aware of sprinkler run off if power to the charging station has not been isolated.
- If there are other EVs in the area, check for fire extension or battery heating even if they do not appear to be running. Consider the following:
  - The vehicle may be in auto stop or ready mode and still be on.
  - Other EVs connected to the same or neighbouring charging equipment may be affected.

Note: Charging systems may not always comply to the minimum electrical standards and associated signage to assist in identification may not be present. Variation in current within the grid can also impact stable charging and may in some cases lead to battery failure.

Special considerations

- Due to the potential for rapid escalation of fire at these incidents, if the vehicle is located in an enclosed location such as a multi-storey or underground carpark:
  - Consider if the fire size and behaviour allow for containment through the operation and boosting of any installed sprinkler systems, rather than close proximity firefighting.
  - Be aware that any sprinkler system may not provide any assistance in cooling a vehicle battery as it may be shielded from sprinkler water spray.

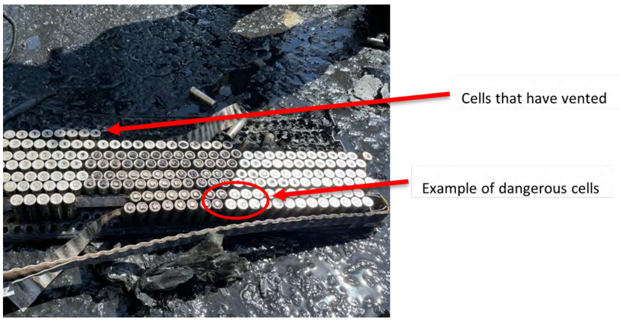

Figure 7: Image source: Fire and Rescue NSW

- Consider the use of any air handling systems to control smoke and potentially toxic gases. Ensure that the exit point of these systems is not directed to a populated area. An exclusion zone taking into account the wind direction must be considered.

- Cells that are intact and have been exposed to abuse or show bulging or deformation should be considered dangerous, handled accordingly, and submerged in a nonconductive clean water bath.

Scene handover and post-incident management

- Consider the use of an agency endorsed handover document.
- Ensure that third parties are aware of hazards and requirements for correct transportation and storage of damaged EVs, in line with jurisdictional arrangements.
- Ensure that third parties understand that the battery must be inspected and made safe by a suitably qualified technician.
- Ensure it is communicated that vehicles with damaged batteries or suspected of having damaged batteries must be kept at least 15 metres from any exposures including other vehicles or buildings.
- Record handover time and third-party details accepting custody in the incident chronology.
- IC is to assess when it is appropriate for third parties to access and/or take custody of the damaged vehicle, as fire investigation purposes may require the vehicle to remain under emergency service custody.
- Consider affixing an adhesive tape to the vehicle to advise of residual risks to the chain of custody that may include police, impound yards, tow truck operators, insurance agencies and vehicle owners. An example is provided in Appendix 3.

Note: International cases of EV vehicles experiencing secondary ignition events up to four weeks after the initial incident have been documented and investigated.

Post incident operations

- Full decontamination measures should be undertaken by crews that have been exposed to smoke, vapour or other contaminants in the incident, in line with agency procedures.
- Medical attention should be sought where exposure has occurred without PPE.
- Consider the decontamination of equipment that may have come into contact with products of combustion or fireground water runoff, particularly with canvas hoses, in line with agency procedures.

References and supporting resources

National Transportation Safety Board. 2020. *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles.* Safety Report NTSB/SR-20/01. Washington, DC.

National Fire Protection Association. 2018. *NFPA's Alternative Fuel Vehicles Safety Training Program Emergency Field Guide 2018 Edition.* Quincy, Massachusetts.

National Fire Protection Association. 2013. *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results.* R. Thomas Long Jr., Andrew F. Blum, Thomas J. Bress, and Benjamin R.T. Cotts- Exponent, Inc

AS/NZS 3000:2018 *Electrical installations* (known as the Australian/New Zealand Wiring Rules)

Löbberding et al. From Cell to Battery System in BEVs: Analysis of System Packing Efficiency and Cell Types. 2020. *World Electric Vehicle Journal.*

Fire Emergency New Zealand Alternative Energy Vehicles Training Module

New South Wales Rural Fire Service OP 1.2.21 Operational Protocol for Incidents Involving Electric and Hybrid Vehicles

Fire and Rescue New South Wales – Operations Bulletin 2021-01 Electric vehicle fires.

Electric Vehicle Council. 2022. *State of Electric Vehicles Report*. Sydney, Australia.

United European Car Carriers, *Electric Vehicle Guideline. Version 1*

2021 Australia/New Zealand Emergency Response Guidebook (AERG2021)- Battery-powered vehicles (with lithium-ion batteries):

EVFireSafe website: https://www.evfiresafe.com/

Appendices

Appendix 1: Basic battery make-up

The following information gives a basic understanding of EV battery systems.

EVs are powered by battery systems or battery packs, which contain modules of cells.

A module contains individual cells connected in series and/or parallel and is encased in a mechanical structure.

A battery system is assembled by connecting multiple modules in series or parallel, together with battery management systems, and is then encased in a housing structure.

Cell

The cell is the smallest component of a battery system, used in EVs and other BESS applications. The main cell types and sizes are:

Cylindrical	Cells similar in size and shape to a "AA" battery. Cells that are most recognisably used by manufacturers such as Tesla. There are a variety of cell sizes which is indicated by the cell numbering 18650, 2170 and 4680.
Prismatic	Generally a rectangular shape with a hard shell casing, designed to have a very thin profile for use in small electronic devices such as mobile phones.
Pouch	Similar in profile to a prismatic cell, encased in a thin polymer/aluminum film or shell, making them lightweight. Found in most EVs due to the ability to maximise space usage due to their thin, flat design.

Figure 9. Typical cell types for lithium-ion batteries. From left to right: pouch cell, cylindrial cell and prismatic cell. Image source: Löbberding et al. 2020.

There are many parts to a cell, with the main components:

Anode	Negative electrode, usually graphite or silicon based. The role of the electrode is switched during the discharge/charge cycle.
Cathode	Positive electrode, usually lithium-metal oxides. The role of the electrode is switched during the discharge/charge cycle.
Separator	A porous, thin membrane placed between electrodes, permeable to ionic flow but preventing electric contact of the electrodes.
Electrolyte	Made up of various chemical compounds which differ between manufacturers. The electrolyte allows the transfer of charged lithium-ions between the anode and cathode.
Battery management system (BMS)	Used to monitor and control power storage systems, assure health of battery cells and deliver power to vehicle systems. The BMS activates controls if cells operating outside safe working limits are detected. i.e. disconnect feeds from charging systems if voltages get too high or low, and monitor temperatures, disconnecting before getting too hot resulting in thermal runaway.

Module

In EVs, multiple cells are joined together to create modules which are held in a frame to protect them from external abuse such as heat or vibration. As an example, a Tesla module contains over 400 cells.

The modules are then grouped together to form a pack where a BMS and cooling system are included to protect the battery.

Causes of cell failure

Types of abuse which may result in a cell failure and initiate thermal runaway can include:

Physical (mechanical) abuse	Puncture, dent, crush or impact.
Thermal abuse	Prolonged heat source above 50°C. Can also include cold temperatures or cycling between extreme temperatures.
Overcharge	Failure of the BMS, where there is differing voltages across cells in modules/batteries, when too many lithium-ions are removed from the cathode, leading to decomposition of the cathode materials, releasing oxygen and thermal energy.
Rapid discharge	Failure of the BMS, where there is differing voltages across cells in modules/batteries caused by releasing energy too quickly.
Internal cell failure	Poor cell/pack design, resulting in electrochemical or mechanical failure.
Impurities in the cell	Metal deposits can form on the battery's anode creating dendrite growth structures that look like horizontal stalactites.

Note: in all types of cell failures the separator will have sustained some form of damage enabling the rapid movement of ions between the anode and cathode. The internal short circuit and heating of the electrolyte results in the chemical breakdown of the electrolyte, a build-up of internal pressure in the cell and possible ignition of the escaping gases.

Appendix 2: Shipboard EV considerations

The *United European Car Carriers Electric Vehicles Guideline* advises that on board EVs are to have a minimum and maximum state of charge (SOC) percentage as 20% and 50% respectively. Wallenius Wilhelmsen have also limited maximum SOC to 50%. Some EV manufacturers have recommended that new EVs should be transported with a SOC not over 30%. It is recommended that this position be adopted across Australia and New Zealand.

AFAC does not recommend that vessels permit on board EV charging. AFAC recommends that vessels intending to fit EV charging facilities on board the vehicle deck areas liaise with their relevant jurisdictional emergency service agencies. Consideration should be given to the following:

- Developing pre-incident plans.
- Installation of vehicle deck fans that can operate in forward and reverse, allowing exhausting of the air to outside of vessel, fitted with temperature rated fans and cabling.
- Locating EV chargers in areas where natural ventilation is occurring.
- Fitting of a ceiling mounted deluge system on each of the vehicle decks to protect any exposures.
- Installation of in-floor sprinkler heads to spray under any EV involved in fire.
- Installation of warning signage advising of the significant risk of electric shock.
- Separation of EV charging stations at forward and aft, in areas physically separated from other combustible vehicles.
- Appropriate manual suppression capability including trained staff, facilities and equipment including appropriate type and volume of extinguishing media and if appropriate, specialist vehicle fire blankets.
- Consideration of the type of EVs permitted to charge and a limit on SOC.
- Installation of CCTV for monitoring by staff of vehicle areas where charge is occurring, including consideration for thermal imaging camera/equipment for monitoring.

Appendix 3: Example handover tape 100x300mm