EI 3618

Hazard analysis for battery electric vehicles for aviation fuel handling operations at commercial airports

First edition

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EI 3618

HAZARD ANALYSIS FOR BATTERY ELECTRIC VEHICLES FOR AVIATION FUEL HANDLING OPERATIONS AT COMMERCIAL AIRPORTS

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FOREWORD

This research report has been prepared by Risktec Solutions Limited[1] under the direction of a Working Group reporting to the EI's Aviation Committee.

It provides a generic hazard analysis of a battery electric vehicle (BEV) deployed for jet fuel handling activities at commercial airports.

This publication also provides recommendations for a system-specific hazard analysis for a BEV deployed for jet fuel handling activities at commercial airports, to support designers and operators to develop their own system-specific safety justification.

The recommendations contained in this publication are intended for chassis manufacturers, vehicle builders, service equipment manufacturers, specifiers/purchasers of BEVs, airport owners, airport authorities, fuel handling facility designers, BEV charging infrastructure providers, fuel handling facility operators, fuel suppliers, into-plane service providers, BEV operators, emergency responders, aircraft operators and any other entity involved in the handling of jet fuel at commercial airports.

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Suggested revisions are invited and should be submitted to the Technical Department, Energy Institute, 61 New Cavendish Street, London, W1G 7AR (e: technical@energyinst.org).

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EXECUTIVE SUMMARY

The Energy Institute (EI) has contracted Risktec to undertake a project with the objective of identifying the risks associated with the use of battery electric vehicles (BEVs) deployed for fuel handling operation activities at commercial airports.

The purpose of this document is as follows:

– To provide an overview of the project scope, methodology and outcomes, for the generic hazard analysis of a BEV deployed for fuel handling operation activities at commercial airports.
– To provide information and guidance on a system-specific hazard analysis for a BEV deployed for fuel handling operation activities at commercial airports, to support designers and operators in developing their own system-specific safety justification.

This project included the following tasks:

– a hazard identification (HAZID) workshop;
– a bow tie analysis, and
– a safety report (this document) detailing the findings of the above tasks.

Details of the methodology and outcomes of these tasks are described throughout this document.

The generic hazard analysis has identified a number of standards, codes of practice and legislation that are relevant to the deployment of BEVs for commercial airport fuel handling operations; see 5.1.1 and Annex G.

The HAZID workshop identified 58 hazards, 46 of which are either considered unique to BEVs or where the risk profile is increased compared to an internal combustion engine vehicle (ICEV); this included the following significant accident hazards (SAHs):

– H-1: battery fire;
– H-2: high voltage (HV) systems in conjunction with fuel spill/vapour collection, and
– H-3: HV – shock/electrocution.

Bow tie analysis was undertaken to explore the development of the three SAHs and associated safeguards further, which were an input for updates to the generic hazard register [1]. The output of the bow tie analysis was a set of generic bow tie diagrams for each SAH; see Annex B.

Fourteen recommendations have been raised through this hazard analysis; these are outlined in 6.2.

The study provides a generic assessment methodology (generic hazard register, bow tie diagrams and recommendations), which can be built upon by BEV fuel handling vehicle designers and operators to conduct a system-specific hazard analysis to support a safety justification for the deployment of specific BEVs for fuel handling operations at specific commercial airports.

The study has not defined the residual risk associated with the deployment of BEVs for fuel handling operations at commercial airports; however, the outputs can be used to support a system-specific deployment at commercial airports, accounting for the hazards that are applicable to the BEV design and commercial airport under examination.

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1 INTRODUCTION

1.1 BACKGROUND

Facility owners/operators, fuel suppliers and aircraft operators are seeking to understand whether additional risks may be introduced by the deployment of battery electric vehicle (BEV) technologies for aircraft fuel handling operations at commercial airports, and the mitigation measures that may be necessary.

Due to the practice of fuelling aircraft with passengers on board, a high severity event could be the total loss of an aircraft containing passengers. Similarly, in the event of a motor vehicle incident (MVI) near (or in an underpass beneath) a terminal building, a significant number of passengers and/or the whole commercial airport operations could be impacted.

1.2 PROJECT OVERVIEW

1.2.1 Work package

The Energy Institute (EI) contracted Risktec to undertake a project with the objective of identifying the risks associated with the use of BEVs deployed for fuel handling operation activities at commercial airports.

This project has included:

– a hazard identification (HAZID) workshop;
– a bow tie analysis, and
– a safety report (this document) detailing the findings of the above tasks.

Details of the method and outcomes of these tasks are described throughout this document.

1.2.2 Objectives

The objectives of this project were as follows:

1. drawing on experience from across the industry, identify hazards and consequences associated with a generic BEV for fuel handling operation activities at commercial airports;
2. identify existing safeguards for the hazards identified in objective one, and
3. where gaps in safeguards are identified, provide recommendations for development.

1.3 PURPOSE OF DOCUMENT

The purpose of this document is to:

– Provide an overview of the project scope, methodology and outcomes for the generic hazard analysis of a BEV deployed for fuel handling operation activities at commercial airports.

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– Provide information and guidance on a system-specific hazard analysis for a BEV deployed for fuel handling operation activities at commercial airports, to support designers and operators to develop their own system-specific safety justification.

This document is intended for use by all stakeholders in BEV development and operation, including, but not limited to:

– BEV original equipment manufacturers (OEMs);
– charging infrastructure OEMs;
– fuel delivery system vehicle integration OEMs;
– BEV operators and maintainers;
– airfield operators;
– emergency services, and
– airline ground operations.

This document is intended for a global audience, and as such, references to local or national legislative requirements have only been included where deemed applicable. Any system-specific analysis should ensure compliance with all relevant local or national legislative requirements.

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2 HAZARD ANALYSIS PROCESS

This section aims to provide a framework for how to execute a risk assessment to support a safety justification for the deployment of BEVs for aircraft fuel handling operations.

2.1 REQUIREMENTS OF OPERATORS AND EMPLOYERS

Operators and employers have a duty of care to protect all people, including employees, contractors and visitors, from any harm, and to comply with the law in many countries. The following steps are considered best practice and shall be executed to ensure owners and operators meet the minimum requirements of various legislation:

– application of applicable codes and standards;
– HAZID (scenarios where harm (fatality, injury, or illness) to personnel may occur);
– hazard analysis (assessment of the degree of potential harm arising to an operator or contractor from the hazard and of how likely the outcome is), and
– hazard evaluation and treatment (are the protective measures sufficient to reduce the risk to an acceptable level (agreed risk acceptance criteria (RAC)) and if not, what further risk reduction measures are required).

2.2 GENERIC APPROACH TO MANAGEMENT OF RISKS AND HAZARDS

Figure 1 outlines the generic approach to management of hazards and risks derived from similar processes used across industries; the outputs of this generic hazard analysis are shown in orange as inputs to a system-specific hazard analysis.

It is recommended that an established process for management of risks and hazards is followed, such as EN ISO 12100 *Principles for the design of safe machinery*.

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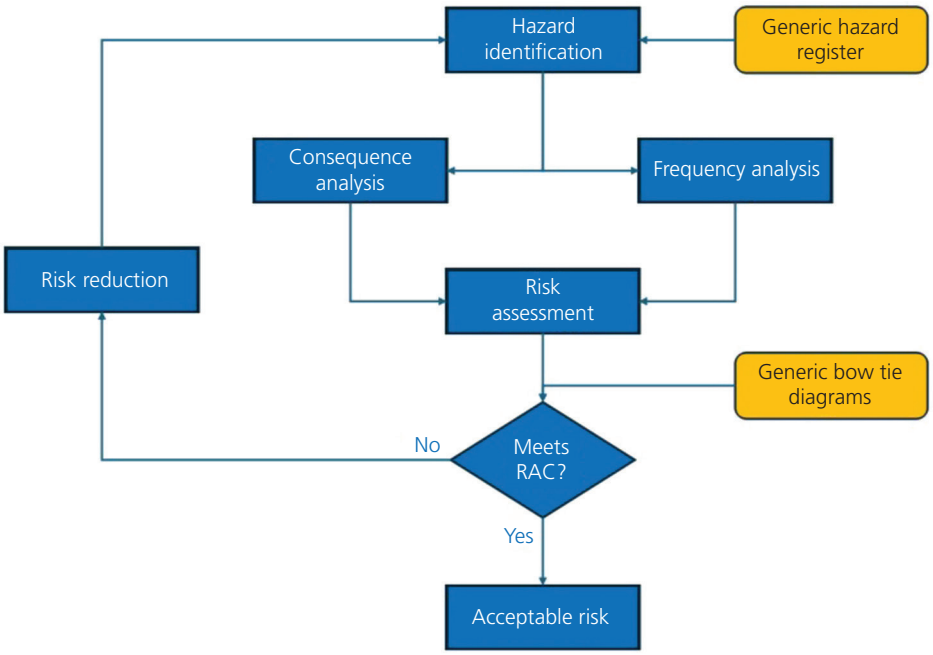


Figure 1: Generic approach to management of hazards and risks

2.2.1 Application of applicable codes and standards

Designers and operators must ensure that all applicable local and international codes of practices, standards and legislation are met. Where applicable, the risk assessment and hazard management processes should be modified in line with local and international requirements. Where operators deem that national legislation requirements are not sufficient, they should meet industry best practice.

2.2.2 Hazard identification

The objective of the HAZID is to use structured review techniques to identify all reasonably foreseeable hazards associated with a BEV. For further details, see 4.2 and 5.2.

The generic hazard register [1] produced for this project may be used as an input to system-specific HAZID.

2.2.3 Consequence and frequency analysis

To evaluate the hazards and whether additional risk reduction measures are required, a risk matrix can be utilised to assess the worst-case severity of each hazard and the likelihood of its occurrence. Most risk matrices use the following parameters:

– severity of the consequence (S), and
– likelihood of the event reaching that severity (L).

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An example of a risk matrix used for the generic hazard analysis can be found in Annex E.

Where possible, a risk assessment may consider historical incident data to determine the expected likelihood of an event occurring, for example, Joint Inspection Group (JIG) BRA 2.0 vehicle collision data. Where these data are not available, the risk assessment should be performed by a suitably qualified, experienced and competent group, using a workshop approach.

If further severity and likelihood analysis is required, a quantified assessment, such as an event tree, may be used.

2.2.4 Risk acceptance criteria (RAC)

Based on the consequence and likelihood analysis, the tolerability of the risk of each hazard can be determined. The tolerability of risks is based on the RAC, which defines the level of risk that is considered acceptable and must meet the minimum legislative requirements. Each hazard's residual risk can be divided into the following groups:

- Acceptable:
  - Further protective measures may be required to reduce the risk. However, it is more probable that the time and effort to do so would be disproportionate to the safety gain.
- Tolerable:
  - The level of risk is considered tolerable to the industry. Further risk reduction measures should be considered and implemented, unless the cost to implement the measures is grossly disproportional to the risk reduction achieved.
- Intolerable:
  - Hazard residual risk cannot be accepted, and further risk reduction measures are required to reduce the risk to a tolerable level.

2.2.5 Screening of hazards

To provide a proportional approach to hazard management, hazards that are considered to be high risk can be taken forward for greater analysis beyond the hazard register. The technique chosen within this study is to perform a bow tie analysis on these hazards. See 4.3 and 5.3 for further details on the bow tie analysis.

2.2.6 Further risk reduction

Where the risk associated with hazards does not meet the RAC, further risk reduction measures must be implemented to reduce the risk to a tolerable or acceptable level. The process outlined should be repeated for any hazards where further risk reduction is required.

It should be noted that further risk reduction should avoid transferring risk to other activities or disciplines. When considering a risk reduction measure, the residual risk of that measure must be assessed and reviewed against the overall risk reduction achieved.

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3 SYSTEM DEFINITION

3.1 GENERIC SYSTEM

The following sections describe the generic BEV system for aircraft fuel handling operations under consideration within this project. The generic system was developed with the EI to enable the worst-case credible consequences of hazards to be assessed. It is acknowledged that deviations from this generic system may modify the risk profile; as such, a system-specific hazard analysis should define the system-specific architecture and processes.

3.1.1 Generic BEV system

Figure 2 shows a simplified overview of a generic BEV system, showing key components and systems.

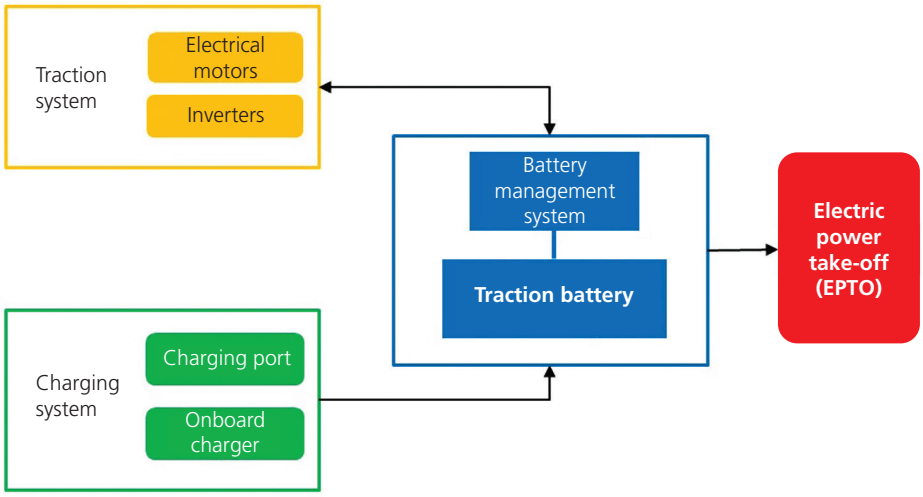


Figure 2: Generic BEV system overview

The batteries provide energy for most of the systems on the BEV. They are typically charged from charging stations using direct current (d.c.) (typically 200 V to 600 V – fast charging) or alternating current (a.c.) (typically 110 V or 240 V – slow charging) via a cable connected to a charging port. The batteries can typically operate in a variety of charge states and environments; however, the long- and short-term performance of the batteries may be impacted by a number of factors, including temperature, altitude, humidity and charge cycles. The batteries may also be charged by the regenerative braking system fitted to a vehicle. The electric power take-off (EPTO) system provides power from the batteries for external systems, such as the fuel delivery system.

3.1.2 Generic fuel delivery system

This hazard analysis has assumed that the fuel delivery system used on BEVs will be broadly similar to that used for ICEVs.

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Two types of delivery system are considered:

– fuel delivery via tanker operations (fuel stored in tanks at fuel depot before being transferred into tank on vehicle – at aircraft fuel is delivered directly from this tank into the aircraft), and
– fuel delivery via hydrant operations (fuel stored centrally in commercial airport infrastructure – typically underground – and delivered via the hydrant vehicle).

Figure 3 shows a simplified overview of a generic fuel delivery system, showing key components and systems.

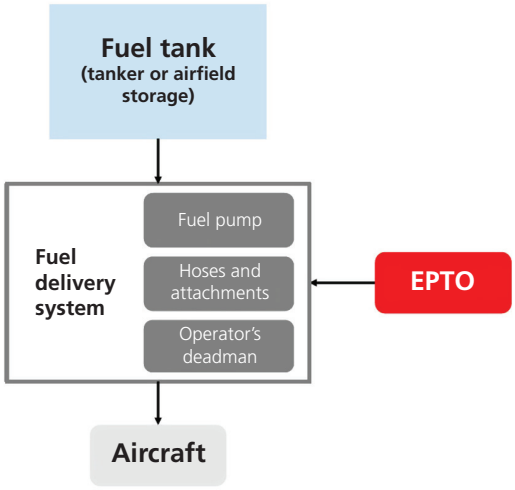


Figure 3: Generic fuel delivery system

A detailed analysis of the fuel delivery system has not been studied as part of this hazard analysis, as it is assumed to be broadly similar to that used on an ICEV. The notable exception is that the power from the EPTO is traction battery sourced, rather than via conventional power sources.

3.1.3 BEV fuel handling operations stakeholders

The stakeholders responsible for fuel handling operations at commercial airports typically include:

– Fuel vehicle operatives who are responsible for driving and operating the fuel handling vehicle, including fuel delivery to the aircraft and the vehicle tank.
– Fuel vehicle maintenance personnel who are responsible for the maintenance of the fuel handling vehicle.
– Aircrew (pilots) responsible for specifying and communicating aircraft fuel weight requirements to the operative.
– Air traffic control (ATC) responsible for controlling the movement of vehicles within controlled areas of the commercial airport, such as taxiways and controlled areas of the apron.

The following stakeholders may also interact with fuel handling operations:

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- Ground service personnel: other personnel working around the aircraft on the stand, such as baggage handlers, customer services, dispatchers, catering staff, etc.
- Airfield operations: personnel responsible for airfield operations.
- Airfield security: personnel responsible for ensuring the integrity of airfield security.
- Emergency services personnel: personnel responsible for responding in an emergency scenario, includes both airfield and local fire, police and ambulance services.

3.2 GENERIC SCENARIO

To assist in developing the generic hazard register, a generic scenario for fuel handling was developed, which has the potential to result in the worst-case consequences. For each scope item, a justification for inclusion is shown:

- A busy commercial airport, with many aircraft on stands and multiple vehicle and aircraft movements simultaneously:
  - Aircraft parked on adjacent stands may provide an escalation to a whole commercial airport incident, and multiple vehicles may decrease the efficacy of emergency response.
- Day or night, in all visibilities:
  - Local variations in traffic flows during the day or night, and human considerations around fatigue and shift management, may cause variance in risk across a 24-hour working period.
- Extremes of weather, including snow/ice, thunderstorms and heat:
  - Consideration of a variety of weather events captures hazards associated with differences in temperature and weather events such as flooding or lightning.
- Fuel operations via a tanker, which is assumed to have a capacity of 40 000 L and be half full:
  - A tanker is considered more hazardous than a hydrant system due to the stored energy of the fuel in the tank. The maximum capacity of standard fuel tankers is assumed to be approximately 40 000 L. A half-full tank will have fuel in a liquid and vapour phase; variations in the concentration of vapour may impact the flammability of the fuel and increase the likelihood of a fuel fire occurring. Hydrant service vehicles (HSVs) have not been directly considered in this scenario; however, it is assumed that the generic scenario will identify the majority of hazards that may be applicable to HSVs.
- The fuel is Jet A or Jet A-1 fuel:
  - Many commercial airports use one of these fuel grades. Jet A-1 fuel has an anti-static additive, which may reduce the likelihood of fuel ignition from static electricity; however, both fuel grades are considered to have a similar risk profile.
- Underwing pressure fuel delivery (two hoses) via an elevated platform (International Air Transport Association (IATA) service level 3):
  - This is the most commonly used method of fuel delivery. The fuel operative is potentially at greater risk of harm on a mechanically or hydraulically actuated platform, due to the increased time and difficulty in evacuating the fuel delivery area in an emergency scenario.
- Fuelling of a commercial passenger jet aircraft full of seated passengers:

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  - There is a greater hazard exposure to a commercial aircraft full of seated passengers. A higher passenger load is likely to increase the time required for a full evacuation of the aircraft.
- Lithium-ion (Li-ion) batteries provide the power for the BEV, including the traction and fuel delivery systems:
  - Li-ion batteries are the most commonly used in BEVs. As this hazard analysis specifically considers the deployment of battery systems, it is also assumed that the fuel delivery system is powered by batteries (either via EPTO from the BEV or a separate battery system).
- The BEV is a road vehicle class chassis fitted with fuel delivery equipment, either on a trailer or mounted on a cargo carrying chassis:
  - It is assumed that BEVs produced by vehicle OEMs will be road vehicle class chassis, with relevant public highway/road certification and a certain standard of crashworthiness. However, the integration of fuel delivery equipment is unlikely to meet the same certification standards, and it is therefore assumed that the vehicle is not certified for use on public highways/roads. Where possible, it is recommended that OEMs use road vehicle class chassis in their designs.

3.3 SCOPE

The scope of the hazard analysis was limited to the following:

- BEV movements:
  - around aircraft;
  - around airfield, and
  - to/from depot, which may include roads with public access.
- Fuelling and defuelling of aircraft:
  - including the connection and disconnection of fuel delivery equipment.
- Fuel delivery into the BEV at depot.
- BEV recharging (including rapid charging via high voltage (HV) connection), which may be inside or outside the fuel depot.
- BEV collisions:
  - with other vehicles;
  - with infrastructure;
  - with aircraft, and
  - includes rollover scenario.

The following were **not** considered in the scope of the hazard analysis:

- BEV maintenance;
- aircraft movements and operations;
- BEV movements on wider public highways/roads, and
- wilful wrongdoing.

3.4 ASSUMPTIONS

The following assumptions have been made as part of this analysis:

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- This is a generic analysis; a system-specific hazard analysis is required to be undertaken by designers and operatives wishing to deploy a BEV for aircraft fuel handling operations. The output of this analysis **does not** constitute a safety justification for the introduction of specific systems.
- Any system-specific hazard analysis is required to comply with the requirements of local or national legislative requirements, irrespective of the conclusions and recommendations of this analysis.
- The hazard analysis has only considered hazards that are unique to, or changed by, the deployment of a BEV for fuel handling activities. Any hazards that are unaffected by BEVs have not been considered further in this analysis. Any system-specific analysis should identify all reasonably foreseeable risks associated with the entire system and assess and analyse the risks associated with them to provide assurance that they are managed to a tolerable level.
- The results of this hazard analysis are not limited to a single Li-ion battery chemistry, acknowledging that a variety of Li-ion chemistries are deployed globally and that the rapid advancement of battery technology may result in specific analyses being obsolete in a short time period.
- It is assumed that operatives are suitably qualified, competent and experienced in operating the vehicles and fuel delivery equipment fitted to BEVs. Where required, relevant training shall be provided and revisited at defined intervals.
- It is assumed that communications between the vehicle operative and other stakeholders, i.e. ATC, are unchanged from an ICEV.
- The hazard analysis is limited to BEVs and has not considered other electric vehicles, such as hybrid electric vehicles (HEVs) or fuel cell electric vehicles (FCEVs).

3.5 DEFINITIONS

The study references a battery thermal runaway event across hazards. A battery thermal runaway event is defined as the process in which a battery generates heat within an individual cell but is unable to dissipate that heat, leading to a continuous rise in temperature.

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4 METHOD

This section presents an outline of the method for the project. An overview is illustrated in Figure 4, with the blue elements representing the tasks and deliverables within the project scope, and the grey element representing the intended use of the project outputs (outside of project scope).

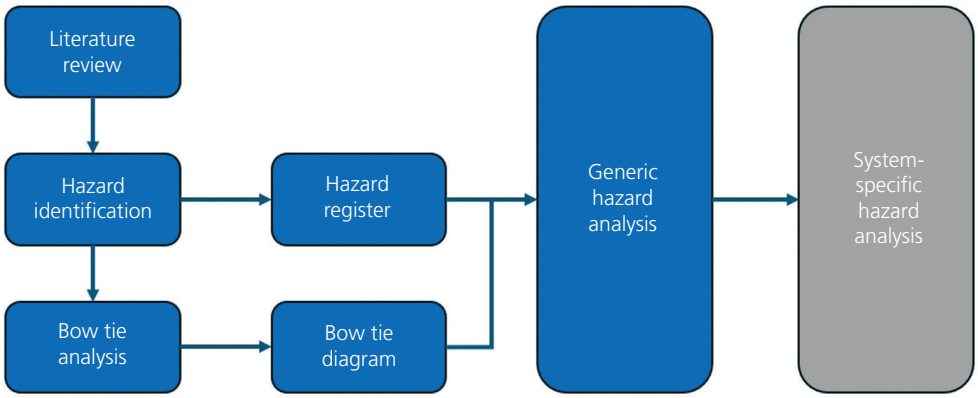


Figure 4: Method overview

The findings from each of the project tasks are presented separately in section 5.

4.1 LITERATURE REVIEW

A desktop review of standards, codes of practice and legislation was conducted. The objectives of the literature review were as follows:

1. Identify a non-exhaustive list of standards, codes of practice and legislation, including relevant clauses, to be referenced against hazards in the hazard register [1].
2. Identify relevant previous incidents and lessons learned to be considered during the HAZID workshop.

The scope of this included documentation relevant to the following:

- BEVs and battery technology;
- carriage and handling of dangerous goods, i.e. fuel, and
- electric ground service equipment (GSE).

The literature review also included a review of previous incidents, including those relating to the following:

- electric GSE;
- aircraft fuel handling operations, and
- BEV incidents, both related and unrelated to commercial airport operations.

The findings of the literature review are presented in 5.1.

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4.2 HAZARD IDENTIFICATION (HAZID)

A two-day HAZID workshop was facilitated remotely on 5th and 6th December 2024. The objectives of the workshop were as follows:

1. Identify all reasonably foreseeable hazards associated with the generic deployment of BEVs for fuel handling operation activities at commercial airports.
2. For each hazard identified:
   a. identify causes and worst-case consequences;
   b. identify any preventative or mitigative safeguards, and
   c. rank the severity of consequences and likelihood of the hazardous event consequence occurring.
3. Where appropriate, raise actions for further analysis required as part of the project or for future workstreams.

A briefing note [3] was produced for the HAZID workshop and was circulated to attendees one week prior to the workshop.

4.2.1 Pre-HAZID workshop meeting

For efficiency during the workshop, a pre-workshop meeting was held with workshop attendees, with the following agenda items:

– present an overview of the methodology;
– allow for feedback and questions on the methodology, and
– validate the list of fuel handling process activities.

4.2.2 HAZID workshop preparation

Due to the generic nature of the hazard analysis, the workshop approach was to consider ‘a day in the life of’ a BEV. Prior to the workshop, the Risktec team pre-populated the HAZID worksheet with a list of expected hazards, causes, consequences and safeguards associated with the fuel handling process activities shown in Table 1.

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Table 1: Fuel handling process activities

Type	Activity	Cycle
Normal day	Startup	Start of shift
	Drive to fuel farm	
	Loading of tanker	
	Drive to aircraft and park on stand	Repeated loading cycle
	Connection to aircraft – including setting up exclusion zone, connecting hoses and bonding to aircraft (noting some countries requiring earthing)	
	Fuelling process	
	Disconnection from aircraft	
	Drive to fuel farm	
	Drive to charging area and connect charger	In shift charging
	Charging (d.c./rapid) – during fuel loading	
	Loading of tanker at end of day	End of shift
	Drive to parking area	
	Overnight charging (a.c./slow)	
Special	Defuel plane	Any
	Unloading of tanker	
	Airport emergency scenario (unrelated to fuelling)	
	Electrical storm warning	

The pre-population exercise used the guide words defined in Annex D. These guide words were developed from different sources, including ISO 12100 [4] and ISO 17776 [5] and Risktec's previous experience. The guide words were used as the foundation to promote discussion and were expanded during the workshop to capture additional hazards.

4.2.3 HAZID workshop

The workshop discussion was led by the chairperson, who ensured that the workshop was discussed in a thorough and systematic manner and encouraged the team to think creatively and laterally.

The workshop team were led through the pre-populated worksheet and were asked to consider how the application of BEVs impacts each hazard when compared to conventionally powered vehicles. This included the following:

– additional/new causes due to BEVs;
– changes in the severity of consequences due to BEVs or their likelihood, and
– changes to safeguards on BEVs.

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4.2.4 Risk ranking

Due to time constraints in the workshop, the severity and likelihood of each hazard were not assessed. When processing the workshop notes, the severity and likelihood were ranked using the risk assessment matrix (RAM) shown in Annex E, as well as the outputs of the literature review and Risktec's previous experience across industries. The RAM was developed from Risktec's previous experience and in line with previous EI project RAMs.

4.2.5 HAZID attendance

The workshop included the following areas of expertise:

– aircraft operators;
– aircraft/airframe OEM;
– battery and BEV powertrain specialist;
– fuelling system manufacturer/designer;
– EV charging and equipment manufacturer/designer;
– airport fire and rescue specialist;
– fuel depot designer/operator;
– vehicle designer/operator, and
– fuelling specialist.

A list of workshop attendees is presented in Annex C.

4.2.6 Hazard register

Following the workshop, the worksheet and notes were processed into a draft hazard register [1], which was circulated to attendees and stakeholders for review. Review included the hazards identified as well as the risk ranking added after the workshop. Comments were incorporated into the hazard register.

As a number of stakeholders and disciplines were not able to attend the workshop, a series of small review sessions were facilitated, following which further updates to the hazard register were completed.

Further details on the hazard register can be found in 5.2.

The generic hazard register can be used as an input to the system-specific approach to management of risks and hazards; see Figure 1.

4.3 BOW TIE ANALYSIS

Following the production of the hazard register [1], the significant accident hazards (SAHs) – sometimes referred to as major accident hazards (MAHs) – were identified. An SAH is defined as a hazard having the potential to lead to fatalities, that is having a consequence ranking of 'major' (1–3 fatalities) or greater.

Using the outputs of the hazard register [1], a bow tie diagram was drafted for each of the SAHs.

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The objectives of the bow tie analysis were as follows:

- Review and validate threats and consequences of the hazards contained within the hazard register.
- Review and validate the barriers for each threat and consequence line.
- Where appropriate, make recommendations for further barriers and safeguards to support a generic safety justification for the deployment of BEVs for aircraft refuelling.

A briefing note [3] was produced for the bow tie workshop and was circulated to attendees one week prior to the workshop.

The generic bow tie diagrams can be used as an input to the system-specific approach to management of risks and hazards; see Figure 1.

4.3.1 Bow tie overview

A bow tie diagram is a graphical risk analysis technique, allowing for a structured approach to identifying what causes may result in an unwanted event and how this, in turn, could ultimately lead to adverse impacts. An example bow tie diagram structure is shown in Figure 5. Definitions for the key elements of the bow tie structure depicted in Figure 5 are provided in Table 2.

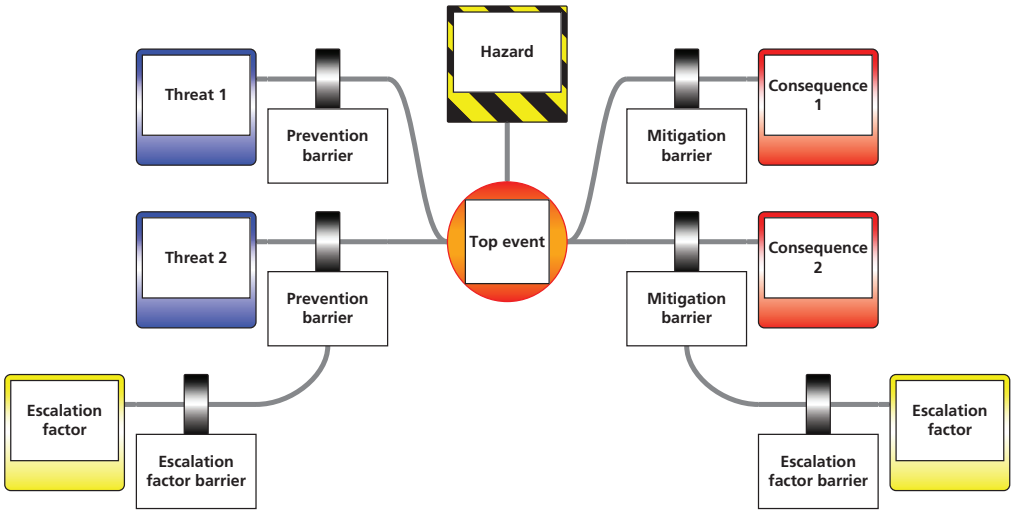


Figure 5: Bow tie diagram structure

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Table 2: Bow tie definitions

Term	Definition
Hazard	Something that has the potential to cause harm to something of concern
Top event	The 'release' of the hazard. The initial consequence that occurs when control of the hazard is lost. Also known as the 'zero consequence event'
Threat	Causes of loss of control of the hazard, which can lead to the top event
Consequence	An event or chain of events that result from the release of a hazard, i.e. what happens when the top event progresses
Prevention control measures (barriers)	Prevention controls are protective measures put in place to prevent threats from releasing a hazard. Prevention controls can be engineered/hardware such as a physical barrier or piece of equipment, limits on operations or actions carried out by people usually in accordance with procedures. However barriers are implemented, they should be effective, independent and auditable
Recovery measures (barriers)	Mitigation measures are the technical, operational and organisational measures that limit the chain of consequences arising from a top event. However barriers are implemented, they should be effective, independent and auditable
Degradation/ escalation factor	Specific conditions that can result in the failure or impairment (reduction in effectiveness) of a prevention or mitigation barrier. These in turn may be prevented or mitigated by degradation factor controls
Degradation/ escalation controls	Degradation controls contribute to maintaining barrier effectiveness by preventing degradation of a barrier. Degradation controls are themselves barriers against the realisation of a degradation factor; however, they may not always meet the criteria of a barrier (effective, independent, auditable)

4.3.2 Bow tie workshop

A bow tie workshop was facilitated on 24th January 2025, to review and validate the draft bowties. During the bow tie workshop, the chairperson led the workshop through a review of the bow tie diagrams and further developed them using the following method:

- review threats and consequences, and
- review the barriers for each threat and consequence line, in turn, to:
  - agree and develop barrier text;
  - identify degradation/escalation factors for barriers where specific conditions are known, and
  - put actions in place for any identified gaps.

Following the workshop, the draft bow tie diagrams [2] were circulated to attendees and stakeholders for review. Review comments were incorporated into the bow tie diagrams, and changes to the hazard register [1] were made accordingly.

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5 FINDINGS

5.1 LITERATURE REVIEW

5.1.1 Standards and guidance

The standards and guidance section, Annex G, presents a summary of standards and guidance identified that are applicable to aviation fuelling or electric vehicles. This is a non-exhaustive review intended to support the development of the generic hazard register, with standards linked to applicable safeguards.

A full literature review is recommended to be carried out as part of the project specification for a BEV-powered refuelling system. This would develop the initial list presented within Annex G to all relevant guidelines and standards applicable to the systems, sub-systems and technologies in question.

5.1.2 Previous incidents

Due to the high-level scope of the project, the generic hazard analysis has not considered the difference in likelihood of incidents between BEVs and ICEVs. However, as an input to the workshop, research was undertaken to understand common causes of incidents involving fuel handling systems, electric GSE and BEVs.

A total of 21 incident reports were studied, in the following high-level categories:

– aircraft fuel handling vehicle – non-BEV (13 incidents), and
– BEV – no airfield-specific application (eight incidents).

These incidents were considered during the preparation and facilitation of the HAZID workshop and during processing into the generic hazard register.

An overview of incidents, causes and lessons learned is presented in Annex F.

5.2 GENERIC HAZARD REGISTER

Following the HAZID workshop, the HAZID worksheet was processed into a generic hazard register [1]. A description of the hazard register is presented in Table 3.

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Table 3: Hazard register descriptions

Column name		Description	
ID		Unique hazard identifier	
Top level event/hazard		Top level event, used to categorise similar hazards	
Hazard/threat		Source of harm or situation with potential for harm	
Cause		Causal factors	
Consequence		Consequences of a hazard include the development of a hazardous scenario up to worst-case consequence	
BEV differences to ICEV		Used to highlight BEV differences to ICEV	
Pre-mitigation risk ranking	Severity	Risk ranking prior to implementation of identified safeguards/ barriers	Severity of hazard – RAM used to score based on worst-case consequence
	Likelihood		Likelihood of hazardous scenario occurring – score justified in comments column
	Risk		Risk = severity × likelihood
Safeguards		Safeguards that may prevent or mitigate the consequences of a hazard (note: acronyms in Table 5)	
Applicable standards		Standards that may be applicable to design or hazard	
Post-mitigation risk ranking		Post-mitigation risk ranking has been shown as a guide but has not been assessed in detail as the hazards and safeguards are high level and not design specific. This column requires development during system-specific assessments to be undertaken by designers and operators	
Recommendations/actions		Recommendations/actions identified in the workshop	
Comments		Comments, including a justification of pre-mitigation likelihood score	

5.2.1 Hazard types

The HAZID workshop identified a total of 58 hazards, which included the following types of hazards:

– Hazards that are unique to BEVs.
– Hazards that are common to both ICEVs and BEVs, but where the introduction of BEVs changes the risk profile.
– Hazards that are unchanged by the introduction of BEVs, i.e. are common between ICEVs and BEVs.

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The hazards have been categorised into high-level hazard groups, as shown in Table 4.

Table 4: Hazard groups

Hazard group		Description
H-1	Battery fire	15 hazards/threats Hazards that may lead to battery fire and development of the consequences of battery fire
H-2	HV systems in conjunction with fuel spill/vapour collection	13 hazards/threats Unique hazards relating to a BEV with HV systems in proximity to aviation fuel
H-3	HV – shock/ electrocution	4 hazards/threats A unique set of hazards around the HV system that are not present in ICEV systems, which do not typically have HV systems present
H-4	Loss of power	3 hazards/threats Hazards relating to loss of power that are unique to BEVs
H-5	Other	11 hazards/threats Hazards identified that are caused by the introduction of the BEV powertrain but do not fit in to categories H1 to H4
H-6	Not unique to BEV/ not impacted by BEV powertrain	12 hazards/threats Hazards identified during the workshop but are not affected by the integration of a BEV powertrain. These hazards were not risk ranked as they are considered to be outside the core scope of the study

The list of identified hazards is not considered exhaustive; a system-specific hazard analysis is required to be undertaken by designers and operators wishing to deploy a BEV for aircraft fuel handling operations to ensure the list of hazards is comprehensive.

5.2.2 Risk ranking

The risk associated with each hazard was ranked according to the methodology outlined in 4.2.4. Note that hazards that may lead to a fire and potential fatalities were categorised as follows:

– Where the fire is likely to be isolated, i.e. where the BEV is parked at a depot away from aircraft and other commercial airport infrastructure, the consequence was assumed to be a single fatality (severity category 4 – major).

– Where the fire is likely to spread, that is where the BEV is moving around the airfield or parked next to aircraft or other commercial airport infrastructure, the consequence was assumed to be multiple fatalities (severity category 5 – severe).

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Using this risk ranking, the following SAHs were identified where the severity category of hazards is 5 (severe) or 4 (major):

– H-1: battery fire;
– H-2: HV systems in conjunction with fuel spill/vapour collection, and
– H-3: HV – shock/electrocution.

5.3 GENERIC BOW TIE DIAGRAMS

The generic bow tie diagrams were developed for the SAHs as listed in 5.2.2.

The list of identified safeguards (barriers) is not considered exhaustive; a system-specific hazard analysis is required to be undertaken by designers and operators wishing to deploy a BEV for aircraft fuel handling operations to ensure the list of safeguards is comprehensive.

5.3.1 Barrier types

Table 5 outlines the barrier types used during the development of the bow ties. The barrier types have been assigned according to the stakeholder responsible for ensuring the barrier's implementation.

Table 5: Barrier types

Code	Definition	Description
OEM-V	BEV chassis/ powertrain OEM	Barriers that are the responsibility of the BEV chassis OEM (or, if applicable, powertrain integration OEM)
OEM-C	Charging infrastructure OEM	Barriers that are the responsibility of the charging infrastructure OEM. This includes the design and installation of the charging infrastructure
OEM-F	Fuel delivery system OEM	Barriers that are the responsibility of the BEV fuel delivery system OEM – assumed to be all equipment that is not related to the traction powertrain
OP-P	Operator procedures	Barriers that are the responsibility of the BEV operator and are related to procedures and processes for the operations of the BEV
OP-M	Operator maintenance	Barriers that are the responsibility of the BEV operator and are related to the maintenance of the BEV
AF	Airfield procedures	Barriers that are the responsibility of the airfield operations team
ES	Emergency service response	Barriers that are the responsibility of emergency services – this may include, but is not limited to, commercial airport and/or local fire services, commercial airport and/or local ambulance services and airfield emergency operations teams
AL	Airline procedures	Barriers that are the responsibility of the airlines – including procedures for aircrew and groundcrew and barriers that relate to interface with passengers

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5.3.2 Barrier categories

Table 6 outlines the barrier categories used during the development of the bow ties. The categories provide an indication of the effectiveness of each barrier, with passive safety devices (PSDs) considered the most effective to human response (HR) and maintenance (MNT) considered the least.

Table 6: Barrier categories

Code	Definition	Description
PSD	Passive safety device	Barriers that are safety devices that act inherently as a protection against the threat, consequence or escalation factor
ASD	Active safety device	Barriers that are safety devices activated in response to certain parameters, to protect against the threat, consequence or escalation factor
HR	Human response	Barriers where a human response is required to ensure that the protection is activated
MNT	Maintenance	Barriers that are related to maintenance of equipment
DV	Development required	Barriers where the protection is currently not well understood or developed, and where further development is required

5.4 GENERIC SAFEGUARDS

The HAZID and bow tie workshops identified a number of generic safeguards to manage the risk associated with each hazard. These safeguards are included in the generic hazard register [1]. The generic safeguards represent examples of safeguards that may manage the risk of each hazard; the list is non-exhaustive, and a system-specific hazard analysis is required to consider safeguards specific to the system.

A number of areas for further development have been identified, which are outlined in 5.4.5. These have formed the basis of recommendations; see 6.2.

5.4.1 Training safeguards

As BEVs are an emerging technology, operatives are unlikely to have specific knowledge on systems and potential hazards. Many generic safeguards include reference to human responses that will require specific training on BEVs. These include those listed in Table 7, which form the basis of recommendation 2. Note that many of these training recommendations may already exist for ICEVs but require adaptation for the introduction of BEVs.

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Table 7: Training safeguards

Hazard ref.	Safeguard
H-1	OP-P: all personnel are trained to recognise signs of a thermal runaway event
H-1	OP-P: all personnel trained in awareness of hazards associated with battery fires, such as: – toxic gas release, and – jet torch, which may release through battery vents or damaged battery boxes To ensure that personnel position themselves away from potentially hazardous areas
H-1	OP-P: operatives trained in appropriate emergency response for battery fires or over-temperature (i.e. vehicle shut down, removal from fuelling areas, evacuation from vehicle vicinity)
H-1.04	OP-P: operative trained to have awareness of collision hazards that may impact the batteries, while driving in areas not controlled by ATC
H-1.06	OP-P: operatives trained in different handling characteristics of BEV, e.g. greater rate of acceleration, to prevent collisions
H-1.06	OP-P: operatives trained in procedures to respond when an early warning from the battery is detected due to over-temperature detection
H-1.06	OP-P: operative training includes interlock override location and operation specific to BEVs
H-1.07	OP-P: operative trained to have awareness of flooding hazards that may impact batteries in areas not controlled by ATC
H-1.11	OP-P: operatives trained to have awareness when battery capacity is compromised (through loss of performance) and will report to maintenance teams
H-2.03	OP-P: operative training and process to minimise risk of spillage in proximity to charging equipment, e.g. not fuel sampling while charging
H-2.04	OP-P: operatives trained to check charging cover for damage
H-2.10	OP-P: training of operations personnel to ensure that EPTO interface is not damaged

5.4.2 Operative maintenance safeguards

The maintenance requirements for BEVs are expected to be different from those for ICEVs. The safeguards are related to the maintenance of BEVs and associated equipment can be found in Table 8 and form the basis of recommendation 4.

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Table 8: Operative maintenance safeguards

Hazard ref.	Safeguard
H-1.03	OP-M: testing of breather membrane functionality as per the manufacturer's procedures
H-1.04	OP-M: operatives follow SOPs for reporting of collisions/damage, and maintenance of batteries to be undertaken in line with SOPs
H-1.05	OP-M: inspection of batteries to be undertaken periodically to identify damage
H-1.11	OP-M: BEV to be used within operating constraints defined by OEM and serviced according to OEM service schedule
H-2.02	OP-M: maintenance procedures to ensure charging cable replacements are suitable and compatible according to OEM specifications
H-2.04	OP-M: operative maintenance to ensure that charging port covers are replaced when missing or damaged

5.4.3 Operative procedure safeguards

The operational requirements for BEVs are expected to be different from those for ICEVs. The safeguards related to the operation of BEVs and associated equipment are shown in Table 9 and form the basis of recommendation 5.

Table 9: Operative procedure safeguards

Hazard ref.	Safeguard
H-1.01	OP-P: procedures to monitor unmanned equipment overnight should be considered
H-1.04	OP-P: operatives follow standard operating procedures (SOPs) for reporting of collision/damage and maintenance of batteries to be undertaken in line with SOPs
H-1.04/ H-1.05	OP-P: operatives conduct a visual check on startup and following any impact during operations, to identify damage to vehicle, specifically around battery box
H-2.03	OP-P: spillage collection kit available in vicinity to charging equipment
H-3.02/ H-3.03	OP-P: startup checks and regular maintenance should include charger and charge cable condition

5.4.4 Emergency response plan safeguards

The emergency response plan (ERP) airport emergency plan (AEP) for the airfield will require an update prior to the deployment of BEVs. The safeguards in Table 10 are related to the ERP AEP and form the basis of recommendation 6.

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Table 10: Emergency response plan safeguards

Hazard ref.	Safeguard
H-1	ES: ERP AEP for areas with limited access includes response to BEV fire
H-1	OP-P: restrictions for parking of BEVs where emergency response access is limited – identified through commercial airport and BEV-specific risk assessments
H-1	ES: public fire services called to fight the escalated incident so as not to affect the commercial airport operations in terms of rescue and firefighting services (RFFS)/airport rescue and firefighting (ARFF) cover – details contained within airport ERP
H-1.07	OP-P: recommissioning strategy for vehicles following flooding – included in ERP AEP (as well as likely weather events)
H-2	ES: emergency response/medical assistance to HV shock – to be documented in ERP AEP

5.4.5 Safeguards requiring further development

The safeguards that were identified as requiring specific further development during the workshops can be found in Table 11 and form the basis of recommendations 7–13.

Table 11: Safeguards requiring further development

Hazard ref.	Safeguard
H-1	AF: airfield environmental management plan includes expected response to battery fire event
H-1.06	OEM-V: additional early warnings from the BEV control system based on parameters that may not be considered relevant for general road applications, e.g. where a road vehicle may be acceptable to operate in a degraded condition, an aviation fuelling vehicle may be recalled for inspection/maintenance. This should include consideration of warning modalities, e.g. audible, visual, both and whether the operative will be able to see/hear those warnings and how the operator should respond to/acknowledge each warning
H-1.03/ H-2.07	OEM-V: design of battery/HV breather location should avoid likely spill areas to prevent accumulation in battery/HV spaces
H-1.03/ H-2.07	OEM-V: testing of battery/HV breather should assess the likelihood of flammable atmosphere accumulation in battery box/HV spaces
H-1.08	OP-P: BEV-specific response to risk of lightning strike to be developed further
H-2	OP-P: position of vehicle and its batteries to be considered when parking near aircraft to maximise separation distances while still allowing for fuelling
H-2.06	OEM-V: vehicle manufacturer should consider sealed fuse in design

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6 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The objectives of this project were as follows:

1. Drawing on experience from across the industry, identify hazards and consequences associated with a generic BEV for fuel handling operation activities at commercial airports.
2. Identify existing safeguards for the hazards identified in objective one.
3. Where gaps in safeguards are identified, provide recommendations for development.

The generic hazard analysis has identified a number of standards, codes of practice and legislation that are relevant to deployment of BEVs for commercial airport fuel handling operations; see 5.1.1 and Annex G.

The HAZID workshop identified 58 hazards, 46 of which are either considered unique to BEVs or where the risk profile is increased compared to an ICEV; this included the following SAHs:

– H-1: battery fire;
– H-2: HV systems in conjunction with fuel spill/vapour collection, and
– H-3: HV – shock/electrocution.

Twelve of the 58 hazards identified are unchanged by the deployment of BEVs – these were considered outside the scope of the generic hazard analysis and were not studied further. For each hazard, the causes, worst-case consequence and generic safeguards were developed and are included within the generic hazard register [1].

The bow tie analysis developed the three SAHs and associated safeguards further, which were an input for updates to the generic hazard register [1]. The output of the bow tie analysis was a set of generic bow tie diagrams for each SAH; see Annex B.

Following the final issue of the generic hazard register [1], a number of areas where further development of safeguards against generic hazards is required have been identified. These are included in the recommendations in 6.2.

Study objectives one and two were met through the generic hazard register and bow tie diagrams development. Objective three is met through the recommendations in 6.2.

Through meeting these objectives, the project has been able to:

– Provide an overview of the project scope, methodology and outcomes, for the generic hazard analysis of a BEV deployed for fuel handling operation activities at commercial airports.
– Provide information and guidance on a system-specific hazard analysis for a BEV deployed for fuel handling operation activities at commercial airports, to support designers and operators to develop their own system-specific safety justification.

The study has not defined the residual risk associated with the deployment of BEVs for fuel handling operations at commercial airports; however, the outputs can be used to conduct a system-specific hazard analysis to support a safety justification for the deployment of specific BEVs for fuel handling operations at specific commercial airports.

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6.2 RECOMMENDATIONS

Table 12 outlines the recommendations that have been raised from the findings of this project.

Table 12: Recommendations

Rec.	Description
1	Battery electric vehicle (BEV) operators, designers and owners should conduct a system-specific hazard analysis to demonstrate that all reasonably foreseeable hazards have been identified and are managed to an acceptable level The generic hazard register (Annex A) and the guide words used in the HAZID workshop (Annex D) may be used as a starting point for a system-specific hazard analysis
2	All stakeholders should develop a training programme for personnel, which should include, but is not limited to, the following elements: – recognising the signs of a battery thermal runaway event, and – awareness of hazards associated with battery fires, such as toxic gas release and its accumulation, to ensure that they position themselves away from them This programme should include periodic refresher training to reduce the occurrence of skills fade and complacency
3	Operators should develop a training programme for operatives, which should include, but is not limited to, the following elements: – procedures in response to an early warning from the battery indicating over-temperature detection during operation or charging; – drive away interlock override location and operation specific to BEVs; – awareness of collision hazards that may impact the batteries, while driving in areas not controlled by ATC; – awareness when battery capacity is compromised (through loss of performance) and reporting to maintenance teams; – appropriate emergency response for battery fires or over-temperature (i.e. vehicle shut down, removal from fuelling areas, evacuation from vehicle vicinity); – process to minimise risk of spillage in proximity to charging equipment, e.g. not fuel sampling while charging; – different handling characteristics of BEV, e.g. greater rate of acceleration, to prevent collisions, and – conduct checks of charging cover for damage, and ensuring that EPTO interface is not damaged prior to connection and to inspect cooling levels Note that many of these training recommendations may already exist for ICEVs but require adaptation for the introduction of BEVs

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Table 12: Recommendations (continued)

Rec.	Description
4	Operators should develop a maintenance programme, which includes, but is not limited to, the following elements: – maintenance of batteries to be undertaken in line with manufacturer procedures; – testing of breather membrane functionality as per the manufacturer's procedures; – inspection of batteries periodically to identify damage; – inspection of charging cables and ports periodically to identify damage; – operating constraints defined by OEM and serviced according to OEM service schedule; – awareness of the analysis of temperature data logs; – procedures to ensure charging cable replacements are suitable and compatible according to OEM specifications, and – ensuring that charging port covers are replaced when missing or damaged
5	Operators should develop an operating procedure that includes, but is not limited to, the following elements: – startup checks including charger and charge cable condition; – the checks required following any impact damage during operations; – SOPs for reporting of collision/damage; – procedures to monitor unmanned overnight equipment from the control room should be considered, including an audible alarm to be sounded on detection of charging fault. This should include consideration of extra safety distances between parked vehicles and a thermal detector, and – use of spillage kit in vicinity to charging equipment
6	The airfield ERP should be updated to include the following elements: – response to BEV fire incident; – BEV-specific response to risk of lightning strike; – recommissioning strategy for vehicles following flooding (as well as likely weather events); – access to areas with limited access includes response to BEV fire; – restrictions for parking of BEVs where emergency response access is limited – identified through commercial airport and BEV-specific risk assessments; – public fire services response to fight escalated incident so as not to affect the commercial airport operations in terms of RFFS/ARFF cover; – emergency response/medical assistance to HV shock, and – appropriate environmental response to battery fire
7	Vehicle OEMs should consider sealed fuses within BEV designs, in line with ECE R100 requirements where practicable
8	Vehicle OEMs should consider designing the battery/HV breather location to avoid likely spill areas to prevent accumulation in battery/HV spaces, in line with ECE R100 requirements where practicable
9	Vehicle OEMs should consider assessment of the likelihood of flammable atmosphere accumulation in battery box/HV spaces through the battery/HV breather membrane, in line with ECE R100 requirements where practicable

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Table 12: Recommendations (continued)

Rec.	Description
10	Vehicle OEMs should consider additional early warnings from the BEV control system based on parameters that may not be considered relevant for general road applications, e.g. where a road vehicle may be acceptable to operate in a degraded condition, an aviation fuelling vehicle may be recalled for inspection/ maintenance. This should include consideration of warning modalities, e.g. audible, visual, both and whether the operative will be able to see/hear those warnings and how the operator should respond to/acknowledge each warning
11	Fuel delivery system/vehicle OEMs should consider the required spacing and protection between batteries and fuel storage systems
12	Operators should consider the position of the vehicle and its batteries when parking near aircraft to maximise separation distances while still allowing for fuelling
13	Airfield operators should ensure that the airfield environmental management plan includes expected response to battery fire event
14	When developing new procedures for BEVs, operators should ensure harmonisation with ICAO standards where practicable
15	Vehicle OEMs should include guidance provided in ISO 17840, Parts 1, 2, 3 and 4 to protect first and second responders and to provide them with critical emergency response for each make and model of BEV. This should include rescue sheets as per the emergency response guide template and propulsion energy design identification for all sides of each vehicle

6.3 NEXT STEPS

It is recommended that BEV designers and operators use the outputs of this project (generic hazard register, bow tie diagrams and recommendations) to conduct a system-specific hazard analysis to support a safety justification for the deployment of BEVs for fuel handling operations. Further details of the recommended process can be found in 2.2.

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ANNEXES
ANNEX A
GENERIC HAZARD REGISTER

						Risk					Risk				
ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-1	Battery fire														
H-1.01	Battery fire	Charging of BEV (a.c.or d.c.)	Charging (d.c. or a.c.) raises temperature of battery increasing likelihood of battery fire. May be escalated by the use of incompatible charging equipment, including unsuitable fast electricity chargers	May increase likelihood of thermal runaway Battery fire Leading to single fatality Location is charging station; therefore may shut down airfield but unlikely to cause major infrastructure damage or aircraft damage	EV not totally isolated while parked like an ICEV would be via 24 V isolation switch Heat during charging cycle may make HV components more appealing to wildlife	4	2	8	OEM-V: vehicle designed to applicable codes and standards, to prevent over-temperature of battery OEM-C: charging equipment designed to applicable codes and standards OEM-V: battery management system manages battery health during charging and shuts down charging if key parameters are out of specification OP-P: procedures to monitor unmanned overnight equipment from the control room should be considered, including an audible alarm to be sounded on detection of charging fault. This should include consideration of extra safety distances between parked vehicles and a thermal detector AF: d.c. fast-charging permits and zoning considerations, such as sunlight accessibility, ground stability, and flood susceptibility	NFPA 407 2027 edition Chapter 9 will provide specific guidance for Electric Fuel Service Vehicles – including guidance on distance of charging locations from fuel dispensing/ storage facilities and aircraft parking IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	1	4		d.c. rapid charging adds more temperature to battery compared to a.c. slower charging Historically low frequency of BEV battery fire during charging, therefore likelihood low
H-1.02	Battery fire	High state of charge (SOC)	High state of charge can increase likelihood and severity of thermal runaway	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to EV	5	1	5	OEM-V: vehicle designed to applicable codes and standards, to prevent high SOC causing thermal runaway of battery OEM-V: batteries used within OEM specifications would be expected to have negligible increase in risk due to SOC OEM-V: battery management system manages battery health during charging and shuts down charging if key parameters are out of specification	See H-1.03 for battery standards	5	1	5		Vehicle expected to be designed to operate up to 100 % SOC therefore very unlikely to occur

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						Risk					Risk				
ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-1	**Battery fire**														
H-1.03	Battery fire	Flammable atmosphere accumulation in battery/HV spaces	Environmental membrane (for slow gas exchange between battery/HV equipment and environment) allows flammable atmosphere ingress,e.g. via thermal cycling air movement following fuel spill in vicinity of vent	Flammable atmosphere in battery/HV space Explosion leading to battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to EV	5	3	15	AF: major fuel spills are reported to ATC and vehicles are diverted away from these areas OEM-V: design of battery/HV breather location should avoid likely spill areas to prevent accumulation in battery/HV spaces OEM-F: design of fuel vents away from areas where flammable gases or vapours may ingress OP-M: inspection and testing of breather membrane functionality as per manufacturer's procedures	UL 1642 *Lithium batteries*	5	2	10	Further development of design of battery/ HV breather location is required by OEMs	Common design feature across majority of batteries/BEV powertrain, likelihood based on potential for fuel spill/vapour to interact with breather
H-1.04	Battery fire	Mechanical damage/ shock to battery	Collision and general damage accumulates during airport operations, e.g. due to collisions with: – luggage cart; – pushback tug; – aircraft; – jet bridge, and – any vehicle with a towbar	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Mechanical damage expected to be the same as for conventional vehicles but damage to batteries considered more hazardous than damage to ICEV	5	5	25	OEM-V: vehicle designed to applicable codes and standards, to prevent mechanical damage to battery or HV system during collisions OEM-V: battery location and protection measures include consideration of collision with airport specific vehicles and infrastructure OEM-V: early warning to operative for battery issues, to enable removal of vehicle to a safe location. e.g. battery error or battery temperature AF: ATC prevents major collisions on taxiways etc. OP-P: driver training and fatigue management to reduce likelihood of collisions OP-P: operatives conduct a visual check on startup and following any impact during operations, to identify damage to vehicle, specifically around battery box OP-P: operative procedures in response to an early warning from the battery indicating over-temperature detection during operation or charging OP-M: operatives follow SOPs for reporting of collision damage and maintenance of batteries to be undertaken in line with SOPs OP-P: operatives trained in different handling characteristics, e.g. greater rate of acceleration, to prevent collisions	ECE R100 Rev.3 – 6.2 Vibration test – 6.4 Mechanical impact – Annex 9C – Mechanical loading including G shock EI 1540 6th edition – 6.2.3 Electric powertrains See H-1.03 for battery standards	5	2	10		Pre-mitigation likelihood of mechanical damage during normal operations discussed as high (probable) in workshop

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						Risk					Risk				
ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-1	Battery fire														
H-1.05	Battery fire	Mechanical damage/shock to battery	Long-term vibrations, including from pumping equipment Road speed control measures	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Mechanical damage expected to be the same as for conventional vehicles but damage to batteries considered more hazardous than damage to ICEV	5	4	20	OEM-V: ehicle designed to applicable codes and standards, to prevent mechanical damage to battery of HV systems from vibrations OEM-V: airport road conditions, including speed control measures, are within load case for a road class chassis OEM-F: shock and vibration load cases considered when the fuelling equipment is integrated OP-P: operatives conduct a visual check on startup and following any impact during operations, to identify damage to vehicle, specifically around battery box OP-M: inspection of batteries to be undertaken periodically to identify damage OEM-F: alarms or automatic shutdown sensors for abnormal vibrations in pumping equipment	ECE R100 Rev.3 – 6.2 Vibration test – 6.4 Mechanical impact – Annex 9C – Mechanical loading including G shock IEC 62660-2:2018 *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing* See H-1.03 for battery standards	5	2	10		Pre-mitigation likelihood of vibrations is high due to daily use; however, airport discussed as a less harsh environment than normal road environment therefore pre-mitigation ranking given as occasional

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						Risk					Risk				
ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-1	Battery fire														
H-1.06	Battery fire	High ambient temperature/ humidity	Environmental conditions and thermal emissions from hot tarmac/concrete High humidity	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Environmental conditions expected to be the same as for conventional vehicles but damage to batteries considered more hazardous than damage to ICEV	5	5	25	OEM-V: vehicle designed to applicable codes and standards – specific to operational environment (and associated temperature ranges) OEM-V: battery management system shuts down batteries on detection of over-temperature OEM-V: early warning to operative for battery issues, to enable removal of vehicle to a safe location, e.g. battery error or battery temperature AF: d.c. fast-charging permits and zoning considerations, such as sunlight accessibility, ground stability, and flood susceptibility	See H-1.03 for battery standards	5	2	10		Depending on location high ambient temperature may occur regularly (probable)
H-1.07	Battery fire	Flooding	Coastal storm Heavy rain Driver error (attempt to drive through deep flood water)	Stranded vehicle Water in battery/HV areas leading to battery fault and battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Exposure to salt water may increase likelihood of thermal runaway	5	4	20	OEM-V: vehicle manufacturer includes wading depth in vehicle specification OEM-C: vehicle parking and charging points located above predicted flood water levels OP-P: recomissioing strategy for vehicles following flooding – included in ERP AEP (as well as likely weather events) AF: ATC management of vehicles during flood events AF: d.c. fast-charging permits and zoning considerations, such as sunlight accessibility, ground stability, and flood susceptibility	See H-1.03 for battery standards	5	2	10		Investigate research on salt water exposure to the batteries Depending on location flooding may occur on a semi-regular basis (occasional)

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						Risk					Risk				
ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-1	**Battery fire**														
H-1.08	Battery fire	Electrical storm	Electrical storm leading to lightning strike on vehicle	EV powertrain damage – stranded vehicle Lightning damage leading to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	No identified difference between likelihood of lightning strike on BEV/ ICEV Lightning strike on BEV powertrain not tested, consequence not confirmed	5	1	5	OEM-V: vehicle designed to applicable codes and standards – isolation of battery system from other vehicle components AF: airport has lightning detection and alarm/warning system	See H-1.03 for battery standards	5	1	5	To confirm with vehicle OEM, effects of lightning on BEV on charging and differences from ICEV	Likelihood of lightning strike considered very low, no operational experience of fuel tankers having been hit by lightning identified
H-1.09	Battery fire	External fire	External fire (jet fuel or other material) propagates to BEV battery	Battery thermal runaway Battery fire Potential for fire spread to et fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	External fires would impact ICEV; however, consequences of fire propagating to battery expected to be different	5	2	10	OEM-V: vehicle designed to applicable codes and standards – battery enclosure passive protection OEM-V: battery protection systems (including battery management system) OEM-V: vehicle designed to applicable codes and standards, to place any live electrical components outside hazardous area zones (e.g. ATEX) OEM-V: permanently energised electrical equipment that may be used in a hazardous area zone (e.g. ATEX) appropriately rated OP-P: operative training includes interlock override location and operation ES: tow points on front and rear of vehicle to allow emergency services to remove the vehicle to a safe location in the event of a fire	ECE R100 Rev.3 – 6.5 Fire resistance – includes a test spec. and requirements	5	2	10		Likelihood improbable due to low frequency of fires at airport
H-1.10	Battery fire	Precursors to battery fire not acted on	Operative wearing ear defenders, working fuelling process, does not see battery warning	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Working conditions for operatives expected to be unchanged regardless of vehicle type; however, faults with battery may not give as many visible clues	5	3	15	OP-P: all personnel are trained to recognise signs of a thermal runaway event OP-P: operatives trained in appropriate emergency response for battery fires or over-temperature (i.e. vehicle shut down, removal from fuelling areas, evacuation from vehicle vicinity) OEM-V: alarm system for battery fire precursor includes means of identifying alarm to operatives while they are wearing PPE and working on the fuelling process OEM-V: early warning to operative for battery issues		5	2	10		Pre-mitigation likelihood based on subjective likelihood that operative may not see warnings of fire starting

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						Risk					Risk				
ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-1	Battery fire														
H-1.11	Battery fire	Battery ageing	Battery degrades as it ages, due to thermal and charge cycles, increasing likelihood of failure and thermal runaway	Battery thermal runaway Battery fire Potential for fire spread to jet fuel tank. Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to EV	5	3	15	OEM-V: battery management system manages battery health and shuts down if key parameters are out of specification OP-M: BEV to be used within operating constraints defined by OEM and serviced according to OEM service schedule OP-P: operatives will be trained to have awareness that battery capacity is compromised (through loss of performance) and will report to maintenance teams	See H-1.03 for battery standards	5	2	10		Pre-mitigation likelihood assumes ageing will happen through the life of the vehicle
H-1.12	Battery fire	Battery fire toxic gas/ vapour	Battery fire (above causes) releases toxic gas/ vapour (including HF/ HCN) initially released from battery vent valve and subsequently from wider fire	Respiratory injury/fatality – dose value low as release is in an open environment unless in vehicle cab Due to: – nearby personnel breathing fumes, and – fumes drawn in to building / aircraft air intake	Unique to BEV – unique compounds created during battery fire Toxic compounds are generally heavier than air and may look like water vapour/steam – compounds are unfamiliar to drivers of conventional vehicles	4	5	20	OEM-V: vehicle designed to applicable codes and standards – minimise exposure to toxic fumes in the event of a battery fire OEM-V: design of vents/burst discs to remove toxic gases away from personnel OEM-V: early warning to operatives for battery issues OP-P: all personnel trained in awareness of hazards associated with battery fires, such as toxic gas release, to ensure that they position themselves away from potential areas of toxic gas accumulation OP-P: all personnel are trained to recognise signs of a thermal runaway event	ECE R100 Rev.3 6.15.1 sets a requirement that following advance warning of a battery issue there shall be no hazardous situation in cab within five minutes See H-1.03 for battery standards	4	3	12		Pre-mitigation likelihood assumes a battery fire has already happened, likelihood is high as toxic fumes are expected to be present with a battery fire
H-1.13	Battery fire	Battery fire in area with limited access	Battery fire (above causes) in area with limited access, e.g. hangars, tunnels, narrow access road, gates with limited space between aircraft and terminal	Delayed or degraded emergency response Potential for fatalities and major damage to airfield/ aircraft, depending on location	Battery fire vs. diesel fuel fire (see other consequences of battery fire)	5	2	10	AF: airfield infrastructure integrator firefighting systems (e.g. in hangars, tunnels) ES: ERP AEP for areas with limited access includes response to BEV fire OP-P: restrictions for parking of BEVs where emergency response access is limited – identified through airport and BEV specific risk assessments		5	1	5		Pre-mitigation likelihood assumes a battery fire has already happened, likelihood based on subjective likelihood of battery fire starting in area with limited access

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						Risk					Risk				
ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-1	**Battery fire**														
H-1.14	Battery fire	Battery fire spread to jet fuel tank	Battery fire (above causes) escalates to whole vehicle fire (Class A fire) and spreads to jet fuel tank Due to thermal runaway of battery fire, and potential torch flame escaping battery containment	Potential for fatalities and major damage to airfield/ aircraft, depending on location	Battery fire difficult to extinguish when in thermal runaway Torch flame unique to batteries Operative has no ability to fight battery fire, ICEV fire can be fought with portable extinguisher	5	4	20	OEM-V: vehicle designed to applicable codes and standards, including shielding and firewalls between batteries and fuel system OEM-F: vehicle designed to applicable codes and standards, including shielding and firewalls between batteries and fuel system	NFPA 407 (2027) Chapter 9: – A.9.1.6.4.7 – battery fire spreading to jet fuel tank – A.9.1.2.1 – requirements of shielding between battery and fuel tank ISO 17840 *Road vehicles – Information for first and second responders* See H-1.03 for battery standards	5	3	15		If there is a jet fuel fire in the tank, the most likely scenario is for the fuel in the tank to absorb heat energy increasing vaporisation, while vapours at the top of the tank burn. This would likely lead to a tank rupture Pre-mitigation likelihood assumes a battery fire has already happened, likelihood based on subjective likelihood of battery fire spreading to jet fuel tank
H-1.15	Battery fire	Battery fire near aircraft	Battery fire (above causes) escalates to whole vehicle fire (Class A fire) and spreads to jet fuel tank and on to nearby aircraft Due to thermal runaway of ttery fire, and potential torch flame escaping battery containment	Potential for fatalities and major damage to airfield/ aircraft, depending on location	See above differences between BEV fire and ICEV	5	3	15	OEM-V: vehicle designed to applicable codes and standards, including shielding and firewalls between batteries and fuel system	14CFR856 See H-1.03 for battery standards	5	2	10		Aircraft are subject to burn through testing; however, older airframes have lower durability and none are tested for exposure to battery torch fire Pre-mitigation likelihood assumes a battery fire has already happened, likelihood based on subjective likelihood of battery fire spreading to nearby aircraft

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						Risk					Risk				
ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-2	HV systems														
H-2.01	HV systems – in conjunction with fuel spill/vapour collection	Charging equipment	Charge cable damage, e.g. due to: – mechanical damage; – long-term UV exposure; – damage from transportation on vehicle, and – vehicle drives off whilst connected to charging supply	Arcing of electrical supply, potentially leading to ignition source for flammable atmosphere Mechanical damage to vehicle and charging equipment – emergency shutdown of vehicle and disruption to airfield operations Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank. Location is charging station therefore may shut down airfield but unlikely to cause major infrastructure damage or aircraft damage	BEVs generally have interlock on charging connection – cannot drive off unless disconnected. Diesel fuel pumps may not have interlock to prevent driveaway; however, they are attended during fuelling process – BEVs are often left unattended while charging	4	4	16	OEM-V: vehicle designed to applicable codes and standards, to prevent mechanical damage to battery or HV system during collisions OEM-C: charging equipment designed to applicable codes and standards, to prevent mechanical damage to battery or HV system during collisions OEM-C: cable adequately protected from UV, water etc. during storage OEM-V: interlocks within BEV powertrain and charging equipment, to prevent driveaway while connected to charge cable OP-P: operatives conduct a visual check on startup and following any impact damage during operations and to ensure charging cable is disconnected OP-M: maintenance or replacement of charging cable following damage from drop or general usage	ECE R100 Rev.3. ADR *European agreement concerning the international carriage of dangerous goods by road* ISO 5474 *Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit* IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	2	8		EV OEMs do have control over charging cables so there may be compatibility issues Pre-mitigation likelihood assumes damage will occur to charge equipment at some point
H-2.02	HV systems – in conjunction with fuel spill/vapour collection	Charging equipment	Non-standard charging cable length – length of cable may cause inductance, which may overload breakers	Increased strength and duration of arcing, ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank. Location is charging station therefore may shut down airfield but unlikely to cause major infrastructure damage or aircraft damage	Unique to BEV – presence of charging equipment	4	3	12	OEM-C: charging equipment compatible with BEV powertrain according to OEM specifications OEM-C: charging equipment designed to applicable codes and standards, to prevent inductance OP-M: maintenance procedures to ensure charging cable replacements are suitable and compatible according to OEM specifications	NFPA 407 (2027) *Electric vehicle supply equipment shall comply with Article 625 of NFPA 70* IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	2	8		Pre-mitigation likelihood dependant on location and if different equipment and charge cable lengths are used

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ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-2	**HV systems**														
H-2.03	HV systems – in conjunction with fuel spill/vapour collection	Charger circuits	Fuel spill near charger unit	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Location is charging station therefore may shut down airfield but unlikely to cause major infrastructure damage or aircraft damage	Unique to BEV – charging equipment	4	2	8	OEM-C: design/location of charging unit to comply with hazardous area zones (e.g. ATEX) OEM-F: vehicle design to ensure that charging ports are well separated from refuelling equipment OP-P: design of charging location to direct fuel spills away from charging area OEM-C: isolation monitoring of charger unit OEM-C: isolation monitoring system architecture – charging equipment isolation monitoring takes priority and communicates this to vehicle system OEM-C: electrical isolation switch for charging equipment OP-P: operative training and process to minimise risk of spillage in proximity to charging equipment, e.g. not fuel sampling while charging	EI 1540 6th edition – 4.15.6 Electric vehicle charging facilities NFPA 407 (2027) 9.2.11. Fuelling or defuelling of an aircraft or aircraft fuel servicing tank vehicle shall not occur while connected to electric vehicle supply equipment NFPA 407 (2027) 9.2.11.2. Fuel shall not be transferred while an onboard BEV battery is being charged at electric vehicle supply equipment IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	2	8	Specific risk assesment to be carried out if charging is intended to take place during tanker loading	Pre-mitigation likelihood assumes charging away from tanker loading therefore fuel operations and spill unlikely Charging while loading is a more challenging and specific scenario that would require detailed risk assessment

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H-2	**HV systems**														
H-2.04	HV systems – in conjunction with fuel spill/vapour collection	Fuel in charger socket	Fuel spill in charger socket area, fuel ingress into charging socket It is foreseeable that an operative may miss fuel in socket area at the end of a shift as they are likely to be used to smell and fuel can look like water	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Location is charging station therefore may shut down airfield but unlikely to cause major infrastructure damage or aircraft damage	Unique to BEV – presence of charging socket	4	3	12	OEM-V: Charging port cover prevents fuel ingress into charging port OEM-V: Charging socket has drain to remove fuel from socket OP-P: Operatives trained to check charging cover for damage OP-M: operative maintenance to ensure that charging port covers are replaced when missing or damaged OEM-V: vehicle designed to applicable codes and standards, to ensure that tolerance of fit removes any fuel from pins when connecting charger OEM-F: vehicle designed to ensure separation between charging ports and fuelling equipment	Charge connector standards include: IEC 62196-2 (Type 2 a.c.) IEC 62196-3 (Type 2 d.c.) SAE 3400 (Tesla) SAE J1772 (Type 1) EI 1540 6th edition – 4.15.6 Electric vehicle charging facilities	4	2	8		Potentially a low likelihood if fuel can drain away – small film of jet fuel on connector pins but expected that connection is tight enough to not cause an issue
H-2.05	HV systems – in conjunction with fuel spill/vapour collection	HV system in vehicle or charger	Damage to battery box or HV cables, e.g. due to: – impact damage; – collision damage; – rodent/bird nests, and – water ingress	Arcing of electrical supply, potentially leading to ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Presence of HV potential in BEV – not present in ICEV	5	4	20	OEM-V: vehicle designed to applicable codes and standards, to prevent mechanical damage to battery or HV system during collisions OEM-V: isolation monitoring to detect degradation of insulation due to damage (e.g. rodents) OEM-V: battery management system manages battery health and shuts down charging if key parameters are out of specification OEM-V: galvanic isolation of HV system shuts down systems on detection of an error message OP-P: operatives conduct a visual check on startup and following any impact damage during operations OP-M: maintenance of battery box of HV cables following damage	IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	5	2	10		Pre-mitigation likelihood assumes damage may occur once a year
H-2.06	HV systems – in conjunction with fuel spill/vapour collection	Pyro fuse in vehicle	Pyro fuse or conventional thermoelectric fuse activation Small-scale explosion Significant arcing time (few ms)	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to BEV – ICEV does not have HV pyro fuse, may have LV pyro fuse depending on manufacturer	5	2	10	OEM-V: vehicle design should minimise likelihood of flammable atmosphere developing in proximity to fuse location OEM-V: vehicle manufacturer should consider sealed fuse in design		5	2	10		Pre-mitigation likelihood low as pyro fuse is only likely to activate in crash scenario

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H-2	**HV systems**														
H-2.07	HV systems – in conjunction with fuel spill/vapour collection	HV breakers in vehicle	HV breakers activation	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to BEV – ICEV does not have HV breakers, may have LV breakers depending on manufacturer	5	5	25	OEM-V: vehicle designed to applicable codes and standards – encapsulated/sealed breakers in design OEM-V: design of battery/HV breather location should avoid likely spill areas to prevent accumulation in battery/HV spaces OEM-V: testing of battery/HV breather should assess the likelihood of flammable atmosphere accumulation in battery box/HV spaces		5	2	10	Further development of design of battery/ HV breather location is required by OEMs	Pre-mitigation likelihood high as HV breakers are expected to operate regularly
H-2.08	HV systems – in conjunction with fuel spill/vapour collection	Fault in systems active after activation of isolation switch leading to sparking	Some systems active after activation of isolation switch, e.g. battery management/ cooling activation when not requested or anticipated	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	ICEV 24 V isolator activation leaves fewer electrical systems powered	5	5	25	OEM-V: vehicle designed to applicable codes and standards, to place any live electrical components outside hazardous area zones (e.g. ATEX) OEM-F: fuel integration design to be cognisant of hazardous area zones (e.g.ATEX) OEM-F: HV killswitch or de-energisation switch to be activated during fuelling. Any LV/HV systems that require energisation during fuelling must be appropriately designed for use in hazardous area zones (e.g. ATEX)	EI 1540 6th edition – 6.2.3 Electric powertrains	5	2	10		Pre-mitigation likelihood high as some battery control systems are anticipated to be always on
H-2.09	HV systems – in conjunction with fuel spill/vapour collection	Trailer power supply	Integration of trailer power supply with EV	HV sparking – electrocution Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to EV	5	3	15	OEM-F: vehicle designed to applicable codes and standards, in regards to EPTO – manufacturer specific	ISO 5474:2024 *Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit*	5	2	10		Pre-mitigation likelihood assumes occasional sparking from trailer power supply
H-2.10	HV systems – in conjunction with fuel spill/vapour collection	EPTO connector	Mating cycles for EPTO connector degrades connection leading to arcing	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to BEV – addition of EPTO	5	3	15	OEM-F: vehicle designed to applicable codes and standards, in regards to EPTO – manufacturer specific. Where possible, ensure the EPTO design is cognisant of hazardous area zones (e.g. ATEX) OP-P: training of personnel to ensure that EPTO interface is not damaged and to inspect cooling levels	ISO 5474:2024 *Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit*	5	2	10		Pre-mitigation likelihood assumes occasional mating cycle for EPTO connector

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H-2	**HV systems**														
H-2.11	HV systems – in conjunction with fuel spill/vapour collection	Hazardous area zones around vehicle	EV components not rated for use in hazardous areas zones (e.g. ATEX), e.g. during tanker loading connection, wing vents	Ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	ICEV also likely to have electrical components not rated for hazardous area zones (e.g. ATEX), however BEV may produce larger arcs in HV components	5	5	25	OEM-V: permanently energised electrical equipment that may be used in a hazardous area zone (e.g. ATEX) appropriately rated OP-P: electrical isolation activated when parked in hazardous area zone (e.g. ATEX) to minimise live electrical components	94/9/EC – ATEX ADR 2017 *European agreement concerning the international carriage of dangerous goods by road* ECE R105 *Motor vehicles and their trailers intended for the transport of dangerous goods by road* Directive 2008/68/ EC *Inland transport of dangerous goods*	5	2	10		Pre-mitigation likelihood assumes vehicle will regularly enter dangerous area zones (e.g. ATEX)
H-2.12	HV systems – in conjunction with fuel spill/vapour collection	Altitude	Operating at altitude	Increased strength and duration of arcing, ignition source for flammable atmosphere Potential to lead to battery thermal runaway Battery fire Potential for fire spread to jet fuel tank Potential for fatalities and major damage to airfield/ aircraft, depending on location	Unique to BEV – clearances distances (HV breakers, arcing) – at higher altitude arcing becomes more likely	5		0	OEM-V: vehicle OEM specifies maximum operational altitude		5		0		Daimler published maximum operational altitude for BEV 4 000 m No likelihood ranking as this is dependent on operating location and managed through use within specification
H-2.13	HV systems – in conjunction with fuel spill/vapour collection	Fire propagates to fuel tank or aircraft	See causes of fuel fire (H-2) – escalation of above hazards to fire on aircraft	Major injuries or multiple fatalities, including ground staff, aircrew and passengers	Causes of BEV and battery fire (see H-1 and H-2)	5	5	25	OEM-F: vehicle design includes appropriate separation (including firewall) of batteries and HV systems relative and jet fuel tanks OP-P: operatives trained in appropriate emergency response for fires or over-temperature (i.e. vehicle shut down, removal from fuelling areas, evacuation from vehicle vicinity) ES: emergency response to fight fire AL: airline/aircraft specific procedures for boarding of passengers whilst fuelling AL: airline/aircraft specific procedures for evacuation of aircraft on ramp		5	2	10		Pre-mitigation and post-mitigation likelihood as for highest ranked fire hazard

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ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-3	**HV – shock / electrocution**														
H-3.01	HV – shock/ electrocution	HV system	Damage to battery box or HV cables, e.g. due to: – impact damage; – rodent/bird nests, and – water ingress	Exposed HV, electrocution to: – vehicle operator, and – vehicle maintainer Potential for fatality of person exposed to HV	Unique to BEV – presence of HV potential in BEV	4	4	16	OEM-V: vehicle designed to applicable codes and standards, to prevent mechanical damage to battery or HV system during collisions OEM-V: isolation monitoring to detect degradation of insulation due to damage (e.g. rodents) OEM-V: emergency electric shut-off (EESO) on vehicle OEM-V: battery management system manages battery health and shuts down system if key parameters are out of specification OP-P: operatives conduct a visual check on startup and following any impact damage during operations OP-M: maintenance of batteries/HV system to be undertaken following collisions or damage OEM-V: equipotential bonding system	ECE R100 Rev.3: – 6.2 Vibration test – 6.4 Mechanical impact – Annex 9C – Mechanical loading including G shock NFPA 407 (2027) – 9.1.13.1 EESO – 9.1.13.1.1 Charging position – 9.1.13.1.2 EESO access – 9.1.13.1.3 Provision of EESO equipment – 9.1.13.1.4 Separation of EESO IEC 62660-2:2018 *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing*	4	2	8		Pre-mitigation likelihood assumes damage will occur to equipment at some point
H-3.02	HV – shock/ electrocution	Charging equipment	Damage to charging equipment, e.g. due to: – impact damage; – rodent/bird nests, and – water ingress	Exposed HV, electrocution to: – vehicle operator, and – vehicle maintainer Potential for fatality of person exposed to HV	Unique to BEV – presence of HV potential in EV Heat during charging cycle may make charging unit more appealing to wildlife	4	4	16	OEM-C: charging equipment designed to applicable codes and standards, including collision protection and durability requirements OEM-C: vehicle charging points located above predicted flood water levels OEM-C: isolation monitoring to detect degradation of insulation due to damage (e.g. rodents) OEM-V: emergency electric shut-off on charger OP-P: startup checks and regular maintenance should include charger and charge cable condition OP-M: maintenance of charging system to be undertaken following collisions or damage OEM-V: equipotential bonding system	EI 1540 6th edition – 4.15.6 Electric vehicle charging facilities NFPA 407 (2027): – 9.1.13.1 EESO – 9.1.13.1.1 Charging position – 9.1.13.1.2 EESO access – 9.1.13.1.3 Provision of EESO equipment – 9.1.13.1.4 Separation of EESO IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	2	8		Pre-mitigation likelihood assumes damage will occur to equipment at some point

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ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-3	**HV – shock / electrocution**														
H-3.03	HV – shock/ electrocution	Charging equipment	Charge cable damage, e.g. due to: – mechanical damage; – long-term UV exposure; – damage from transportation on vehicle; – vehicle drives off whilst connected to charging supply, and – operative trips and disconnects charger during charging	Exposed HV, electrocution to: – vehicle operator, and – vehicle maintainer Potential for fatality of person exposed to HV	Unique to BEV – fuel pump for ICEV will have unique hazards associated with it	4	4	16	OEM-C: charging equipment designed to applicable codes and standards, including collision protection and durability requirements OEM-C: interlocks prevent vehicle from being driven off whilst connected to charger OEM-C: isolation monitoring to detect degradation of insulation due to damage (e.g. rodents) OP-P: startup checks and regular maintenance include charger and charge cable condition OEM-V: emergency electric shut-off on charger OEM-V: equipotential bonding system OP-P: the charger and charging cable must be properly arranged to keep them safely clear of foot traffic while ensuring the vehicle can drive off without overstretching or tangling	EI 1540 6th edition – 4.15.6 Electric vehicle charging facilities NFPA 407 (2027): – 9.1.13.1 EESO – 9.1.13.1.1 Charging position – 9.1.13.1.2 EESO access – 9.1.13.1.3 Provision of EESO equipment – 9.1.13.1.4 Separation of EESO IEC 61851:2014 *Electric vehicle conductive charging system* IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 63110:2022 *Protocol for management of electric vehicles charging and discharging infrastructures* IEC 62196:2022 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	4	2	8		Pre-mitigation likelihood assumes damage will occur to equipment at some point
H-3.04	HV – shock/ electrocution	Electric fuel pump	Fuel pump back flow – acts as a generator	Electrical power supplied from fuel pump motor – system overload/exposed HV/ electrocution to: – vehicle operator, and – vehicle maintainer Potential for fatality of person exposed to HV	Unique to BEV – fuel pump backflow in ICEV will have unique hazards associated with it	4	2	8	OEM-F: fuel pump system electrical protections OEM-F: check valve in fuel pumping system prevents pump back flow OEM-F: refueller only: centrifugal pump that cannot be driven by back-flowing fuel OEM-F: refueller only: asynchronous motor that does not operate as a generator without external excitation OEM-F: refueller only: inverter that is protected against corresponding voltages OEM-V: equipotential bonding system	NFPA 407 (2027): – 9.1.13.1 EESO – 9.1.13.1.1 Charging position – 9.1.13.1.2 EESO access – 9.1.13.1.3 Provision of EESO equipment – 9.1.13.1.4 Separation of EESO	4	1	4		Considered low likelihood with safeguards as experienced few times in the industry. Safeguards change likelihood to very unlikely It is assumed that a HAZOP or similar study will be undertaken by OEMs to understand aspects of fuel flow around tanker and pipework and causes of failure

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ID	Top level event/ hazard	Hazard/threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-4	**Loss of power**														
H-4.01	Loss of power	Stranded BEV at startup (beginning of shift)	EV charge insufficient to start vehicle – vehicle not charged overnight/ failure of charging equipment/lack of use/storage/inactivity Electrical fault in BEV powertrain on startup	Unable to start vehicle, disruption to airfield operations	Specific to powertrain – differences around towing, also depends on damage Permanent magnet motors create voltage – potential hazards during towing (touch potential, electrocution, overheating – hot surfaces etc.). Damage to vehicle by towing incorrectly – similarity in ICEV vehicles that there are processes to follow Expected similar likelihood to ICEV	2	3	6	OP-P/AF: operatives and airfield procedures developed to include towing stranded BEV AF: recovery crews trained on BEV towing procedure OP-P: information on BEV response should be made public for each vehicle OP-P: updates on safety guidelines from OEMs communicated to first responders and airfields OEM-F: fuelling integration designer ensures that instructions of OEM (chassis) are not invalided by fuelling equipment integration		2	2	4		Pre-mitigation likelihood assumes remote likelihood of stranding at charge station
H-4.02	Loss of power	Stranded BEV while driving	Electrical fault in BEV powertrain while driving	Stranded vehicle, disruption to airfield operations	Unique to BEV – increased potential for HV, sparking or fire hazard due to BEV powertrain fault	3	3	9	OEM-F: OEM design and testing of HV and battery systems prevents/ mitigates faults OP-M: maintenance regime for BEV prevents electrical faults		3	2	6		Pre-mitigation likelihood assumes remote likelihood of BEV system loss of power while driving
H-4.03	Loss of power	Power drained	Fuelling pump drains battery	Stranded vehicle, partially fuelled aircraft disruption to airfield operations	Similar to ICEV running out of fuel during fuelling, but more likely due to limited battery capacity	3	4	12	OP-P: operative charges BEV when battery SOC is running low to prevent BEV system power loss during driving or fuelling OP-P: mandatory pre-fuelling check conducted by operative to confirm sufficient charge prior to commencing fuelling process OEM-F: EPTO protection will cut off supply of power to fuel system when battery is reduced to a pre-defined level, to allow vehicle to move off		3	3	9		Pre-mitigation likelihood assumes occasional (yearly) occurrence of complete battery power drain Fuel pump power requirement up to 70 kW: assume fuelling takes 15 min (up to 17,5 kWh battery capacity is required per fuelling cycle)

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ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-5	**Other**														
H-5.01	Other	Slip, trip and falls	Charge cable	Personnel injury	Unique to BEV – charge cable likely to be connected for longer duration than diesel fuel hose, including overnight	2	5	10	OP-P: operatives given training on safe work practices around vehicle	IEC 62893:2017 *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV*	2	4	8		Likelihood high as people may have to step over charge cables daily to access or inspect the vehicle
H-5.02	Other	Charge connector	Dropped charge connector	Foot injury Damage to charge cable (see damaged charge cable hazard H-2.01 and H-3.03)	Equivalent to dropped diesel fuel nozzle hazard	1	5	5	OEM-C: charge cable design and testing should include dropping and misuse	Charge connector standards include: IEC 62196-2 (Type 2 AC) IEC 62196-3 (Type 2 DC) SAE 3400 (Tesla) SAE J1772 (Type 1)	1	4	4		Likelihood high as charge connector is anticipated to be used daily
H-5.03	Other	EV throttle response	Increased acceleration/ response to throttle input	Increased likelihood of collision or rollover, leading to battery fire, or personnel injury	BEVs potentially have increased acceleration/ response to throttle input	3	2	6	OEM-V: throttle map/acceleration limiter gives throttle response similar to ICEV OP-P: training and familiarisation given to operative on new vehicles		3	2	6		Torque not high enough to cause tank rupture or damage Rapid acceleration does not increase likelihood of thermal runaway (normal operating scenario) Likelihood and severity based entirely on BEV design and performance specification, anticipated to be low if BEV is designed to replicate ICEV performance
H-5.04	Other	Vehicle collision with personnel	Multiple causes, e.g.: – personnel steps out in front of vehicle; – vehicle reverses over; personnel, and – quiet running	Equivalent to ICEV collision with personnel	EV sound difference – negligible if regulation followed EV powertrain response difference	3	3	9	OP-P: drivers of vehicles given sufficient training to react in time to sudden events on the road and around the airfield	Regulation (EU) No 540/2014 of the European Parliament and of the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems requires active noise system (AVAS)	3	2	6		Pre-mitigation likelihood assumes remote likelihood of collision with personnel
H-5.05	Other	Vehide rollover	Collision or driver error via turning at speed or on ramped surface	See HV sparking in proximity to jet fuel spill hazards	ICEV rollover is likely to result in diesel spill as well	5	3	15	OEM-V: lateral stability indicator system to vehicle cab fitted by vehicle OEM OP-P: vehicle limited to airfield speed limits, which reduces likelihood and severity of collisions	NFPA 414 – rollover threshold E/ECE/TRANS/505 *Concerning the adoption of universal conditions of approval and reciprocal recognition of approval for motor vehicle equipment and parts* – from 11/7/10 all new trailers over 10 t to be fitted with Electronic Stability Control (ESC)	5	2	10		Pre-mitigation likelihood assumes rollover may occur, anticipate similar likelihood to ICEV rollover
H-5.06	Other	EV regen braking	EV powertrain uses regen braking via motors on throttle lift-off Regen braking may be limited when battery SOC is high (nowhere for generated power to be stored) Regen braking system failure	Collision with person or infrastructure Insignificant difference in braking force over ICEV	On throttle lift-off: ICEV has engine braking EV has regen braking Deceleration response anticipated to be similar	3	3	9	OEM-V: torque controller blends friction and regen braking to give braking response similar to ICEV OEM-V: on regen system fault torque control uses 100 % friction braking OP-P: training and familiarisation given to operative on new vehicles OP-P: startup routines include brake test		3	2	6		Pre-mitigated likelihood low as braking systems are designed to stop a fully loaded vehicle from highway speeds therefore airport use case is likely to be within this bounding condition

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						Risk					Risk				
ID	**Top level event/ hazard**	**Hazard/threat**	**Cause**	**Consequence**	**BEV differences to ICEV**	**S**	**L**	**R**	**Safeguards/barriers**	**Applicable standards**	**S**	**L**	**R**	**Recommendations/ actions**	**Comments**
H-5	**Other**														
H-5.07	Other	EV powertrain weight	EV powertrain potentially 1t to 3t heavier than equivalent ICEV powertrain	EV powertrain weight increase insignificant compared to loaded tanker weight May be more significant for hydrant dispenser and could lead to stranded vehicle or inability to maintain vehicle	Consideredr to be insignificant for tanker but more significant for hydrant dispenser	3	3	9	OP-M: maintenance facility equipment weight limits defined and confirmed against OEM vehicle specifications	Local vehicle weight restrictions may apply	3	2	6		Batteries are approx. 1 t for 200 kWh – anticipate two or more batteries – ICEV powertrain is approx. 1 t
H-5.08	Other	Electrical storm	Lightning strike nearby while charging	Spike in power supply through charge cable	Unique to BEV – no charging cable present on ICEV	4	4	16	OEM-V: procedures for charging during an electrical storm and sufficient protections within the design OEM-V: charging equipment designed to applicable codes and standards	IEC 61851 Industry standard on charging equipment – grid and charging station limit over voltage scenario (2,5 kV flux)	4	1	4		Pre-mitigated likelihood of lightning strike nearby considered likely but depends on location
H-5.09	Other	Chemical compatibility	Airfield chemicals and substances interaction with BEV powertrain, e.g, – de-icing fluid, and – jet fuel	Consequences dependent on chemicals, potential for battery degradation or increased likelihood of HV hazards No adverse reactions anticipated between airfield chemicals and BEV powertrain, therefore severity low	Potentially unique interaction between batteries and chemicals	2	5	10	OEM-V/AF: substance catalogue generated for airport operations and reviewed by BEV OEM – compatibility testing where required		2	5	10		Pre-mitigated likelihood high as airfield chemicals (jet fuel/de-icing fluid) are used regularly
H-5.10	Other	Chemical compatibility	EV chemicals and substances introduced to airfield, released following damage to vehicle e.g, – electric motor, cooling oil, and – battery electrolyte	Minor environmental consequences	Industry moving towards motor cooling oils that are more isolating but these are more flammable	2	2	4	OEM-V/AF: substance catalogue generated for airport operations and reviewed by BEV OEM – compatibility testing where required		2	2	4		Additional BEV chemicals only released in accident scenario, pierce of battery box without fire or piercing of motor case, likelihood considered to be low
H-5.11	Other	Vehide equipotential bonding	Electrical fault in HV systems connected through equipotential bonding	Fault in internal HV systems leads to loss of BEV system failure Isolation of HV system protects people from electrocution/ electric shock	ICEV equipotential bonding is at 24 V – HV system in BEV	3	2	6	OEM-V: vehicle designed to applicable codes and standards – isolation of systems		3	1	0		Severity 3 assigned in line with potential for loss of functionality leading to potential widespread airport disruption

						Risk					Risk				

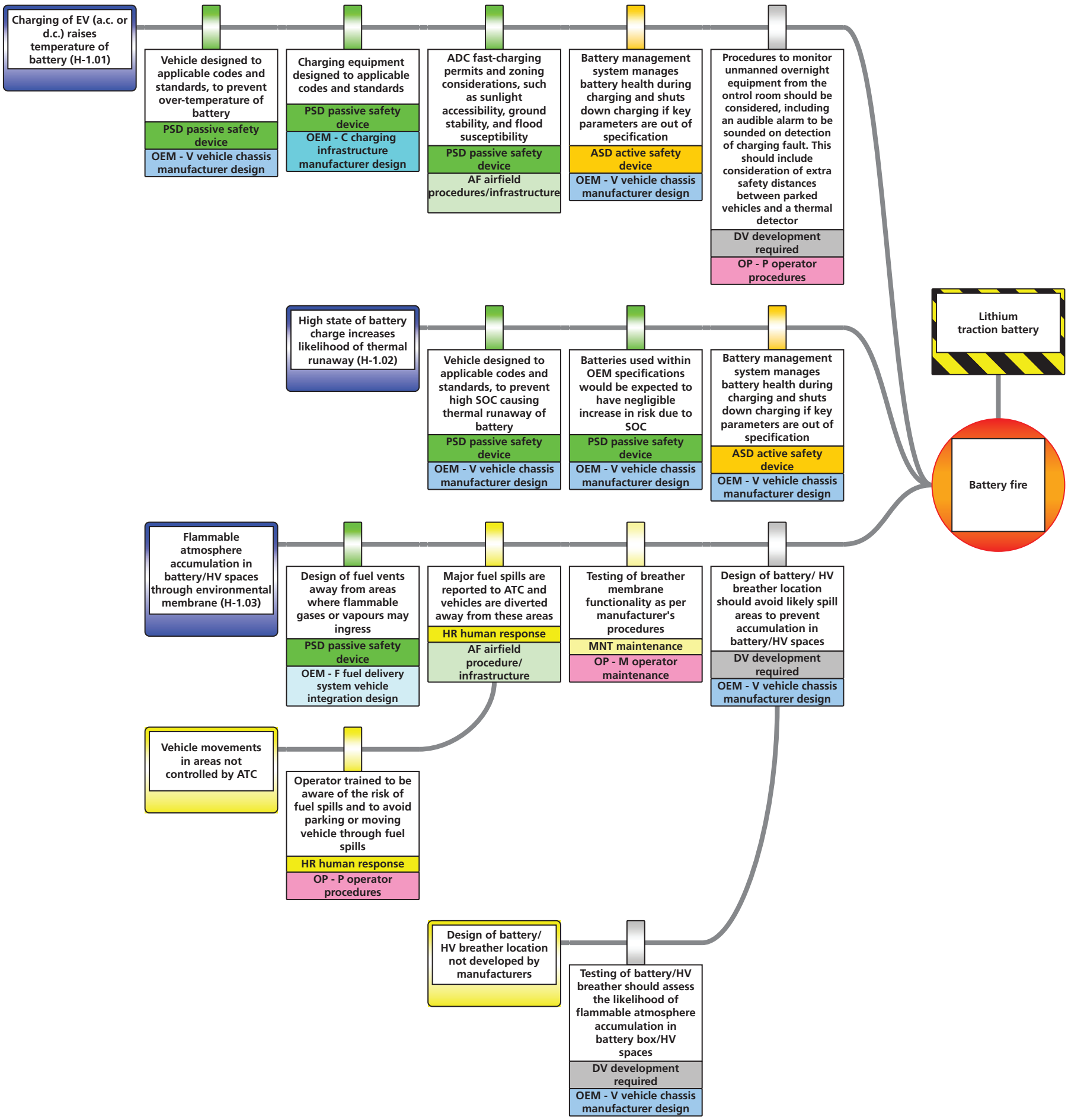
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ID	Top level event/ hazard	Hazard/ threat	Cause	Consequence	BEV differences to ICEV	S	L	R	Safeguards/barriers	Applicable standards	S	L	R	Recommendations/ actions	Comments
H-6	**Not unique to BEV/not impacted by BEV powertrain**	*Hazards that were identified during the workshop but are not affected by the integration of a BEV powertrain – note that these hazards have not been risk ranked as are considered outside the core scope of the study. Any system-specific hazard identification should consider identification of all reasonably foreseeable hazards*													
H-6.01	Non-battery specific	Working at height	Access to equipment at height to conduct checks	Fall from height, injury	No identified difference										
H-6.02	Non-battery specific	Operational profile	Low speed with multiple stop start cycles compared to more usual operating profile	Abnormal component wear, e.g. coolant system build up without high load to flush it through	Equivalent to ICEV speed and stop/start operating profile				OP-P: maintenance requirements include hours-based tasks						
H-6.03	Non-battery specific	Unable to operate fuelling equipment following loss of PTO/EPTO	EPTO/PTO fault	Disruption to airport operations	Equivalent to ICEV powertrain fault and loss of PTO										
H-6.04	Non-battery specific	Salt spray/air	Coastal location	No adverse consequence identified	No difference to ICEV										Considered a normal use case – well covered in existing standards
H-6.05	Non-battery specific	Hot components	Hot powertrain components	Hot surfaces as ignition source for fuel spill/flammable atmosphere Burn Injury	EV components are cooler than ICEV, particularly exhaust components and catalyst, which can be over 100 °C (up to 600 °C)										
H-6.06	Non-battery specific	Cold components	None identified	None identified	None identified										
H-6.07	Non-battery specific	Bonding	Bonding to aircraft as part of fuelling process	None identified	None Identified HV system on the same bonding loop as vehicle chassis										
H-6.08	Non-battery specific	Fuel spill	Driving through fuel spill on the ground	Ignition source for flammable atmosphere	ICEV will have more ignition sources compared to BEV				OEM-V: electrical motors protected in the event of a fuel splash						
H-6.09	Non-battery specific	EMC immunity	EMC emissions on airfield interfere with BEV systems, e.g. aircraft weather radar	EV system failure due to EMC	No identified differences, electronic systems all conform to the same standards					TSO C63f – Airborne Weather Radar Equipment ARINC 708-6 – AIRBORNE WEATHER RADAR					
H-6.10	Non-battery specific	EMC interference	EMC emissions from BEV interfere with airport systems	Airport/aircraft systems failure due to EMC	No identified difference to present ICEVs										
H-6.11	Non-battery specific	Cyber security	Cyber attack Vehicle systems Charger connection	Unauthorised control of systems	Vehicle connections and security expected to be identical between BEV and ICEV				OEM-F: check for firmware updates regularly. Install security patches and system updates						
H-6.12	Non-battery specific	Fire in proximity to compressed air/pressurised components	Vehicle fire (battery or ICEV fire) escalates to compressed air or pressurised components, such as tyres or flexible rubber hoses	Failure of components leading to depressurisation of components, potential for release of residual fuel/ hydraulic oil, which may escalate fire	Causes of fire but no difference in consequences to compressed air or pressurised components				Positioning and protection of batteries away from compressed air, pressurised components or flexible rubber hoses						

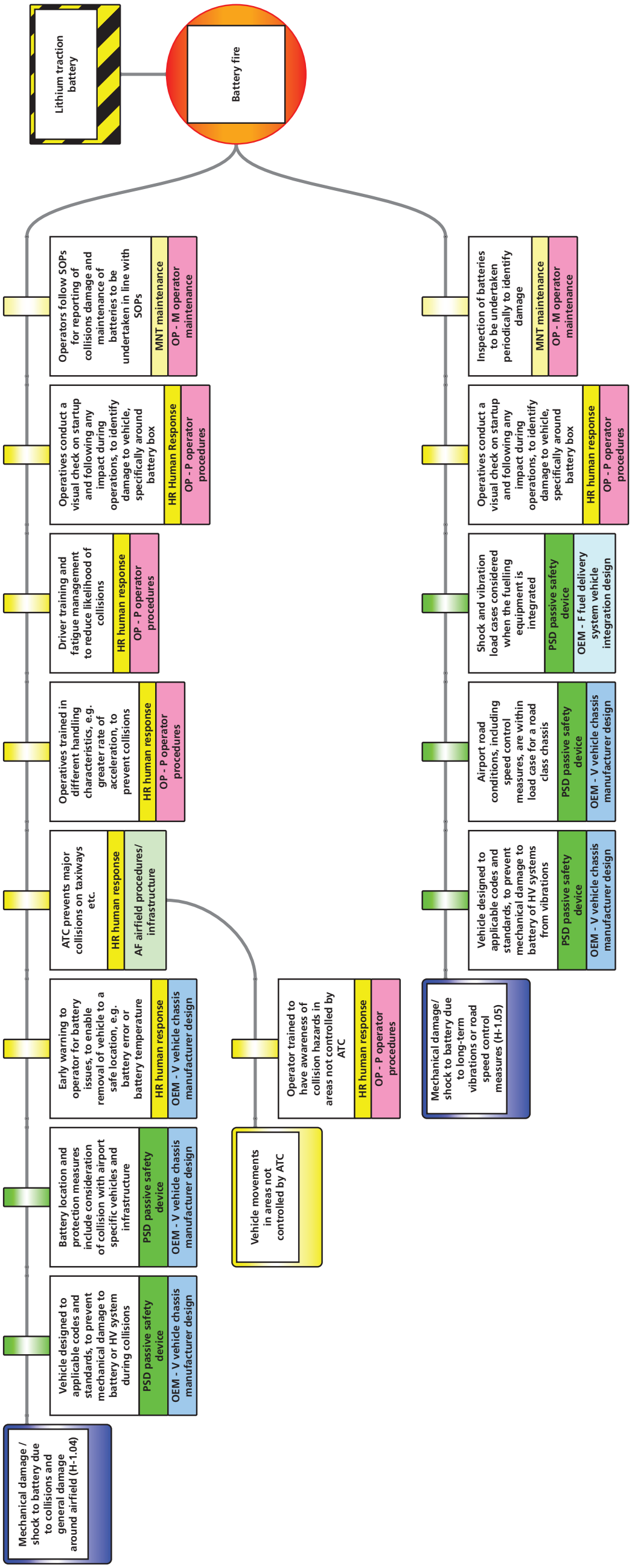
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ANNEX B
BOW TIE DIAGRAMS

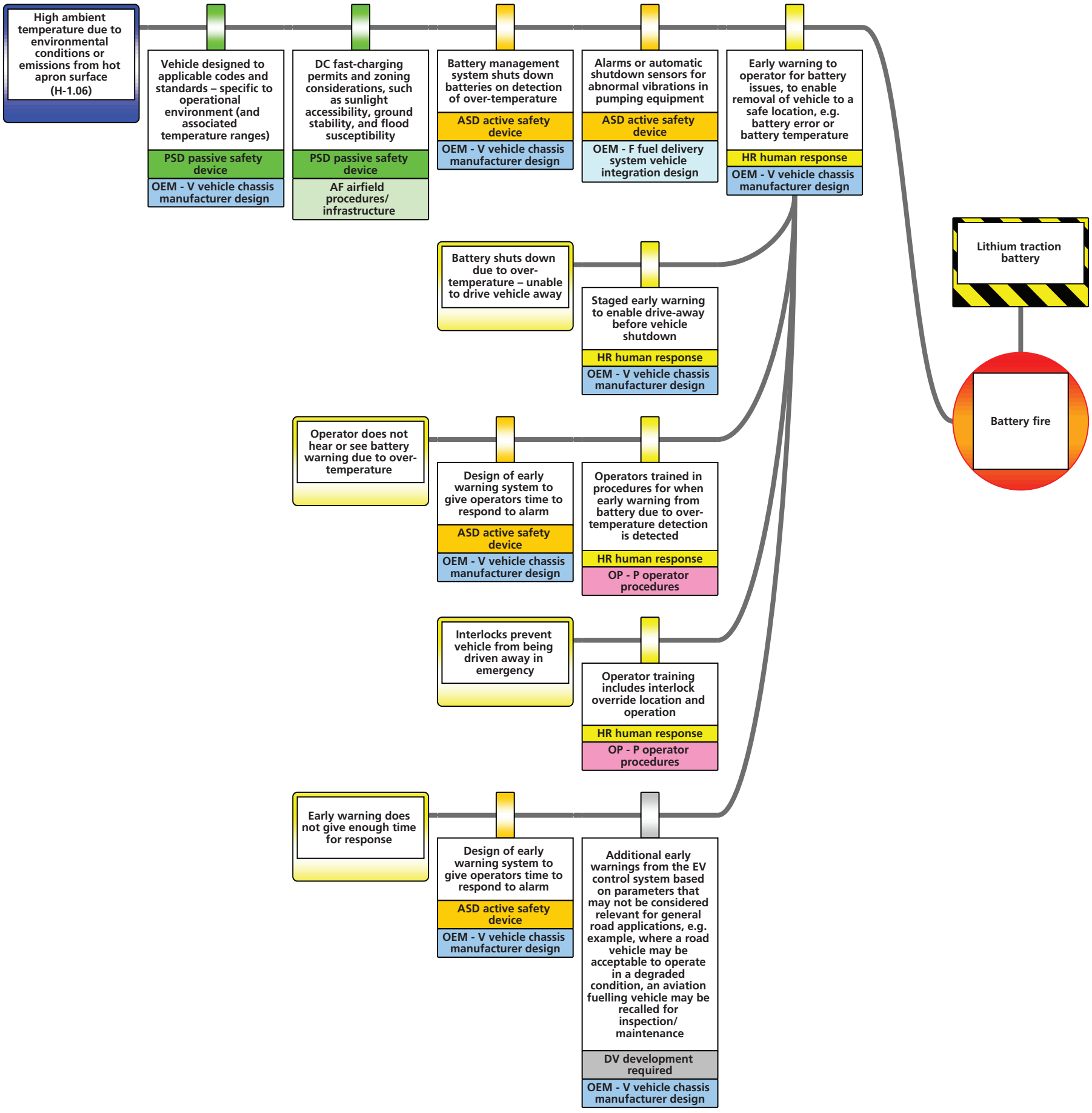
B.1 BATTERY FIRE



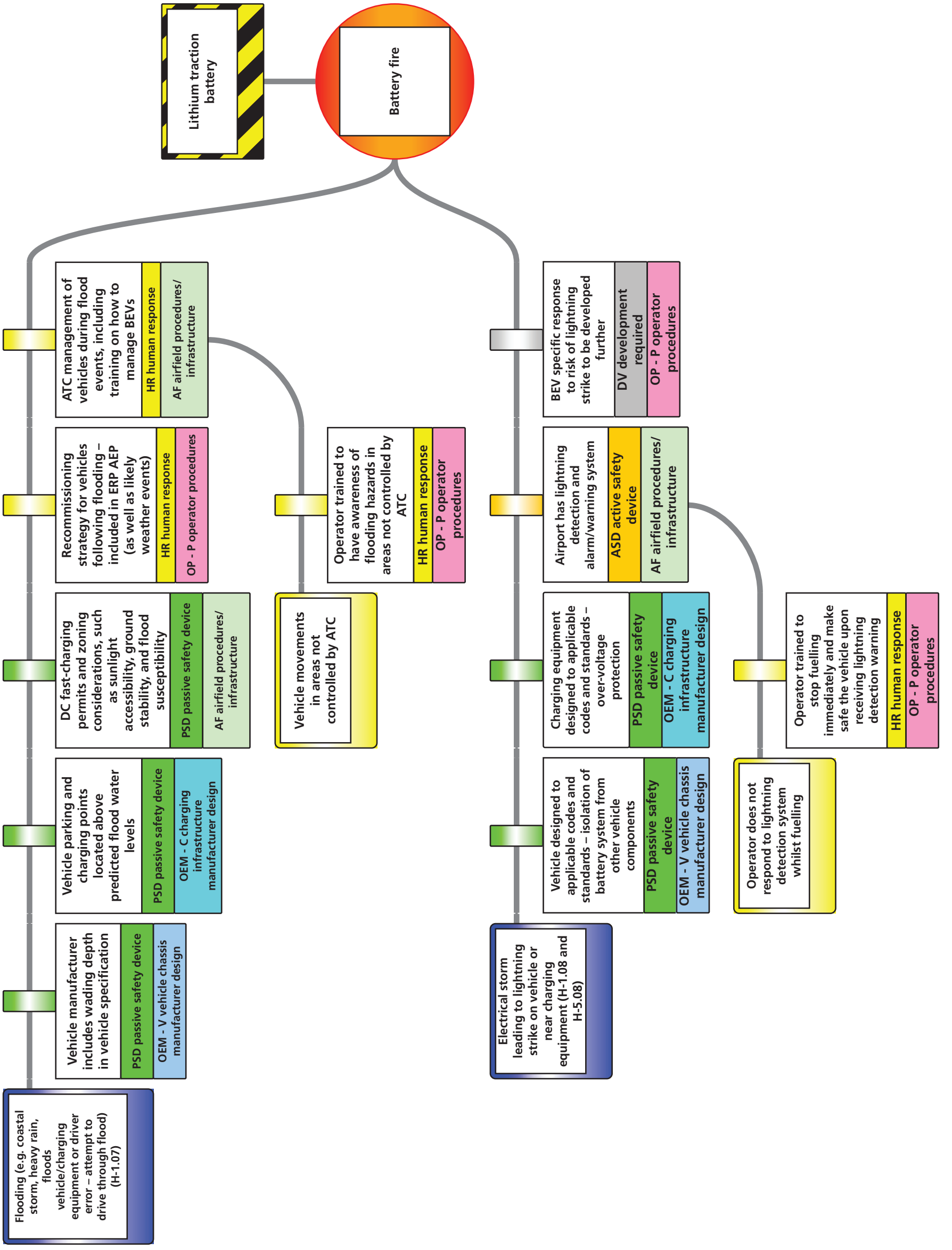
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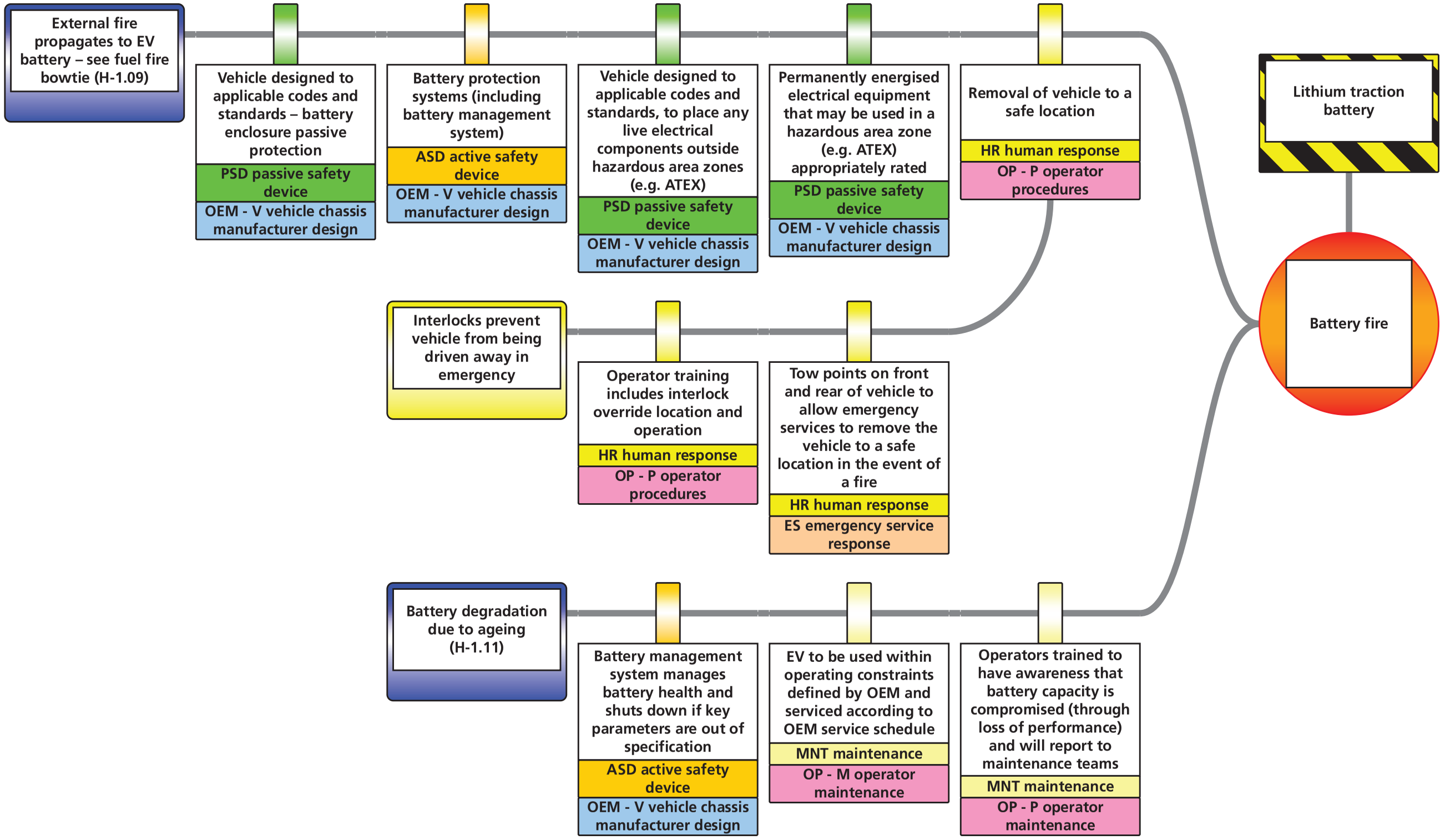
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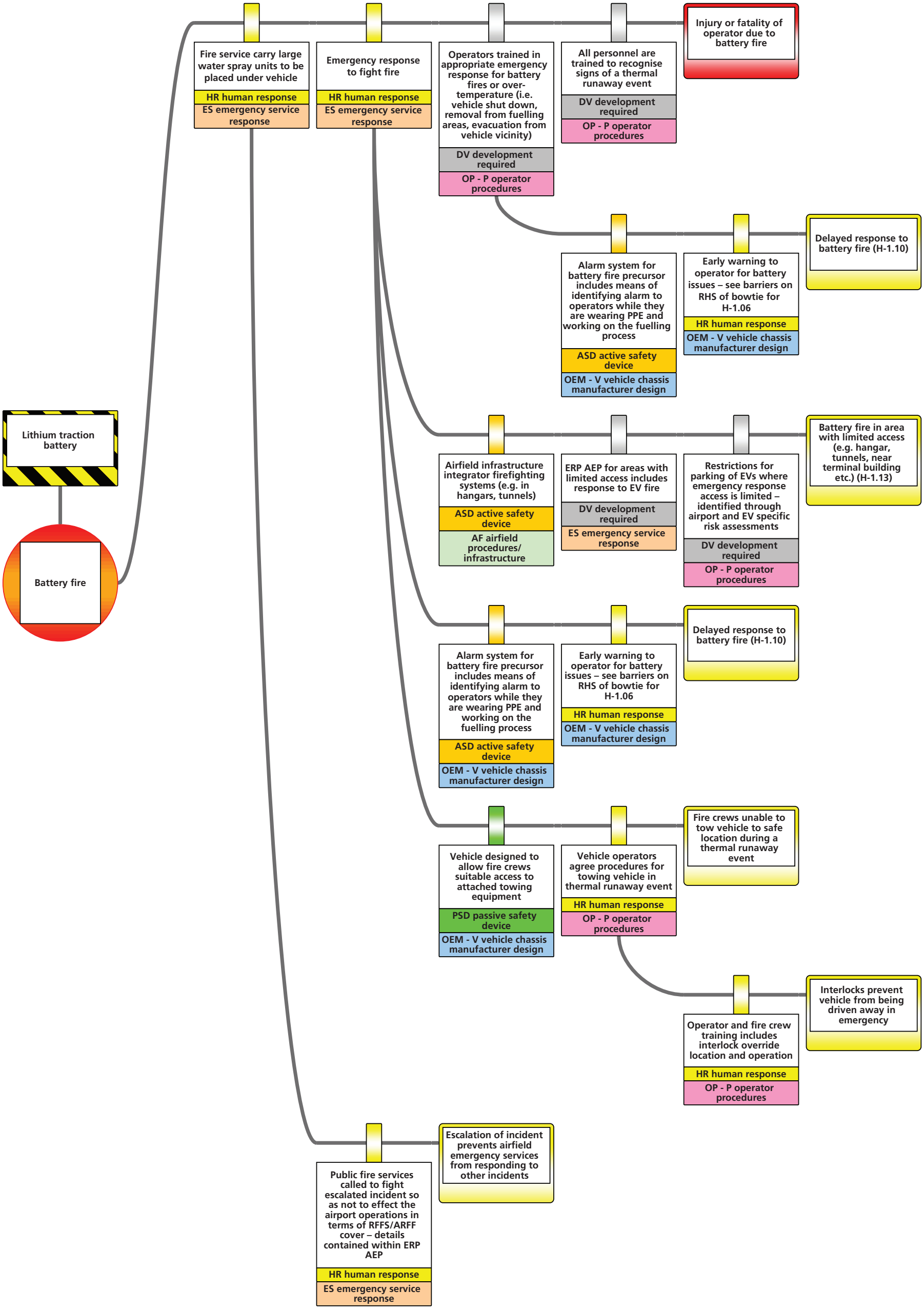
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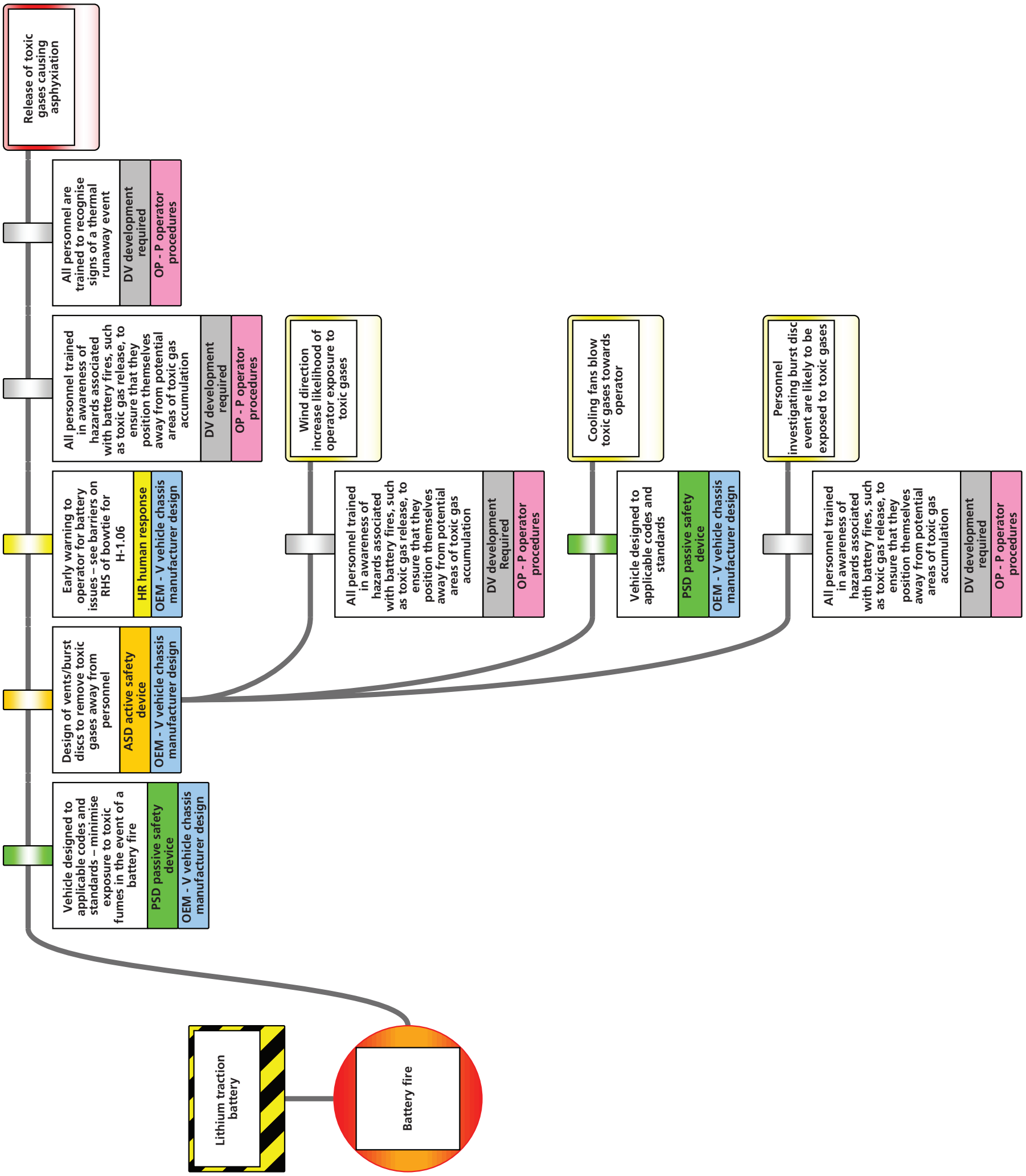
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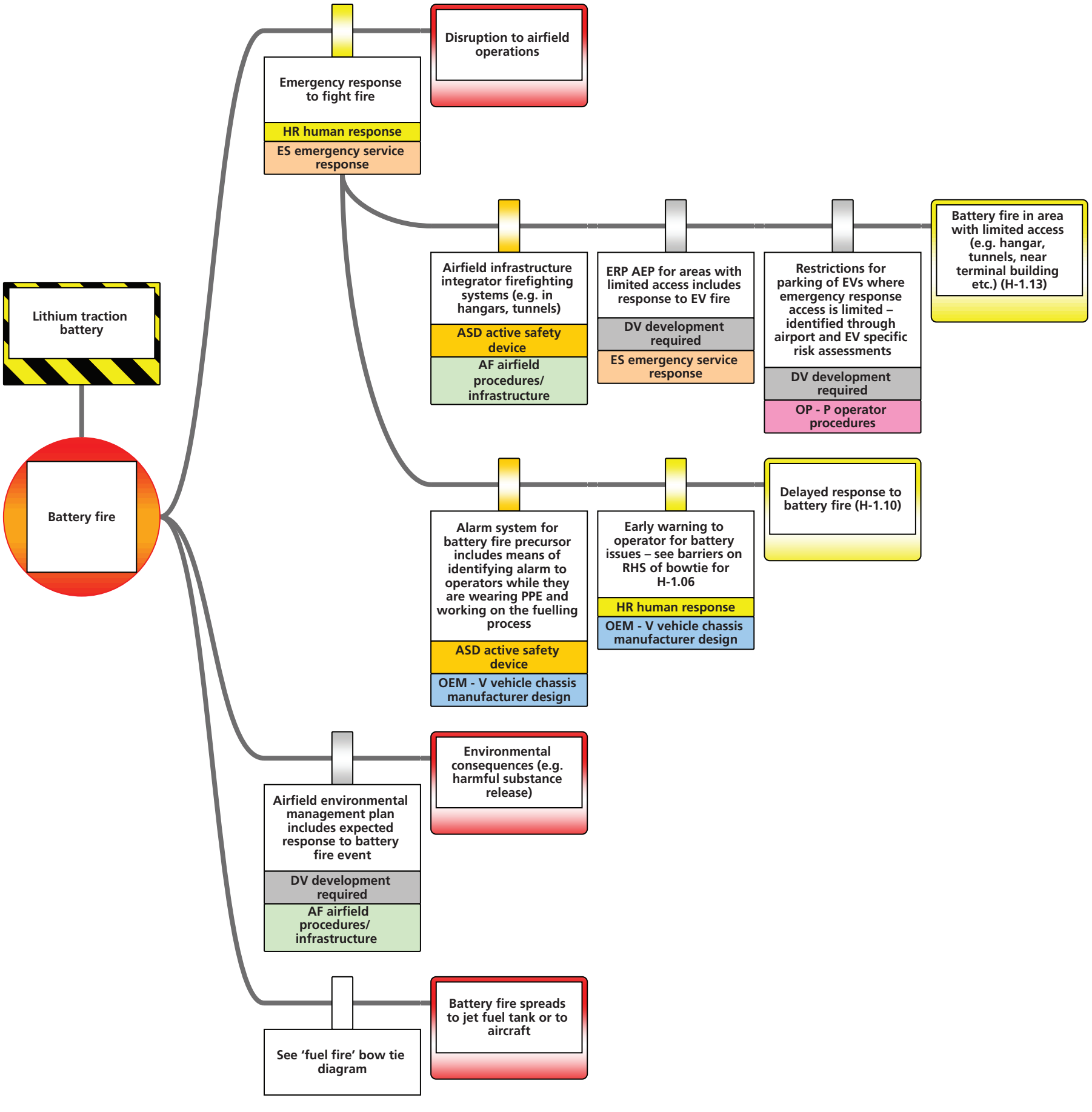
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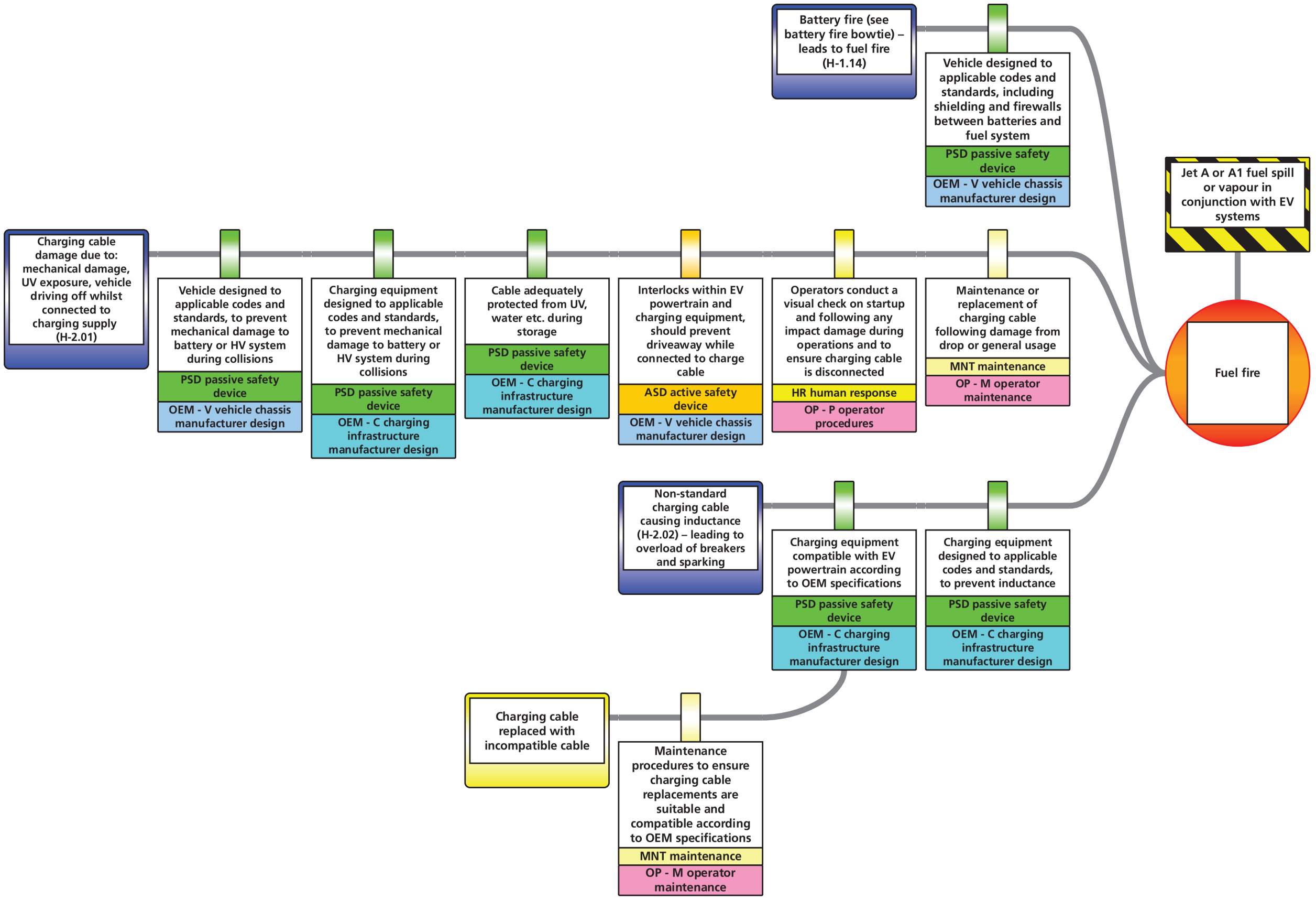


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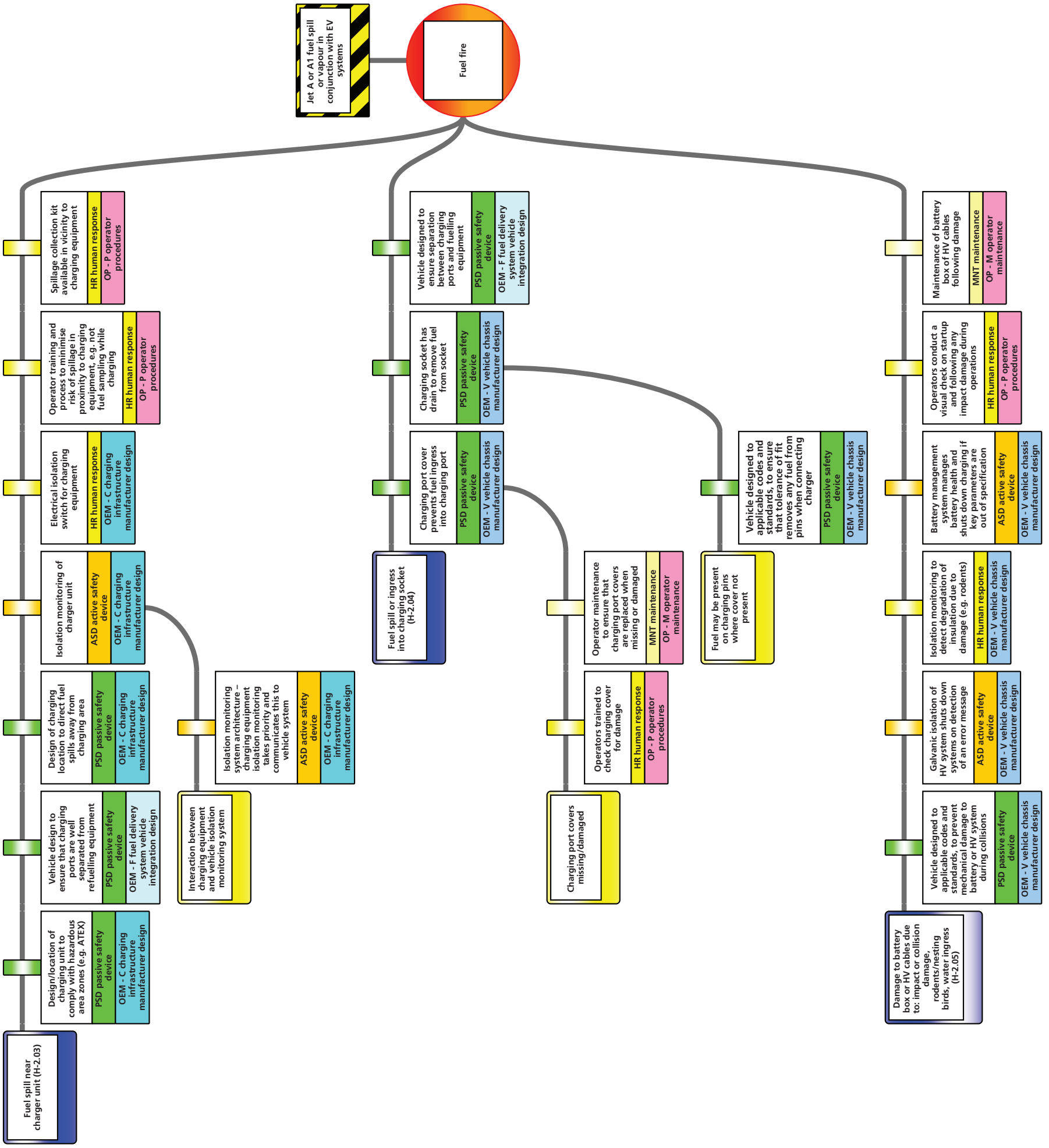


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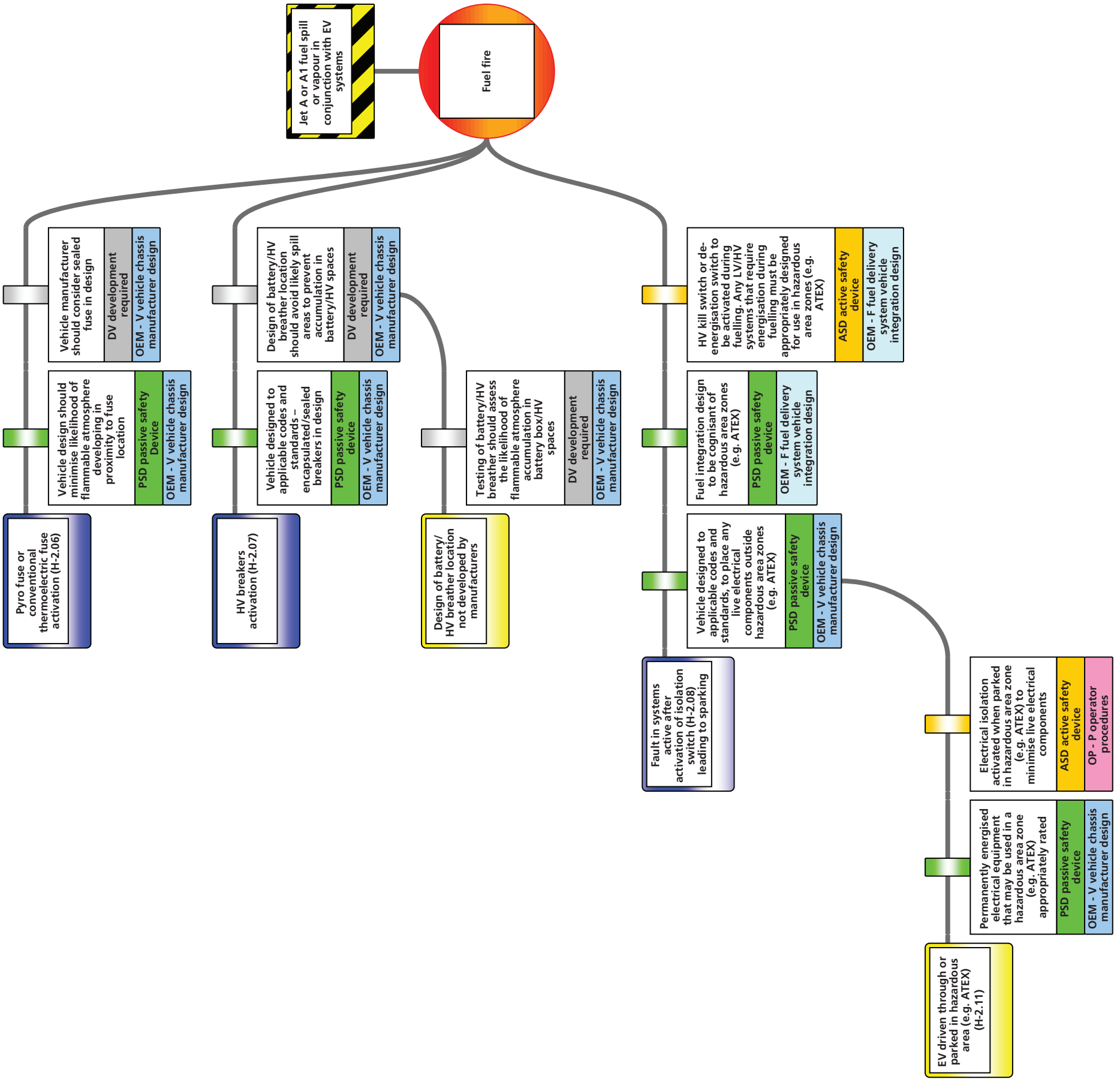
B.2 FUEL FIRE



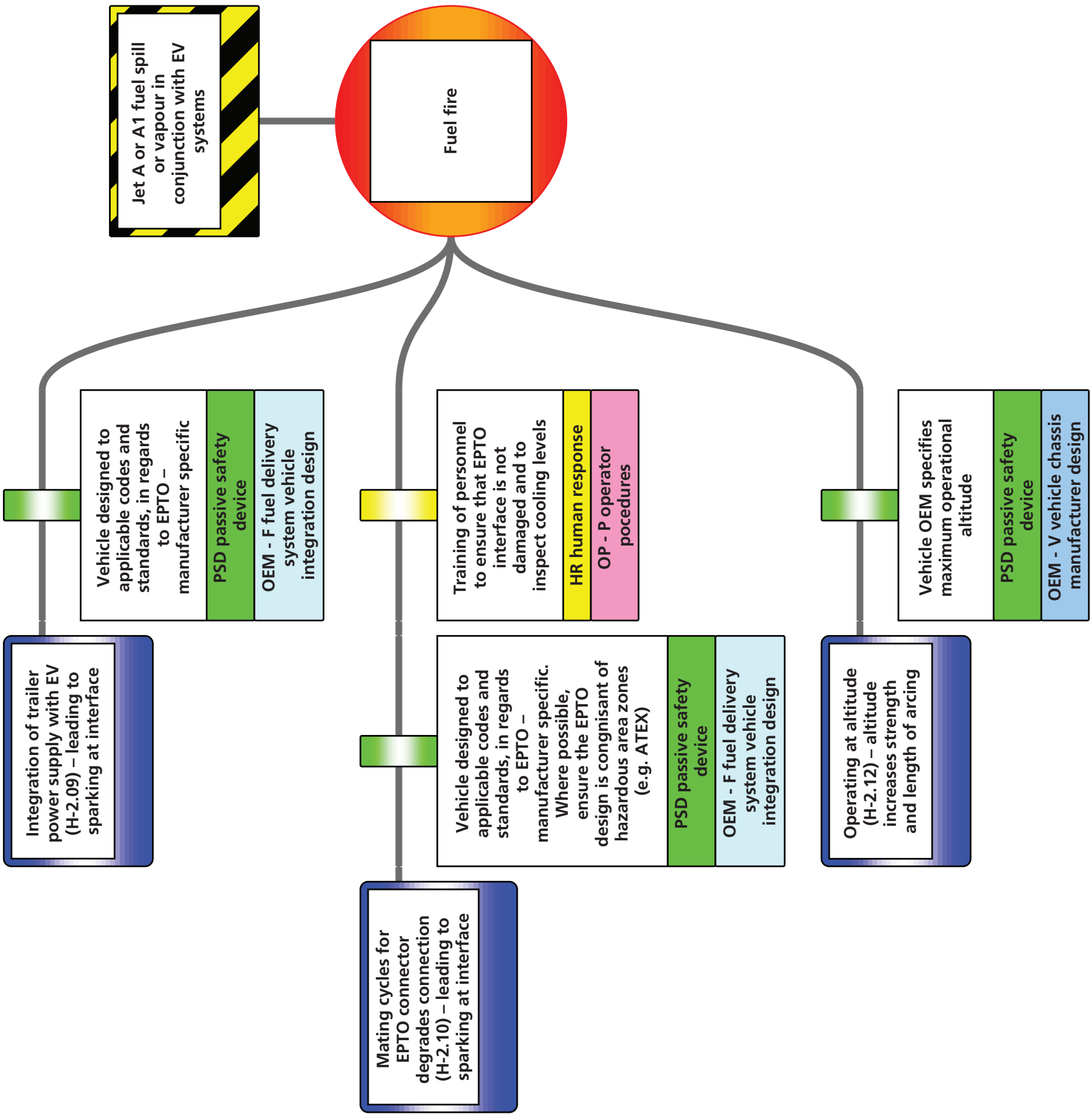
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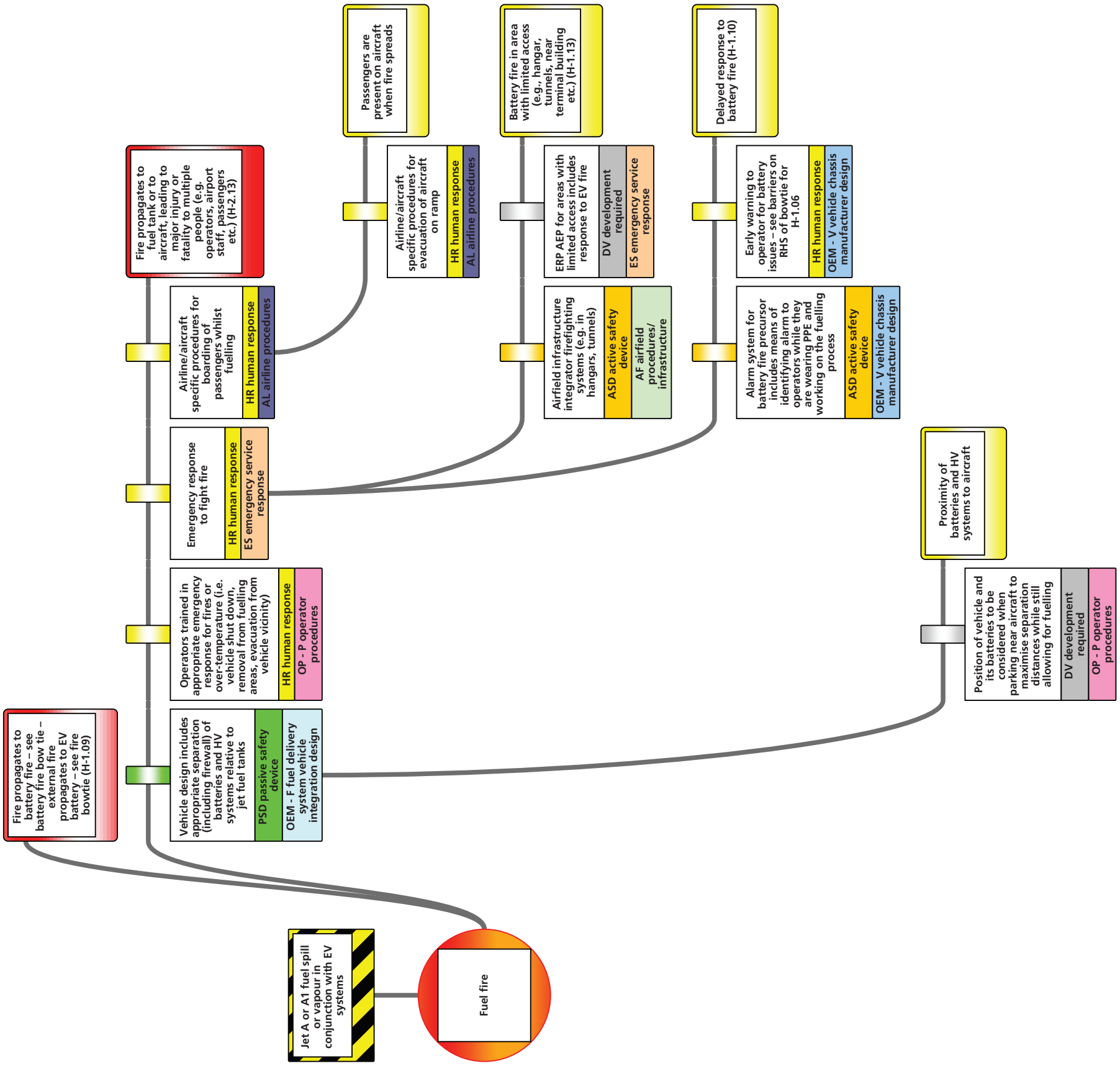
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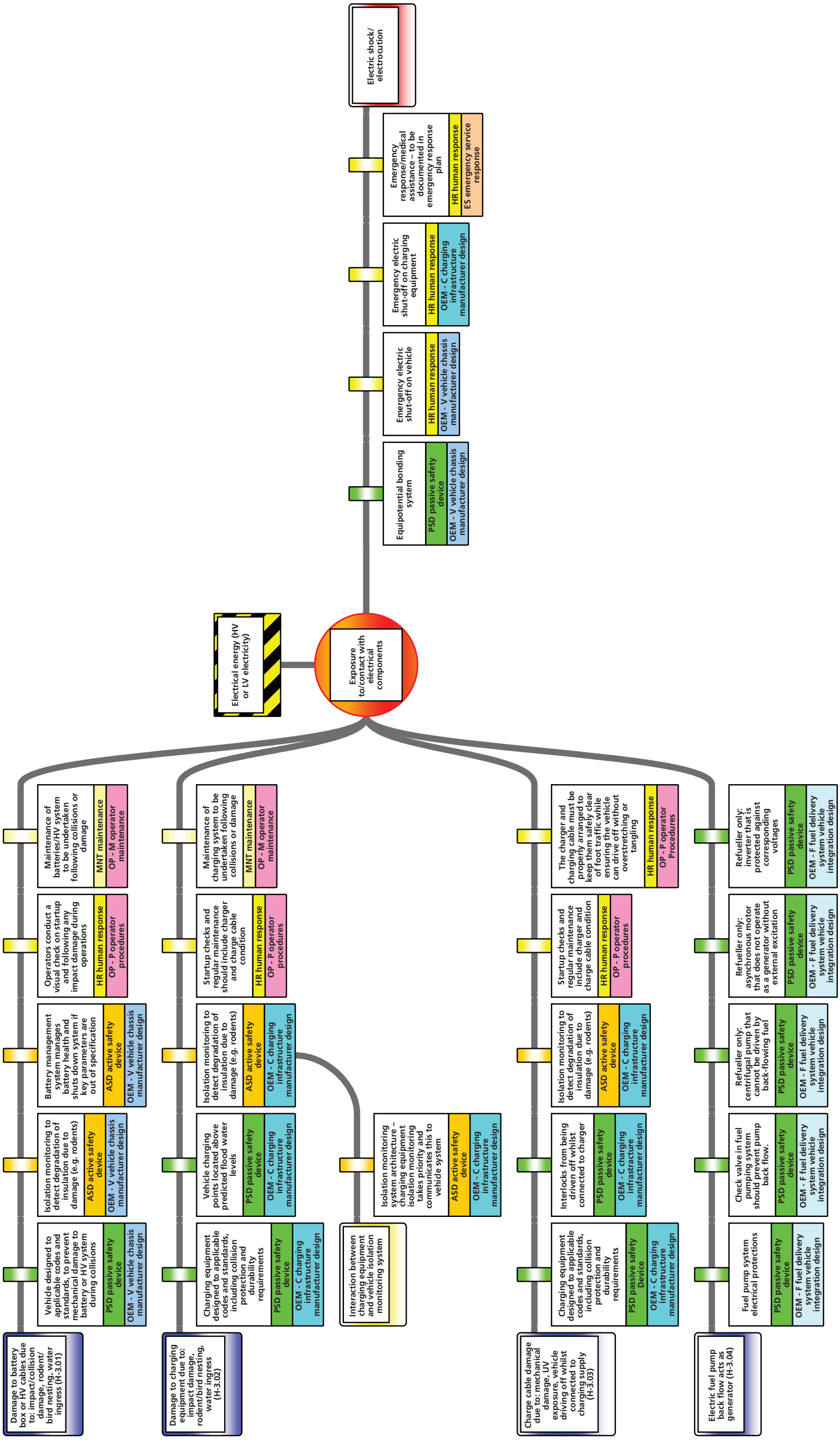


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B.3 EXPOSURE TO/CONTACT WITH ELECTRICAL COMPONENTS



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ANNEX C
WORKSHOP ATTENDANCE

Name	Organisation	Role	HAZID Workshop		Bow tie Workshop
			05-Dec-24	06-Dec-24	24-Jan-25
Matthew Sephton	Risktec	Principal Consultant, Workshop Chair	Y	Y	Y
Thomas Fairclough	Risktec	Senior Engineer, Workshop Scribe	Y	Y	Y
Bill Geck	American Airlines	Fuel Engineering Manager	Y	Y	Y
David Wroth	Underwriters Laboratories	Senior Director, Thermal Runaway Incident Program, UL Standards and Engagement	Y	Y	Y
Hans Nikolaus Beck	Daimler Trucks	Autonomous Driving Control Systems Engineer			Y
Hendrik Schmeil-Karzhavin	Swiss International Air Lines	Technical Manager IFQP and Ground Auditor	Y	Y	
Jack Kreckie	ARFF Working Group	Retired Fire ARFF Chief	Y		
Jason Goff	Swissport	ITP Operative	Y	Y	Y
Joël Boiteux	TotalEnergies	Vehicle Design	Y	Y	Y
John Thurston	World Fuel Services	Technical Authority (Fuels)	Y	Y	Y
John Trew	Falck Fire Services UK	Technical Director		Y	
JP Belières	Boeing	Airframe OEM Representative	Y	Y	
Luc Maes	Sky Tanking	Fuel Depot Operator	Y		
Marta Fernandez	Exolum	HSSE			Y
Mohamad Ahmad	Air BP	Global Vehicle Fleet Management Lead	Y	Y	
Paul Carmody	Q8 Aviation	Technical Services Manager	Y	Y	Y
Seyfullah Yavuz	Turkish Fuel Services	Operations Manager	Y	Y	Y
Steve Threadgold	Shell Aviation	Fuelling Vehicle Engineering Manager	Y	Y	Y
Terry Bosserman Sr.	Garsite	VP Sales	Y	Y	
Tobias Aurand	Daimler Trucks	Daimler Truck Senior Expert HV-Safety and Consulting	Y	Y	
Tobias Luecking	Daimler Trucks	Daimler Truck – Manager R&D HV-Battery Safety	Y	Y	

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ANNEX D
WORKSHOP GUIDE WORDS

Guide words	Stakeholders
No/not	Fuel handler
More than	Depot staff, planning, training, management
Less than	Flight crew (pilots)
As well as	Flight crew (cabin crew)
Part of	Airfield operations/ATC
Reverse	Ground crew (dispatcher, ramp staff)
Other than	Passenger services staff
Sooner than	Fire and rescue
Later than	Aircraft maintenance personnel
	Environment Agency (or equivalent)
	Overnment regulatory bodies (e.g. UK HSE)
	Investigative bodies (e.g. CAA/FAA/NTSB/AAIB)
	Vehicle recovery team
Hazards	**Interfaces**
Electrical hazards	Low EV charge
	Charge point dwell/overload/failure
	Loss of electrical power
	EMC
	EV hardware failure (short circuit/thermal runaway)
Fire/explosion hazards	Flammability – flash, pool or jet fire
	Flammability – vapour cloud explosion
	Combustibility – ignition/flash fire
	Battery fire reignition
	Rapid phase transition
Thermal hazards	Hot surfaces (exhausts, aircraft engines)
	Cold surfaces (fuel systems)
	External fire
	Thermal expansion /contraction
	High velocity leak or jet spray
Dynamic situation hazards	Collision with road vehicle
	Collision with aircraft
	Collision with infrastructure
	Collision with personnel
	Noise
Material/substance hazards	Jet A or A-1 spill/mishandling/pumping equipment or external / overflow
	Battery leakage
	De-icing fluid
	Hydrant maintenance substances
	Corrosive substances
	Toxic substances
	Asphyxiates
	Other explosive substances
	Other flammable substances
Mechanical hazards	Lack of use/mid- or long-term storage/inactivity
	Rotating/moving/shear points
Ergonomic hazards	Access to equipment at height on vehicle
	Elevated platform
	Slips, trips, falls – fuel spill/pipes/charging cable
	Human error in fuelling process
	Access to equipment on vehicle (batteries, fuelling equipment) in event of fire
Environmental hazards	Extreme heat
	Extreme cold (snow and ice)
	Flooding
	Electrical storms
	High winds
	Tectonic activity
Pressure hazards	Fuelling systems overpressure
	Fuelling systems under pressure
	Connections to aircraft (connection not made correctly)
	Tank or vessel rupture

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ANNEX E
RISK ASSESSMENT MATRIX

			Experience		**Unlikely to occur in life cycle of system**	**May occur once in life cycle of system**	**May occur on a few occasions during the life cycle of the vehicle**	**May occur once a year**	**May occur multiple times per year**
Safety consequence	Operational consequence	Example scenario			Very unlikely	Improbable	Remote	Occasional	Probable
					1	2	3	4	5
Multiple fatalities	Destruction of airfield infrastructure	Battery fire escalates to jet fuel tank or aircraft fire	Severe	5	5	10	15	20	25
Single fatality Multiple major injuries (loss of limbs, sight, long-term illnesses) Permanent disablement or long-term sick leave	Shut-down of entire airfield	Battery fire that does not escalate to jet fuel tank or aircraft fire HV electrocution	Major	4	4	8	12	16	20
Serious injury requiring medical treatment (i.e. single major injury or multiple minor injuries). Lost time injury (>1 week off work)	Disruption to entire airfield	Vehicle collision with person	Moderate	3	3	6	9	12	15
Recordable incident, minor medical treatment including restricted work Lost time injury (<1 week off work)	Disruption to some airfield operations	Slips, trips and falls on cables	Minor	2	2	4	6	8	10
Minor injury (cuts, abrasions, minor skin or eye irritation, etc.) No sick leave required	Minor operational disruption (small delay, etc.)	Cable dropped on foot	Slight	1	1	2	3	4	5

High risk	Further risk reduction measures are required to reduce the risk to a tolerable level
Medium risk	The level of risk is considered tolerable to the industry. Further risk reduction measures should be considered, unless the cost to implement the measures is grossly disproportional to the risk reduction
Low risk	Further protective measures may be required to reduce the risk if the time and effort to do so is not disproportionate to the safety gain

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ANNEX F
INCIDENT REVIEW

Source	Date	Category	Type	Cause	Lessons learned
Skybrary	05/09/2001	Aviation refueller	Incorrect procedure	Pressurised fuelling hose breaking loose, causing fire	Inadequate positioning of vehicle Inattentiveness of operator
FSS Aero	01/12/1998	Aviation refueller	Fuel leak	Fuel leak caused fuel truck to set on fire, spreading to aircraft being refuelled	Source of fuel leak could not be determined
JIG Online – 2018-145	Pre-2018	Aviation refueller	Vehicle movements	Fuel truck reversed into engine cowling, distraction and failure to apply parking brake	Alert system to indicate the handbrake is engaged Gate mapping Specific operator training
JIG Online – 2018-27	Pre-2018	Aviation refueller	Aircraft movements	Aircraft wing tipnear refuelling truck, apron had recently been modified and marshaller did not have enough visibility	Management of change Briefing when apron markings change
JIG Online – 2018-28	Pre-2018	Aviation refueller	Vehicle movements	Malfunction of brake interlock system on vehicle Insufficient space between vehicles when driving	Safe distance when driving Maintenance and inspection of brake interlocking system
JIG Online – 2018-31	Pre-2018	Aviation refueller	Vehicle movements	Failure to apply parking brake	Updating and reviewing procedures for applying parking brakes Using handbrake alarms
JIG Online – 2018-32	Pre-2018	Aviation refueller	Fuelling system failure	Pressure loss in hydrant due to floating suction failure	Regular checks of floating suctions
JIG Online – 2018-34	Pre-2018	Aviation refueller	Extreme weather	Electrical discharge from thunderstorm near area where fuelling was taking place Defective thunderstorm warning flashlights	Installation of reliable warning system Protocols to stop fuelling during thunderstorm
ASN	16/02/2016	Aviation refueller	Vehicle failure (conventional power)	Smoke coming from vehicle engine – hydrant fuelling	Fitting of interlock or power take-off (PTO) device that prevents the fuelling process when gear is not in neutral
Skybrary	10/05/2019	Aviation refueller	Aircraft movements	Aircraft movements and limited visibility	Fitting driver displays with rear and side-view cameras (Menzies) Review of airside vehicle pperator permit (AVOP)
NTSB	03/06/2016	BEV (non-aviation)	Battery fire (while being transported)	Short circuit between battery bolt and upper cells in Li-ion module while being shipped	Vibration tests for prototype battery systems
NTSB	08/05/2018	BEV (non-aviation)	Vehicle crash, escalated fire via BEV system	Loss of vehicle control leading to battery damage Arcing at HV terminal causing individual cells to explode	None stated

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Source	Date	Category	Type	Cause	Lessons learned
NTSB	23/07/2022	BEV (non-aviation)	BEV system failure	Moisture in the HV Li-ion battery system leading to fire damage ERP did not account for appropriate firefighting response to Li-ion battery fire	Li-ion batteries require specific firefighting approach – application of cool water required to reduce stranded energy and reduce risk of fire restarting
NTSB	25/09/2017	BEV (non-aviation)	Vehicle crash, escalated fire via BEV system	Loss of vehicle control leading to battery damage Damage to battery modules – stranded energy leading to secondary fire after vehicle fire had been extinguished (while being towed)	Li-ion batteries require specific firefighting approach – application of cool water required to reduce stranded energy and reduce risk of fire restarting Using HV disconnect to protect against electric shock Thermal runaway and battery reignition awareness – can happen significantly after accidents
NTSB	23/03/2018	BEV (non-aviation)	Vehicle crash, escalated fire via BEV system	Reignition of battery fire due to stranded energy in battery	Li-ion batteries require specific firefighting approach – application of cool water required to reduce stranded energy and reduce risk of fire restarting Using HV disconnect to protect against electric shock Thermal runaway and battery reignition awareness – can happen significantly after accidents
NTSB	Unknown	BEV (non-aviation)	BEV system failure	Reignition of battery fire due to stranded energy in battery	Li-ion batteries require specific firefighting approach – application of cool water required to reduce stranded energy and reduce risk of fire restarting Using HV disconnect to protect against electric shock Thermal runaway and battery reignition awareness – can happen significantly after accidents
NTSB	07/01/2013	Battery fire on aircraft	Battery fire	Short circuit within a cell of the APU, leading to thermal runaway, which cascaded to adjacent cells Failure of Boeing to incorporate design requirements to mitigate effects of internal short circuit	Sources of excessive heating, including electrical contact resistance from components and connections, to be identified, minimised and documented as part of the design Research into thermal runaway Testing of batteries
UAE Aviation safety Study	01/12/1998	Aviation refueller	Aviation fueller failure	Suspected fuel leak near vehicle transmission	
UAE Aviation safety Study	05/09/2021	Aviation refueller	Fuelling process failure	The operator lowered the fuelling lift platform, which caused one of the refuel hoses to disconnect from the wing. Fuel was spraying on to the vehicle, which caused the fire. The refuel operator was fatally injured and the aircraft was substantially damaged	
UAE Aviation safety Study	06/07/2003	Aviation refueller	Fuelling process failure	Fuelling vehicle 'lurched' forward causing one of the refuel hoses to disconnect from the wing. Due to the shut-off of the hydrant prior to the movement of the vehicle, only a small amount of fuel had spilled on to the apron	
Idaho National Laboratory	Jan-24	BEV	Flooding	A Teardown Study of Flood Damaged Electric Vehicles Flooded BEV teardown following Hurricane Ian in 2022, Idalia in 2023	Spontaneous BEV fires have been noted following water immersion Corrosion and debris from water immersion cause damage to battery packs

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ANNEX G
STANDARDS AND GUIDANCE

File ref.	Number	Publication date	Name	Publisher	Area	Relevant clauses
1	SRP/0001/2016	04/2017	*Fuelling vehicle fire during aircraft fuelling*	Air Accident Investigation Sector General Civil Aviation Authority The United Arab Emirates	Aircraft refuelling	The objective of this Safety Study is to gain an understanding of the current situation in the UAE regarding the potential for fire during fuelling of aircraft, analyse the recent event and suggest safety recommendations to enhance safety and prevent a recurrence
2	150/5230-4B	28/09/2012	*Advisory circular – aircraft fuel storage, handling, training, and dispensing on airports*	U.S. Department of Transportation Federal Aviation Administration	Aircraft refuelling	Specifications and guidance for the storage, handling and dispensing of aviation fuel on airports. Additionally, this a.c. provides standards and guidance for the training of personnel who conduct these activities
3	CAP 789 Edition 2	18/02/2011	*Requirements and guidance material for operators*	CAA Civil Aviation Authority Safety Regulation Group	Aircraft refuelling	This civil aviation publication (CAP) describes 'best practice' means of compliance with EU-OPS and JAR-OPS 3, the operational requirements of the Air Navigation Order (ANO) and International Standards and Recommended Practices (SARPs) Chapter 9 contains details on refuelling
4	CAP 748	07/2004	*Aircraft fuelling and fuel installation management*	CAA Civil Aviation Authority Safety Regulation Group	Aircraft refuelling	This CAP is intended to provide guidance to aerodrome licensees whose aerodromes have facilities for fuel storage, however complex or simple these facilities may be. This guidance is intended to assist them in the production of procedures for fuel storage, management, handling and distribution
5	Spec 103 Revision 2023.1	2023	*Standard for jet fuel quality control at airports*	A4A	Aircraft refuelling	ATA Specification 103 provides guidance for the safe storage and distribution of jet fuel at airports as currently practised in the commercial aviation industry. It also includes forms that can be used to record the performance of tests and inspections
6	MNL5-5TH-EB	2017	*Aviation fuel quality control procedures: 5th edition*	ASTM International	Aircraft refuelling	Manual 5 provides a complete explanation of several common procedures used by fuel handlers to assess and protect aviation fuel quality
7	BS EN 12312-5:2021	2021	*Aircraft ground support equipment. Specific requirements – Part 5: Aircraft fuelling equipment*	BSI	Aircraft refuelling	Document does not deal with hazards with respect to a standard automotive chassis This document specifies the technical requirements to minimise the hazards listed in Clause 4, which can arise during the commissioning, operation and maintenance of AFE when used as intended, including misuse reasonably foreseeable by the manufacturer, when carried out in accordance with the specifications given by the manufacturer or his authorised representative
8	BS EN 1915-1:2023	2023	*Aircraft ground support equipment. General requirements – Part 1: Basic safety requirements*	BSI	Aircraft refuelling	Not specific to fuelling equipment This part of EN 1915 does not apply to automotive parts approved for public vehicles in the EU and European Free Trade Association (EFTA), when used on GSE for the purpose for which they are designed Closely linked to 12312
9	EI 1540 6th edition	2023	*Design, construction, commissioning, maintenance and testing of aviation fuelling facilities*	Energy Institute	Aviation refuelling	High-level document with a lot of details on aviation fuelling facilities including vehicles and specifically electric powertrains 3.1.1 Lightning 4.15.6 Electric vehicle charging facilities 6.2.3 Electric powertrains
10	REF/ISBN: 9780852938294	2017	*Aviation fuelling hazardous area classification*	Energy Institute	Aviation refuelling	This work was commissioned to provide an authoritative hazardous area classification for aviation fuelling with jet fuel and to propose internationally acceptable direct examples. This was in recognition that there is a large degree of standardization in aviation fuelling vehicle design (hydrant dispensers, refuellers and hydrant carts) and that of vehicle-mounted service equipment

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File ref.	Number	Publication date	Name	Publisher	Area	Relevant clauses
11	14 CFR Part 139	2004	*Certification at airports*	Code of Federal Regulations	Airport requirements	Airport requirements include firefighting equipment and specifications, with no reference to electric vehicles Fuelling personnel training – 139.321
12	NFPA 407	2022	*Standard for aircraft fuel servicing*	National Fire Protection Association (NFPA)	Aviation refuelling	Outlines vital safety requirements for the equipment, procedures and installations related to fuel servicing of aircraft Presently does not include electric fuel servicing vehicles; upcoming update is expected to include this
13	ANSI/CAN/UL 5840:2022	2022	*Electrical systems of battery powered aviation ground support equipment*	American National Standards Institute (ANSI)	Electric ground service equipment	1.1 These requirements cover the electrical system of lithium-based battery-powered airport ground support equipment (GSE) with respect to a risk of fire, electric shock and explosion hazards associated with the battery-powered electrical system 1.2 These requirements also cover these electrical systems when they are used to convert fuelled GSE to battery-powered GSE 1.3 In accordance with 1, the minimum GSE electrical system consists of the battery and integral battery management system, interconnecting cables, and input connections for recharging the battery. In addition, the electrical system can also include powertrain components, electric motors, electric brakes, charging equipment and similar based on manufacturer preference
14	UN ECE R100 ReV. 3	23/03/2022	Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric powertrain	United Nations	Electric vehicles	Wide-ranging requirements for electric vehicles, including safety requirements
15	ISO 5474-1:2024	2024	*Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit*	International Organization for Standardization (ISO)	Electric vehicle charging	This document specifies general requirements for conductive power transfer with a voltage up to 1 000 V a.c. (alternating current) and up to 1 500 V d.c. (direct current) between electrically propelled road vehicles and external electric circuits
16	ISO 17840	2022	ISO 17840 *Road vehicles – Information for first and second responders*	International Organization for Standardization (ISO)	Emergency response	This documents helps to ensure the safety and efficiency of first and second responders during rescue operations involving passenger cars and light commercial vehicles
17	ADR	2017	*European agreement concerning the international carriage of dangerous goods by road*	United Nations Economic Commission for Europe (UNECE)	Carriage of dangerous goods	Outlines regulations for vehicle compliance for carriage of dangerous goods
18	IEC 61851	2014	*Electric vehicle conductive charging system*	International Electrotechnical Commission (IEC)	Electric vehicle charging	
19	IEC 62893	2017	*Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV*	International Electrotechnical Commission (IEC)	Electric vehicle charging	
20	IEC 63110	2022	*Protocol for management of electric vehicles charging and discharging infrastructures*	International Electrotechnical Commission (IEC)	Electric vehicle charging	
21	IEC 62196	2022	*Plugs, socket outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*	International Electrotechnical Commission (IEC)	Electric vehicle charging	
22	UL 1642	-	*Lithium batteries*	Underwriters Laboratories (UL)	Batteries	

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File ref.	Number	Publication date	Name	Publisher	Area	Relevant clauses
23	UL 2580	-	*Standard for batteries for use in electric vehicles*	Underwriters Laboratories (UL)	Batteries	
24	IEC 62133	2021	*Safety testing for lithium ion batteries*	International Electrotechnical Commission (IEC)	Batteries	Secondary cells and batteries containing alkaline or other non-acid electrolytes
25	IEC 62660	2022	*Secondary lithium-ion cells for the propulsion of electric road vehicles*	International Electrotechnical Commission (IEC)	Batteries	
26	ISO 12405	2011	*Electrically propelled road vehicles – Test specification for lithium ion traction battery packs and systems*	International Organization for Standardization (ISO)	Batteries	
27	UL 5840	-	*Electrical systems of battery powered aviation ground support equipment*	Underwriters Laboratories (UL)	Aviation ground support – electric vehicles	
28	UL 2202	-	Electric vehicle (EV) charging systems equipment	Underwriters Laboratories (UL)	Electric vehicle charging	
29	UL 2251	-	*Plugs, receptacles, and couplers for electric vehicles*	Underwriters Laboratories (UL)	Electric vehicle charging	
30	UL/ULC 2271	-	*Batteries for use in light electric vehicle (LEV) applications*	Underwriters Laboratories (UL) Underwriters Laboratories of Canada (ULC)	Batteries	
31	UL 2734	-	*Connectors and service plugs for use with on-board electrical vehicle (EV) charging systems*	Underwriters Laboratories (UL)	Electric vehicle charging	
32	ECE R100 Rev. 3	-	*Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric powertrain*	United Nations Economic Commission for Europe (UNECE)	Electric vehicles	
33	EI 1540	2023	*Design, construction, commissioning, maintenance and testing of aviation fuelling facilities*	The Energy Institute (EI)	Aviation fuelling	
34	14CFR856	-	Title 14 Code of Federal Regulations Part 856	Federal Aviation Administration (FAA)	Legislation	
35	ISO 5474	2024	*Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit*	International Organization for Standardization (ISO)	Electric vehicles	
36	SAE J3400 (Tesla)		*Connectors and inlets for the North American charging system (NACS) for electric vehicles*	Society of Automotive Engineers (SAE)	Electric vehicle parts	

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File ref.	Number	Publication date	Name	Publisher	Area	Relevant clauses
37	SAE J1772	2024	*Electric vehicle and plug in hybrid electric vehicle conductive charge coupler*	Society of Automotive Engineers (SAE)	Electric vehicle parts	
38	Directive 94/9/EC	-	*Equipment and protective systems intended for use in potentially explosive atmospheres (ATEX)*	European Parliament and Council	Legislation	
39	Directive 2008/68/EC	-	*Inland transport of dangerous goods*	European Parliament and Council	Legislation	
40	NFPA 414	2017	*Standard for aircraft rescue and fire-fighting vehicles*	National Fire Protection Association	Emergency response	
41	E/ECE/ TRANS/505	-	UN 1958 Agreement	United Nations Economic Commission for Europe	Legislation	
42	TSO-C63f	-	*Airborne weather radar equipment*	Federal Aviation Administration (FAA)	Environment	
43	ARINC 708-6	-	*Airborne weather radar*	Aeronautical Radio Incorporated (ARI)	Environment	
44	JIG 1	09/2021	*Aviation fuel quality controls and operating standards for into-plane fuelling services*	Joint Inspection Group (JIG)	Aviation refuelling	
45	JIG 2	09/2021	*Aviation fuel quality controls and operating standards for airport depots and hydrants*	Joint Inspection Group (JIG)	Aviation refuelling	

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ANNEX H
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The first list is ordered by reference number as used in this report. The second list contains the same references, ordered by publisher.

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[2] Risktec Solutions Ltd. *Battery EVs for aircraft fuel handling operations – Draft bow tie diagrams* EI-08-R-05, Issue 1.0, 31/01/2025

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[8] International Electrotechnical Commission. *Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV* IEC 62893:2017

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[11] Underwriters Laboratories. *Lithium batteries* UL 1642

[12] Underwriters Laboratories. *Batteries for use in electric vehicles* UL 2580

[13] International Electrotechnical Commission. *Safety testing for lithium ion batteries* IEC 62133. 2021

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[15] International Organization for Standardization. *Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems* ISO 12405

[16] Underwriters Laboratories. *Electrical systems of battery powered aviation ground support equipment* UL 5840

[17] Underwriters Laboratories. *Electric vehicle (EV) charging systems equipment* UL 2202

[18] Underwriters Laboratories. *Plugs, receptacles, and couplers for electric vehicles* UL 2251

[19] Underwriters Laboratories/Underwriters Laboratories of Canada. *Batteries for use in light electric vehicle (LEV) applications* UL/ULC 2271

[20] Underwriters Laboratories. *Connectors and service plugs for use with on-board electric vehicle (EV) charging systems* UL 2734

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[24] International Organization for Standardization. *Electrically propelled road vehicles – Functional and safety requirements for power transfer between vehicle and external electric circuit* ISO 5474:2024

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UL 2251 *Plugs, receptacles, and couplers for electric vehicles*

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ECE R100 Rev. 3. *Uniform provisions concerning the approval of vehicles propelled by electric power*

ECE R105 *Motor vehicles and their trailers intended for the transport of dangerous goods by road*

ADR 2017 *European agreement concerning the international carriage of dangerous goods by road*

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ANNEX I
ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used within this publication:

a.c.	alternating current
AEP	airport emergency plan
APU	auxiliary power unit
ARFF	airport rescue and firefighting
ATC	air traffic control
AVOP	airside vehicle operator permit
AVAS	acoustic vehicle alerting system
BEV	battery electric vehicle
d.c.	direct current
EESO	emergency electric shut-off
EI	Energy Institute
EMC	electromagnetic compatibility
EPTO	electric power take-off
ESC	electronic stability control
ERP	emergency response plan
EV	electric vehicle
FCEV	fuel cell electric vehicle
GSE	ground service equipment
HAZID	hazard identification
HEV	hybrid electric vehicle
HSV	hydrant service vehicle
HR	human response
HV	high voltage
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICEV	internal combustion engine vehicle
ID	Unique hazard identifier
ISO	International Organization for Standardization
ITP	into plane
JIG	Joint Inspection Group
kV	kilo volt
L	likelihood of event reaching specified severity
Li-ion	Lithium-ion
LEV	light electric vehicle
LV	low voltage
MAH	major accident hazard
MNT	maintenance
MVI	motor vehicle incident
OEM	original equipment manufacturer
PPE	personal protective equipment
PSD	passive safety device
PTO	power take-off
R	risk value
R&D	research and development
RAC	risk acceptance criteria
RAM	risk assessment matrix
RFFS	rescue and firefighting services
S	severity of consequence
SAH	significant accident hazard
SOC	state of charge
SOP	standard operating procedure

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