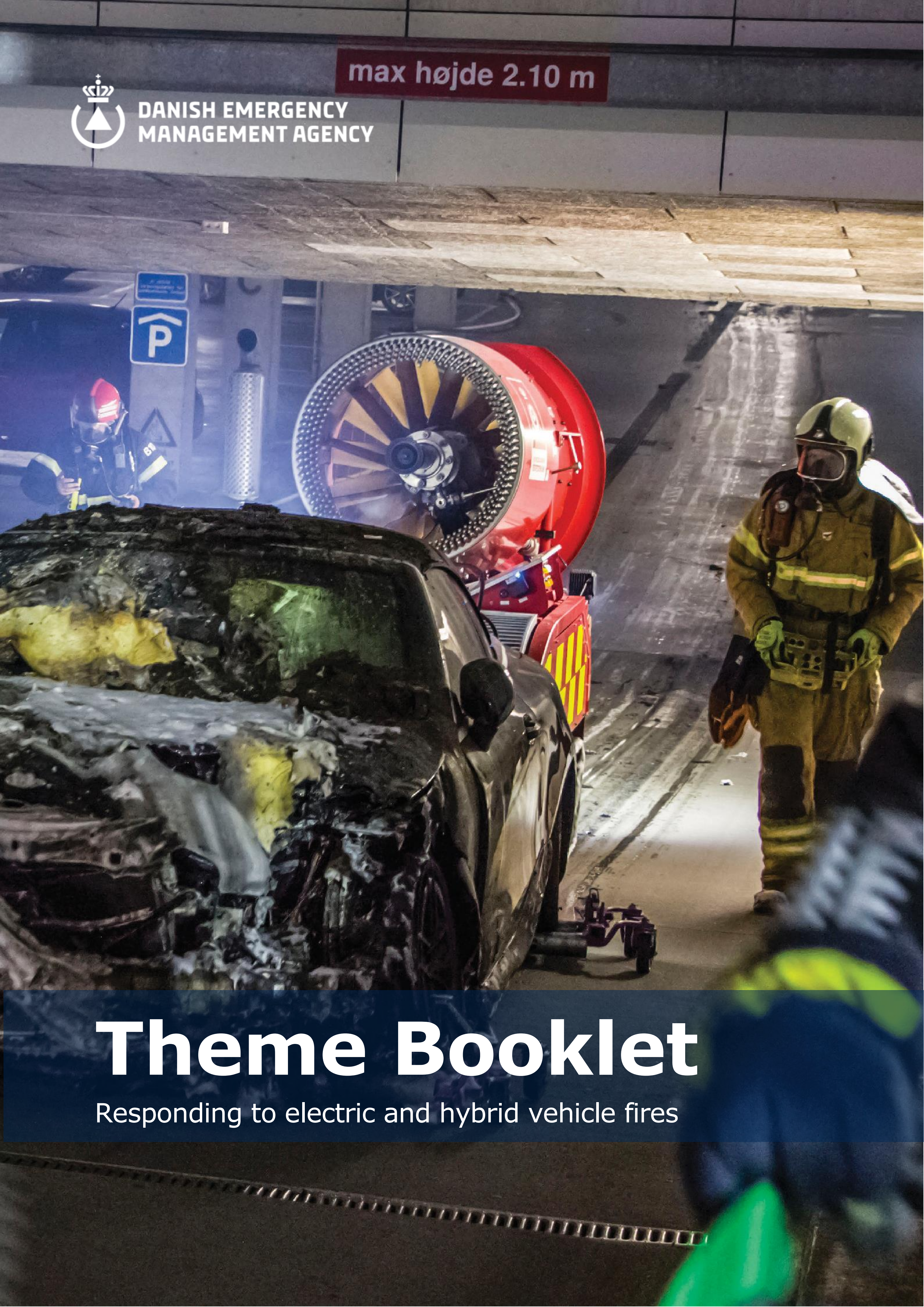
DANISH EMERGENCY MANAGEMENT AGENCY



Theme Booklet

Responding to electric and hybrid vehicle fires

Theme booklet: Responding to electric and hybrid vehicle fires

Front page photo: Bjørn Nielsen/www.bpln.dk

Table of Contents

General information

Response tactics and technical supervision

Appendix

Action card

About learning materials from the Danish Emergency Management Agency

Textbook
A textbook contains an in-depth professional review of a subject area within emergency preparedness. The textbook is for anyone who needs a thorough knowledge of the subject.

Theme Booklet
A theme booklet is a supplement to other teaching and learning materials. The focus of the booklet is on one or more subject areas. As a rule, a theme booklet is targeted a specific professional group, for example, technical leaders or incident commander.

Method booklet
The method booklet has a focus on up-to-date knowledge within a specialised area of emergency preparedness. The method booklet is addressed to firefighters and team leaders who need up-to-date knowledge on the topic in question on a daily basis.

Student booklet
Student booklets are publications prepared according to guidelines from the Danish Emergency Management Agency Centre for Education. It often contains locally relevant cases. Student booklets are prepared for firefighters as a supplement to other learning materials.

Teaching video
Teaching videos are shorter or longer videos that cover one or more professionally defined areas within the different areas of focus. All audiences can view the videos.

Introduction

In connection with the green growth strategy, the Danish emergency response organisation would like its own sector to address the challenges of increased use of lithium-ion batteries (Li-ion) as an energy source in various forms of transport, including electric and hybrid vehicles, in the best possible way.

In December 2020, a political agreement on a green growth strategy for road transport was agreed upon. This agreement is estimated to result in one million zero- and low-emission cars in Denmark by 2030. According to Statistics Denmark, electric and hybrid cars account for an increasing share of new car sales on an annual basis.

This development is expected to continue further in the coming years, along with an increase in emergency response operations, both for passenger electric vehicles, but also for other means of transport, such as buses and ferries.

As a result, the emergency response team will have to react more often in these new types of operations.

In the spring of 2021, the Danish Emergency Management Agency published a new booklet on emergency preparedness in the event of a fire in electric and hybrid vehicles.

Even before it was published, however, it was already clear that the theme booklet would not be sufficient on its own, partly because the use of Li-ion batteries is constantly evolving with, among other things, larger battery packs, and partly because firefighting is only part of the rescue services' efforts in responses that involve electric and hybrid vehicles.

This theme booklet has been created in collaboration with the Danish Emergency Management Organization. A special thanks goes to Nordjyllands Beredskab, Hovedstadens Beredskab and Beredskab Øst for their contributions to this booklet.

This theme booklet replaces the publication 'Indsats ved brand I El- og hybridbiler’ from March 2021.

Danish Emergency Management Agency, January 2023

About Theme Booklets

The development of energy-efficient Li-ion battery packs is moving fast. In several areas of transport, we can expect a general increase in the use of high-voltage battery packs, which are becoming increasingly compact for the sake of usability, among other things.

Today, for example, more electric vehicles (EVs) are being produced with battery packs of up to 1000V. The term electric car usually covers both pure electric cars, hybrid electric cars and plug-in hybrid electric cars of the passenger vehicle class.

The theme booklets 'Responding to fires in electric and hybrid vehicles' and 'Special conditions for rescue in electric and hybrid vehicles' should be read in conjunction with each other. The two booklets describe the health and safety conditions, as well as the response tactics that should be considered in case of road accidents or fires where an electric car has been involved.

A firefighting or rescue response to a road traffic accident involving an electric vehicle that affects the battery pack can be difficult to manage for emergency services and other emergency responders at the scene of the accident.

This is due, among other things, to the high voltage in live cables and in the Li-ion batteries in the vehicles, which have a significantly higher voltage than the regular 12 V batteries in cars.

In a damaged EV, it can also be complicated to gain proper access to live parts to ensure that cables and wires are not live. A fire in the high-voltage battery or the risk of fire can further complicate efforts.

Please note that the theme booklets cover electric cars with high-voltage batteries up to 1000 V.

Photo: Bjørn Nielsen/www.bpln.dk

Structure and use of the theme booklets

The target group is primarily local fire and rescue service technical management, while some aspects will be relevant for individual firefighters. In each section a number of fact boxes are important reading for the deployed crew.

It is based on some general principles for response tactics and co-operation with other emergency response personnel in the response sector. The descriptions of other actors' possible tasks at the scene of an emergency (police, health emergency services and transporters) are solely input for inspiration for a solution that is not necessarily covered by the Emergency Management Act. Any implementation is the responsibility of the relevant authority at the scene of the incident.

The structure of the theme booklets is based on an operational approach. The sections gradually provide rescue services with the knowledge they need to conduct a safe, hazard-free and occupational health and safety response involving electric vehicles. The sections described here cannot be taken on their own, as they are based on some general principles for incident management, etc.

The theme booklets are based on national and international knowledge about electric cars, as well as experience from the municipal rescue services. They expand on existing learning materials, but with updated knowledge about specific risks and response tactics, as previously published materials only provide limited information about electric and hybrid vehicles.

The described conditions can be used in the teaching and training of operational skills in rescue preparedness to raise awareness of the potential risks.

The theme booklets describe the response team's options with general considerations about the working environment and protective equipment that the technical supervisor should observe. In general, the theme booklets highlight a number of guidelines at an overall level. Depending on the situation, technical management is carried out by the team leader or an incident commander.

Some sections can be fully or partially used as a reference for tactical prioritisation during the first response. The material is also intended to provide guidance for the individual rescue organisation's own operational conditions, including the content of action cards.

Finally, there are a number of appendices with various background information, such as characteristics of electric vehicles, use of tools and protective equipment, etc.

Information from alarm, call centre and Acute Medical Coordination (AMC)

The fact that an accident involves an electric car is an important piece of information for the emergency services. All stages before the arrival of the emergency services - from the alarm and control centre, Acute Medical Coordination (AMC) and the first police vehicle - can contribute to this.

The first persons present at the scene of the accident may provide relevant information. This may include the police, emergency medical services, passengers in the electric car or other people at the scene of the accident who can contribute to the early identification of whether an electric car is involved.

Alternatively, information on the occurrence of an accident involving an electric vehicle should be communicated to the first units as early as possible. This allows the crew to take appropriate action, including the calling of additional units and special equipment.

A Q&A guide has been developed that can be used when raising the alarm and by the first vehicles on the scene (see 'Action card - Question guide for call centre, AMC and first responders).

There may also be a need to call the emergency services for road accidents, where they are otherwise not normally called because of the risks an electric car can entail. There may also be situations where the police or health emergency services are first at the scene of the accident. This ensures that their safety is taken care of, as well as the need for a common approach to managing the effort. Separate appendices and action cards have been prepared as a guide.

Technical assistance

In Denmark, a vehicle's means of propulsion can be retrieved by entering the vehicles registration number on the "motorregister.skat.dk" website under the tab "Fremsøg køretøj" (Search vehicle). However, there are exceptions to this, because registration numbers for special vehicles of, for example, the police, defence and emergency services, are not publicly available.

A number of software solutions and information systems can be obtained in advance. What these systems have in common is that they are best utilised via a tablet or similar device. This can be done both online and offline.

The Joint European Organisation for the Safety Classification of Vehicles (Euro NCAP), in cooperation with the International Association of Fire Services (CTIF), has published an App - Euro Rescue[1].

It can be downloaded in the App Store and Google Play, as freeware. The program contains all approved European car brands and describes the structure of the vehicle, including the potential hazards.

Other systems operate via subscription, which provides access to information about the vehicle's data, location of key components, etc.

Summary of general conditions

Increased awareness
When handling electric vehicles damaged in traffic, including rescuing people and extinguishing fires, the response crew should be trained in a number of special conditions. For example, some electric cars have high-voltage batteries up to 1000 V.

Depending on the situation, the team leader or an incident commander carries out technical management. Often, a response operation involving electric vehicles creates additional tasks and a number of risks, which suggests that there is a greater need for an incident commander to oversee or assist the technical management.

The manufacturers own rescue sheets should be followed as far as possible with the proviso that the electric car will most often be damaged.

In addition to the high-voltage battery, the electric car itself may have high voltage in e.g. cables that are still live. Electric vehicles damaged by traffic also carry a risk that their battery packs may spontaneously burst into flames. Both should be part of the risk assessment.

- Identify the location of the main switch and disconnect it if possible. However, in a damaged EV, it can be complicated to gain proper access to relevant parts to ensure that cables and wires are not live.

- Preparing safety hoses with a total water output of at least 400 l/min is recommended - even without visible smoke from the high-voltage battery.

- Wind direction and the safety of people outside the hazard area are to be taken into account due to the risk of fire and the development of smoke and hazardous gases from the high-voltage battery.

A fire in an electric car can quickly develop into a dangerous situation Photo: Bjørn Nielsen/www.bpln.dk

Tools and equipment
Tools used when cutting or touching electric vehicle parts should be approved for 1000 V. You can decide to use safety mats or safety covers.

The technical leader (a specialised team leader) should mark the location for cuts in the bodywork based on an assessment of the location of high-voltage cables (orange in colour) in case it is necessary to cut in the electric car.

Thermal imaging cameras can be useful to monitor the temperature of the battery, which can indicate the development of a fire in the Li-ion battery.

Personal safety
PPE (Personal Protective Equipment) should be approved for work up to 1000 V when handling, touching or cutting the electric vehicle body or cables. Using rubber safety gloves is desirable.

Due to the risk of fire, the smoke diving team should prepare for deployment using full respiratory protection. This should be adopted in cases of smoke development, risk of fire in the high-voltage battery or suspicion of the development of dangerous gases.

A safe distance should be maintained during extinguishing work, due to the risk of contact with live components. In operations where live components and water are combined, extreme caution should be observed.

Consideration should be given to the fact that water - as in rain/snow and extinguishing water - significantly increases conductivity. The risk of arcing should be taken into account when choosing PPE and the correct tools and equipment.

Actions on the incident site
Several authorities are involved in the response to road traffic accidents if there is a danger to people or animals and the emergency services are called.

The deployed forces should be informed as early as possible that an electric vehicle is involved in the accident.

- The damage site should be marked as early as possible as a high-voltage working area at a distance of at least 1 meter from the electric vehicle. This can be done by cordoning off with a black/yellow hazard strip and visibly marking with hazard signs on and around the electric car.

- If smoke or gas is emitting from the high-voltage battery, ensure that no one is in the plume of smoke except personnel wearing full respiratory protection.

If the police and the emergency medical services arrive at the scene before the emergency services, they can assist with the above.

In an emergency, injured persons who cannot get out of the vehicle on their own can be moved if contact with damaged parts of cables and bodywork can be avoided.

Two people should be present when working with live voltage so that the vehicle can be pushed to the side of the road if necessary.

Use of gear and protective equipment

A rescue operation or road accident with an electric vehicle carries special risks compared to a similar operation in a conventional petrol or diesel-powered car.

When it comes to the use of gear and protective equipment, it is important that the crew is instructed and trained in its use and that they are aware of the special risks before they are deployed.

As a concept, electrical components cover both obvious electrical components, such as cables, wires and the high-voltage battery itself, to components that are deemed to be potentially conductive - special metal parts, bodywork, chassis, fenders, etc.

EN 50110-1 specifies that when working near live parts, shields, barriers, enclosures or insulating covers for electrical parts can be used.

Personal protective equipment (PPE), together with electrically insulated covers and insulated tools, are essential measures to address risks when working with electric vehicles under voltage.

Personal protective equipment, such as goggles and rubber gloves, should be used in case of direct or risk of contact with the electrical and voltage-conducting components of the electric vehicle.

Electric cars should not be touched without proper PPE, including safety gloves, which are approved for 1000 V. The following list sets out European standards for different types of personal protective equipment (PPE), the latest versions of which should be used:

Subject	Personal protective equipment (PPE)
Head	Helmet - EN 50365:2003
Eyes	Suitable visor or glasses - EN 166: 2002
Body	Firefighter clothing - EN 61482-1 and 2
Feet/Body	ESD approved footwear - EN 15090: 2012, type F2A
Hands	Suitable gloves EN 60903: 2004
Other covering	"Rubber mats" DIN VDE 0680/1, EN 61111, EN 61112

You can read more about requirements for PPE and the use of these in Appendix 3 on 'Tools, equipment and protective equipment'.

Assessment of voltage in the electric car

In a specific incident, it will be the incident commander or team leader who assesses whether the electric car, and not least the high-voltage battery, is sufficiently intact to be secured, i.e. de-energised, according to the manufacturer's description or rescue sheets.

The high-voltage battery will not be without voltage. That said, disconnecting the main circuit breaker will cause no voltage to be released from the battery.

In practice, the mere fact that the electric car has been in an accident (where emergency services are called) makes it difficult to assess whether the high-voltage battery is still intact.

If there is any doubt about this, it should be assumed that no safety functions in the electric car work normally and that 'all' parts of the electric car can potentially be energised.

The assumption that voltage may be present on the electric vehicle means that, according to EN 50110-1, suitable and sufficient personal protective equipment (PPE) should be worn when working under/with voltage. PPE, insulated tools and electrically insulated covering of conductive materials will minimise the possibility of contact in those areas of the electric vehicle where there may be a risk of contact during work.

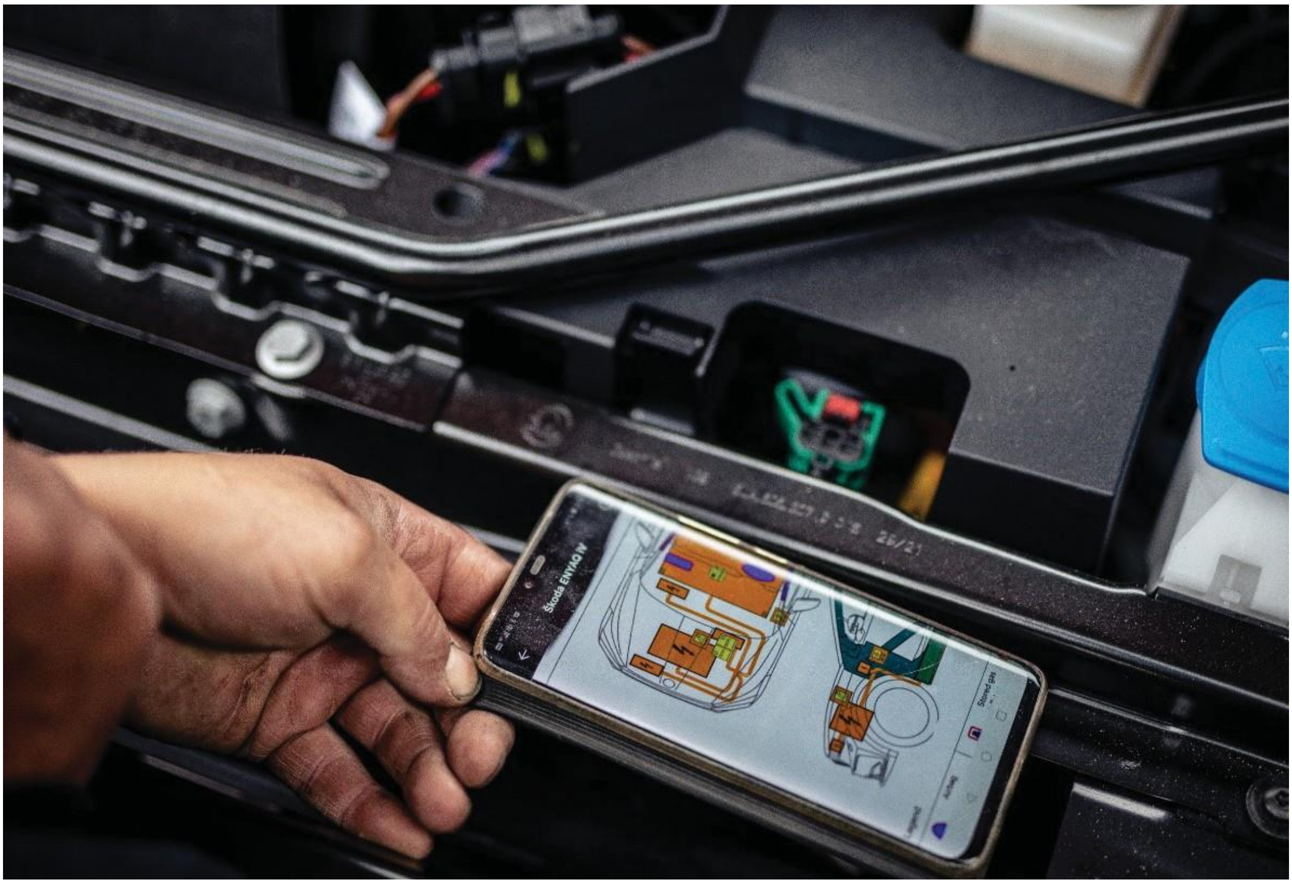
In general, it would not make sense to perform a control measurement of voltage in the electric vehicle in the context of a response. Components with voltage will not necessarily be visible or apparent. There may also be damage so that voltage can be conducted through any random conductive material in the electric car, just by small mechanical impacts to the bodywork, etc.

The emergency response team is not expected to be able to perform this measurement, as it would require prior expertise (e.g. an electrician) to assess the applicability and perform the correct type of measurement in relation to the voltage level.

The response team should pay extra attention to whether the high-voltage battery starts to emit fumes, sounds or sparks, etc. This may indicate that a heat build-up in the high-voltage battery is developing. In addition, as in all work with cars, attention should be paid to the ordinary 12 V battery.

Internationally, rescue sheets and other information from manufacturers are available, and rescue organisations can help assess the voltage in the electric vehicle. However, it is important to be aware that they do not necessarily cover all situations where an electric car is crashed or burnt.

It also requires that the team leader and the crew have access to rescue sheets during the actual response. The crew should be trained in the use of this type of information in advance so that it can best be utilised in a situation where the electric car is likely to be damaged.



Rescue sheets detail the construction of the electric car
Photo: Danish Emergency Management Agency

Tools and marking
In electric vehicles, the manufacturer uses markings/signs to warn crews and other emergency responders of the risk of electric shock. These markings/signs are visible in places in the car where there is a risk of contact with the high voltages from the high-voltage battery.

Orange-coloured cables will contain high voltage. The recommendation is that all contact or work with the electrical components - even without visible damage - be carried out using insulated tools approved for 1000V, approved safety gloves and other PPE.

When working with electric vehicles, the work area should be cordoned off and signs should be posted to signify high voltage hazards. As a general rule, this will correspond to a hazard area with a minimum distance of 1 m to the electric car. Physical barriers such as a black/yellow hazard strip or markings in the form of fire hoses and an articulation of the hazard area can be used.

A further visualisation of the risk of contact with voltage in and around the electric vehicle can be done by marking the electric vehicle with stickers or magnets with a high-voltage danger sign.

Hazard strip markings and danger signs are retained at the end of the operation, when the crew is discharged from the scene and hands over the crashed electric car to other parties such as the police and transporters.

Upon handover, information about the condition of the electric vehicle, the status of the switchgear, including the charging cable, disconnection of the main switch, ignition and any safety devices should be clearly communicated to the new person in charge at the scene of the accident, similar to the instructions in EN 50110-1 for communication when working on electrical installations.

See more in Appendix 6: Handover and transfer of a damaged electric car

IMPORTANT INFORMATION REGARDING VOLTAGE ON THE ELECTRIC VEHICLE

- Pay attention to vehicle labelling for high-voltage components.
- The high-voltage battery cannot be de-energised.
  Avoid touching or cutting orange cables.
- Due to visible and hidden damage in the electric vehicle, a control measurement of the voltage in the electric vehicle is not possible in practice.
- Possibility of using mats, safety covers, etc.
- Tools, instruments and accessories should comply with DS/EN 61010-1 or equivalent. Use of personal protective equipment (PPE) approved to 1000 V.
- The risk of arcing should be taken into account when choosing PPE and the correct tools and equipment.
- The workplace (hazard area) where the electric vehicle is located is limited and clearly marked at a distance of at least 1 m from the electric vehicle.
- Handover to police or transporter upon leaving the scene.

Special attention in the case of fire

A fire in an electric vehicle's high-voltage battery can lead to a different and more complex response than traditional car fires, as in addition to the problem of high voltage, a different and more aggressive fire scenario can also develop.

It is important that the deployed personnel take these risks into account, both in the tactical prioritisation of the response, as well as by using the proper materials, equipment and personal protective equipment (PPE), and that they can manage the risks around the high-voltage batteries (up to 1000V).

It is also important that the individual manufacturers own rescue sheets are followed as far as possible[2].

There is a focus on fire in electric cars or situations where there is a risk that a fire may occur in the electric car's high-voltage battery. The theme booklet is based on the existing knowledge and experiences, obtained from the emergency response efforts in the case of fire in electric cars or the Li-ion battery located in the open air or in a building.

Dealing with a fire in an electric car where the high-voltage battery is burning or at risk of catching fire will often place different demands on technical supervision than in a similar incident in a conventional car.

The theme booklet highlights the tactical options and can support the incident commander and team leader's handling of this type of response - regardless of where the electric vehicle is located. Both when it comes to an offensive response, possibly with acute danger to life, or a defensive response, which allows for better 'planning' of the response, as both types will entail a number of special conditions in relation to a safe working environment.

It is necessary for the operational forces to be familiar with the special characteristics and risks of electric vehicles so that a proper response can be carried out, based on the assessment of the possibility of ventilation of smoke, deployment time and water consumption for extinguishing the fire, etc. Particular attention should be paid to the relatively short deployment time, high water consumption, marking of the area and passing on information at the end of the response.

As a supplement to the theme booklet, it is a good idea to consult the Danish Emergency Management Agency's theme booklet on 'Special conditions for rescue in electric and hybrid cars', which describes the special risks involved in freeing trapped people in electric vehicles.

Risk of fire

A fire can occur spontaneously in the high-voltage battery due to a number of defects. The risk of damage to battery cells such as impact, shock and penetration of the battery membranes as well as overheating of the battery pack can lead to sudden and violent fires.

The risk of fire is also present - even if there is no identification that a fire is under way in the battery. The fire can break out up to several hours and even days after the incident has occurred.

Given the response time of the emergency services, the fire will often be advanced, which can make it difficult to assess the cause of the fire. However, identifying whether it is a fire in the EV itself or a fire in the battery should be done as early as possible. It is important to understand that a seemingly simple fire in an electric vehicle can quickly change if it reaches the battery.

If you need to free trapped people or deal with an electric vehicle where contact cannot be avoided, you can read more about prioritisations, protective equipment and the five phases of rescue in the theme booklet 'Special conditions for rescue in electric and hybrid vehicles' in the section on response tactics and technical management.

Special conditions in fire processes
Fire, smoke and the damage/deformations that are clearly visible on the electric vehicle help indicate a possible risk of a damaged high-voltage battery. It can be heat development, 'thermal runaway', sounds, smoke development, unnatural odours or fluid running out of the battery.

Damage to the battery, such as impact, shock and damage to the battery's membranes, as well as overheating of the battery, can lead to a risk of severe fires. The causes of a fire in an electric vehicle's high-voltage battery can generally be divided into three types of conditions.

- Indirect impact: Heat impact that affects the battery from the outside, such as overheating by arson of an electric car or a fire in a building where an electric car is parked.
- Internal influence: Electrical short circuit where there is an internal fault in the battery cells, e.g. due to overcharging.
- Direct impact: Mechanical deformation (bent, penetrated, crushed, etc.) where, for example, a violent road accident causes a defect in the battery, resulting in a short circuit resulting in fire and the release of hazardous gases, etc.

A fire scenario in the event of a fire in a high-voltage battery develops rapidly. There is usually an odd sound from the battery. Next, the battery will produce smoke and eventually burn, possibly with smaller jet flames or slight explosive discharges, as the cells in the battery pack 'ignite'.

Extinguishing experiments with asphyxiating extinguishing agents have proved ineffective and unsuccessful, as Li-ion batteries burn by means of a self-oxidising process. The process can 'feed' itself without the supply of oxygen from outside. This can cause violent temperature increases of up to approximately 1.000°C.

If effective cooling of the overheated battery is not initiated, the battery fire will continue until no more flammable material is present. This process typically lasts from 2 hours up to one day.

RISKS WHEN COOLING THE HIGH-VOLTAGE BATTERY

- Li-ion fires can emit hydrogen fluoride gas (HF gas) in peaks of high concentrations. Gas emissions from the Li-ion battery can be white-ish, thick and smelly and settle along the ground, but can also appear as thick smoke.
- It is important that the battery is located for effective cooling/extinguishing of flames. Location of high-voltage battery can be in the bottom of the car, trunk, under the hood or in the middle of the car between the front seats.
- Be aware of re-ignition of the battery after extinguishing the fire.

Risk assessment in the event of a fire in the high-voltage battery

Li-ion batteries vary in size, voltage and capacity, but typically range in voltage from 400 up to 1000 V. High-voltage batteries based on Li-ion technology store energy using chemicals. Experiments have shown that Li-ion batteries themselves are not more flammable than other batteries if the batteries are not damaged, and charged with approved equipment.

If the incident commander or team leader assesses that there is a risk that a fire may start before the rescue effort is completed, special considerations should be taken. A simple fire sequence in an electric vehicle's high-voltage battery can quickly change very violently and the smoke from a high-voltage battery can create large amounts of, among other things, HF gas.

Typically, in newer 'pure' EVs that rely on a large battery, the location of the high-voltage battery will be at the bottom of the vehicle. However, the batteries can also be placed in the luggage compartment, under the hood or in the middle of the car between the front seats. Cooling should be as direct on the high-voltage battery as possible. Covers can be removed to achieve a better effect.

When a fire develops in the electric vehicle, care should be taken to ensure that people without respiratory protection are not exposed to smoke, gas or remain in the smoke plume.

In the event of the development, or just suspicion, of a fire in the electric vehicle, full respiratory protection is put in place to avoid exposure to the smoke. If the fire is in a sealed room with no possible ventilation, it can present a challenge to deployment time.

The purpose of using fire hoses with a strong water output is to provide protection for people in the hazard area (safety) - and to cool or, if possible, limit the spread of fire to the surrounding environment and vehicles (extinguishing). It is recommended using safety hoses with a total water output of at least 400 l/min[3].

Whether or not a fire in the battery can be extinguished or cooled sufficiently with 400 l/min will be a practical judgement that should reflect the chosen response tactics so that unnecessary amounts of water are not used.

Work with a safety distance corresponding to the water output, jet pattern and extinguishing agent. The following are recommended distances for extinguishing electrical fires (52mm solid bore fire nozzle with a pressure of 5 bar - DIN VDE 0132). The safety distance to the nozzle is recommended to be:

- Low voltage <1000 V, 200 l/min: - scattered beam – min. 1 m; concentrated beam - min. 5 m
- High voltage > 1000 V, 200 l/min: – scattered beam – min. 5 m; concentrated beam - Min. 10 m

Four safety considerations with regard to fire in electric cars should be observed by the firefighters:

- **Gases/vapours/smoke:** Some of the chemicals in a Li-ion battery (often volatile organic solvents) can produce flammable vapours with a low flash point if they leak.
  - For example, HF gas can be developed, which is not flammable, but is a toxic and colourless gas with a pungent odour. The gas is easily soluble in water and can end up in the extinguishing water as hydrofluoric acid. Hydrofluoric acid is a colourless solution that can cause corrosive damage on contact.

- **'Thermal runaway':** At high temperatures, the Li-ion battery can enter a critical state, starting an internal self-reinforcing decomposition process ('thermal runaway'), which ends with each battery cell being heated vigorously from within when the stored chemical energy is released.

- The 'thermal runaway' can only be stopped by cooling the battery cells, which is made difficult by the fact that the batteries, for safety reasons, are wrapped in protective measures and placed in safe or hidden places in the vehicle.
- There may be a risk of pressure bursting a closed battery box regardless of battery type[4].

- **Re-ignition of the battery:** In order to ensure the safety of the crew in the event of an accident with a Li-ion battery, the incident commander/team leader should be aware that a fire may occur spontaneously in the battery due to defects.
  - This is even if there has been no prior indication that a fire is developing. These conditions can happen up to several hours and days after the event has occurred. It is important to give important information to the transporter.

- **Stranded energy:** There may be stranded energy left in the battery cells that have not been burned or otherwise affected.
  - This poses a great risk to the response team working on the electric vehicle during or after the response. Stranded energy cannot be 'tapped' by an electric car.
  - In addition, it should be considered that the high-voltage battery cannot be de-energised.

In a fire in a Tesla during charging on 1 January 2016 in Brokelandsheia in Norway, a fire broke out in the high-voltage battery of the electric car. The fire lasted 23 hours and the car was completely burnt out. After the extinguishing efforts were over, 400V high voltage was still present in about ¼ of the battery.
Photo: Østre Agder Fire Department

'Thermal runaway' trials

'Thermal runaway' is a description of a temperature increase in the high-voltage battery, where heat in the internal components leads to pressure on the battery cells. It initiates a process of acceleration of increased temperature and release of additional energy. The problem with 'thermal runaway' can arise if the battery cells or the thin partition/diaphragm, which keeps the components of the battery pack separate, are damaged or otherwise punctured, which can lead to a short circuit.

It is important to be aware that damage and deformation to the damaged electric vehicle can increase the risk of developing a 'thermal runaway' and fire in the high-voltage battery. The risk of thermal runaway occurs when the critical temperature (down to around 90°C) in the high-voltage battery is exceeded.

It can be difficult to identify whether there is a heat build-up and thus a risk of fire. However, identifying this, for example through the use of a thermal imaging camera, should be done as early as possible. Other signs of an incipient fire in the battery can be vapours, smoke, noises, etc. from the high-voltage battery.

QR code for a video about 'thermal runaway'

QR code for a video with an incident involving a 'thermal runaway'

In 2016, two full-scale trials of fire in electric cars were conducted in Norway. An experimental report 'Full-scale fire test of electric vehicles'[5] was completed, which includes a description of the development of the fire, including temperature development, etc. The first experiment described in the report describes a 'thermal runaway' triggered by a rear-end collision of the electric car. The speed corresponds to a collision at 70 km/h.

The Swedish research institute RISE has published a number of reports on Li-ion batteries and electric vehicles.[6]

The National Transportation Safety Board (NTSB) has published a study report entitled 'Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles'[7], based on three accidents involving electric vehicles, which have subsequently led to emergency response measures. The report's conclusions describe the same kind of consequences in electric vehicle accidents that result in thermal runaway. In the video, the NTSB explains the incidents and what to look out for when responding.

The NTSB report on the safety of electric vehicle fires.

Main switch
High-voltage batteries in an electric car have a high DC voltage and contain significantly more energy than the ordinary 12 V batteries in a passenger vehicle with a petrol or diesel engine.

In the case of an electric car, it is essential for the crew to disconnect the main circuit breaker if this has not happened, and thereby make all the electric vehicle's systems powerless. The main circuit breaker is positioned differently, depending on the brand or model.

Electric cars typically have one or more 12 V batteries, which can be disconnected in the usual way. The 12 V part will remain supplied with voltage until one of the battery terminals is removed in the 'normal' way. It should be noted that the battery pack itself (Li-ion) cannot be de-energised.

ON DISCONNECTING THE MAIN CIRCUIT BREAKER

A distinction is made between the ordinary 12 V batteries and the high-voltage batteries.

Please note that the high-voltage battery itself cannot be de-energised.

If an electric car has been involved in a road accident and has subsequently burst into flames, the main circuit breaker is very likely to be disconnected. This means that there will be no voltage in the electric car's systems, except in the high-voltage battery itself.

Note that if the battery pack is mechanically deformed, parts of the EV chassis etc. may be electrified.

There are several indicators that the main circuit breaker may be disconnected in connection with a road accident. These include:

- High energy accident, without the items below
- Activated airbags or belt tensioners
- Rear or frontal collision
- Side collision

Electric vehicles under charge
If a damaged electric vehicle is connected to a charger, there will be an increased risk for people who come into direct contact with the electric vehicle. The reason for this is that a voltage path can be created through the ground conductor, which means that the person can be shocked by contact with one pole.

The electric car is relatively safer if the ground connection through the charging cable is removed - you would then need to touch two parts of the car to come in contact with a dangerous voltage. However, most electric cars lock the plug when the cable is connected, which means that it is difficult to get the cable out. Common rescue equipment will typically not be considered compliant with EN IEC 60900, which is prescribed for working under voltage.

However, if the car has been involved in an accident, all normal safety measures in the car are assumed to be ineffective. The high-voltage battery terminals can be directly exposed or have an electrical connection to chassis parts that are normally insulated.

Therefore, proper personal protective equipment (PPE) should be used so that when switching off or disengaging, it is not possible to come into (electrical) contact with several different conductive parts of the car at the same time. Use of mats and safety covers is advised.

SAFETY WHEN WORKING WITH ELECTRIC VEHICLES

The following measures are particularly important in order to achieve the best safety when handling a damaged or burning electric vehicle:

- If the electric vehicle is connected with a charging cable to a charging station, this should, if possible, be removed or disconnected completely before any further work is done directly on the electric vehicle, for example by disconnecting the power supply to the cable by disconnecting the group using the RCD/switchboard.
- Insulated mats can be used, where the earth conductor/charging cable cannot be disconnected.
- If possible, the main circuit breaker in the vehicle should be disconnected before further work - its location is available via relevant rescue documents/APPS.
- Please note, however, that if the high-voltage battery is damaged or the electric vehicle is mechanically damaged by pressure or breakage of metal parts, it should be considered that the risk of unintentionally energising the vehicle, even if the charging cable and main switch are disconnected will be very high.
- If direct contact with a damaged electric vehicle is required, it is always recommended to use personal protective equipment (PPE) and equipment as previously described, as well as safety covers.

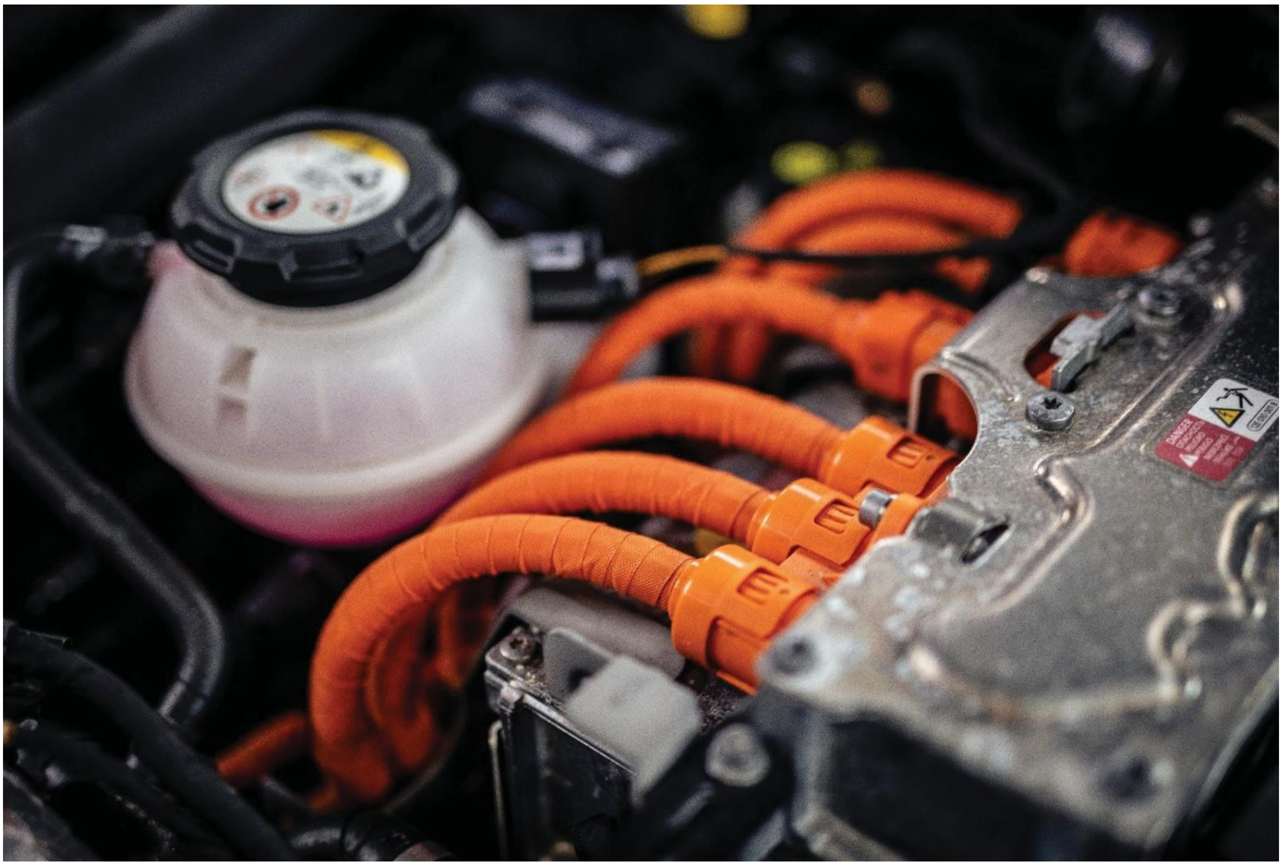
Location of the high-voltage battery

Depending on the vehicle brand, the high-voltage battery can be located in different places in the electric vehicle. Certain vehicle brands have the batteries placed in the same place, regardless of the model, while others have the battery located in different places.

Larger battery packs will often be located at the bottom of the electric vehicle, but can also be in the trunk, under the hood or in the middle of the vehicle, between the front seats.

In general, access to the high-voltage battery can be very complicated, due to the membranes in the battery pack and a location where availability can be extremely limited due to damage to the body.

The location of the high-voltage battery and whether it is damaged influence the technique and response tactics that the crew should use during the operation.



Cables with high voltage will most often be orange, as here in the engine compartment Photo: The Danish Emergency Management Agency

You can read more about safety, special risks and applicable legislation, regulations and standards in appendix 2 on 'Safety when working with electric vehicles'.

IMPORTANT INFORMATION FOR THE FIREFIGHTER

- Personal protective equipment (PPE) approved for 1000 V: Safety gloves, protective clothing (arc flash protection), safety helmet with visor - alternatively safety goggles/eye protection, approved footwear or step mat for contact with the electric vehicle and disengagement.
- Safety equipment: Tools approved for 1000 V. Insulating rubber mats must be used to cover conductive material. High-voltage batteries in an electric car have a high electric DC voltage and contain significantly more energy than the ordinary 12 V batteries in a passenger vehicle with a petrol or diesel engine.
- During an intervention in an electric vehicle, it is essential for the crew to disconnect the main switch if possible and de-energise all the electric vehicle's systems.
- If this is not possible, it is important that a safety distance is taken into account when extinguishing the fire, depending on the water output and extinguishing technique.
- Please note that the high-voltage battery itself cannot be de-energised.
- Two people must be present when working under voltage to ensure that someone can step in in the event of an electric shock.
- Marking of the hazard area with high voltage signage - this is maintained upon clearance of the incident site (min. 1 m).
- Assessment of the condition of the vehicle's high-voltage battery, disconnection of the main switch, voltage, damage to cables.
- Extra attention if sounds, smoke, or unnatural odours are observed from the battery or fluid running out of the battery. This may indicate heat development/'thermal runaway' in the high-voltage battery.
- Marking with barriers and 'Danger - high voltage' signage is maintained after the intervention when handing over to the police or haulage company. Avoid unnecessary twisting of the vehicle during the operation and while it is being loaded onto the transport.

Response tactics - Fire

In the event of a fire or identified risk of thermal runaway in an electric vehicle, there are two types of intervention that can be used. The method used will be decided depending on the situation.

- Fire in high-voltage battery with an *offensive approach*. Direct switch-off and cooling of battery- or electric vehicle.
- Fire in high-voltage battery with *defensive approach.* Let the electric car burn out, place in an electric car container or similar option for cooling.

In addition to the above, it will be possible to carry out combination efforts where an offensive approach is first used and then a defensive approach, for example in the event of a fire in an electric car in a building.

It should be noted that the development of a fire in the high-voltage battery will be difficult to extinguish, and that an offensive or defensive approach will therefore often be about ensuring that fire does not spread to related vehicles, building parts, etc.

When setting up the incident site and hazard area, it is important that the technical leader ensures that the hazard area is large enough so that emergency personnel who have not worn full respiratory protection and other persons are not exposed to smoke. The same applies to the location of equipment and vehicles, regardless of whether the electric vehicle is located in the open air or in a building.

In the event of a fire in the high-voltage battery, decisions on a number of factors should be made by the technical leader early in the intervention process:

- Need for additional personnel, as the job may take some time
- Temporary or continuous water supply
- Logistics around fire suits, compressed air appliances, cleaning point, etc.

Furthermore, the technical leader should be aware of the risk of the incident developing, as the smoke from the high-voltage battery can create large amounts of HF gas. These elements should be taken into account by the technical leader when establishing the cordon area and placing the facilities necessary on site.

Precautions in the event of an electric vehicle fire
Common to both the offensive and the defensive effort methods is that in the vast majority of the efforts, there is no immediate danger of the crew receiving an electric shock from the vehicle's high-voltage system. The battery and electrical components are a closed system that operates independently and is separate from the rest of the vehicle structure.

It is essential that the main switch in the electric vehicle is disconnected if this has not happened automatically.

There is only a risk of electric shock, if there has been damage to the high-voltage electrical components or a fire has occurred in the high-voltage battery. If the electric vehicle is charging, there should be a special focus on disengaging/disconnecting the charger.

To minimize the risk of damage to personnel and equipment, it is important that the deployed personnel continuously assess the situation in relation to damage development and the current risks on site.

The deployment time should reflect the time that is necessary when using breathing apparatuses, to ensure that PPE is removed correctly (guidelines on handling and cleaning of turnout gear). In practice, this means that with an air content enabling approximately 30 minutes of working time (depending on what kind of work is performed, access path, etc.), the actual working time will be around 20 minutes. This is already known from hazmat incidents, where firefighters in hazmat suits who do not use an air bank have to pull out before the withdrawal signal on the device sounds.

As a rule of thumb, one should avoid contact with smoke and escaping gases and deploy 'with the wind behind you' in the hazard area. If work is carried out in the vicinity of the hazard area, where the crew can be exposed, for example, by changing wind direction, the correct PPE should be used. All equipment must be decontaminated after national guidelines.

IMPORTANT INFORMATION FOR THE FIREFIGHTER

- Avoid staying in the smoke without full respiratory protection.
- Be aware of the actual working time when taking into account stricter procedures for decontamination.

Safety hose minimum 400 l/min

- Attention to the risk of electric shock through extinguishing water.
- Safety distance equivalent to extinguishing a fire with 1000 V present.
- Safety distance to electric vehicle of at least 1 m to avoid unnecessary contact.
- Attention to development on the incident site.

Prior to starting
If the EV's high-voltage battery has been damaged and high-voltage power cables have been exposed, there will be a risk of high voltage being present in the body of the EV.

Therefore, it is important that the crew takes the necessary precautions. In addition to the use of an immersion suit and a smoke extraction apparatus, the crew should use safety equipment and tools approved up to 1000 V.

In the process of securing the vehicle, it is important to focus on the personal safety of the crew and any bystanders. In the event of a fire in an EV battery where the main switch is not disconnected, there will be a minimal risk of the EV moving on its own power - if it is in gear.

To avoid this, it is important that the electric car is secured. There are devices such as a 'plug' to insert into the charging socket, which causes the electric car to go into charging mode so it can't be driven. Depending on the extent of the fire, this may be an option.

Electric cars have a high torque, which means that the securing of it should be effective. Cribbing should be carried out if possible. If the main switch is disconnected, the electric vehicle will not be able to start and drive itself.

For some types of electric vehicles, capacitors are located at each wheel. These have an auxiliary function when starting and braking and in this connection generate power.

During the operation
In the event of fire in electric vehicles, personnel within the safety distance should wear full respiratory protection. In cases where the electric car is burning in the open, BA teams (Breathing apparatus teams) should be deployed with the wind behind them and for the shortest possible time. This is to minimise the exposure of hazardous substances to the turnout gear.

Do not allow the BA teams to come into contact with electrical components. If this cannot be avoided, protective equipment approved for 1000 V must be used.

If the electric vehicle is charging and it's not possible to disconnect the charger, use the correct safety distance. This also applies in the event of a fire in the battery itself. Work with a safety distance corresponding to the water output, jet pattern and extinguishing agent. The following are recommended distances for extinguishing electrical fires (52mm hose with a solid bore nozzle at a pressure of 5 bar - DIN VDE 0132). The safety distance to the nozzle is recommended to be:

- Low voltage < 1000 V, 200 l/min:
  - scattered beam - min 1 m; concentrated beam - min 5 m

- High voltage > 1000 V, 200 l/min:
  - scattered beam - min 5 m; concentrated beam – min 10 m

Battery access
To gain access to the essential components of the electric vehicle, it is important not to cut a hole in the bonnet or cut the car's side panels, as there then is a risk of hitting high-voltage components if the main switch is not disconnected.

Cooling or turning off an electric vehicle's battery can be difficult, due to the location of the battery. Depending on the brand of the vehicle, the battery may be located in different places in the vehicle. Some vehicle models have the batteries placed in the same place, regardless of the model, while other vehicle brands have placed the battery in different places.

The battery can be located at the bottom of the vehicle, in the boot, under the hood in the middle of the vehicle or between the front seats. This has an impact on extinguishing efforts, as it can be a problem to cool or switch off the battery.

It is important to determine the location of the battery as early as possible, as it affects the deployment method (technique and tactics) that the response team should use during the response.

Note that the high-voltage battery itself cannot be de-energised.

Battery frame integrated under seats in the cab. Photo: Toyota

Monitoring and cooling the battery
If the critical temperature of the Li-ion battery (90-250 °C depending on the type) is exceeded, a 'thermal runaway' may occur, which may cause the battery to either burn or burst.

Therefore, any temperature development in either the high-voltage battery or the car fire should be monitored, for example with a thermal imaging camera, which can be done on an ongoing basis.

Cooling with water directly on the battery pack can be effective in some cases. However, it should be noted that the effect should be monitored with a thermal imaging camera, as the location, construction and packaging of the battery can make it difficult to achieve effective cooling.

Method for lifting the electric car for a more direct cooling of the battery pack at the bottom of the car
Photo: Hovedstadens Beredskab

Response to electric vehicles on fire, in completely and partially enclosed spaces

Prior to response
For electric vehicle fires in enclosed or partially enclosed spaces such as underground car parks, the response depends on whether the battery is on fire and whether people are at risk. If there are people at risk, an offensive tactic should be used.

If only the battery is on fire, a particular point of attention is the smoke from the fire, as it contains a high concentration of harmful substances.

It should be assessed whether to carry out a relatively resource-intensive offensive response, with the risks this entails in terms of smoke dispersion, large amounts of extinguishing water on the floor, short deployment time for BA team teams, etc. or whether it is possible to remove the electric car from the building. However, this requires the use of special equipment in order for this type of action to be possible.

During the response
In enclosed spaces without any form of ventilation (natural or mechanical), the deployment time will be relatively short, as the deployment time should reflect the time taken after the smoke diving to decontaminate PPE according to national procedures.

In practice, this means that with an air content enabling approximately 30 minutes of working time (depending on what kind of work is performed, access path, etc.), the actual working time will be around 20 minutes. This is already known from hazmat incidents, where firefighters in hazmat suits who do not use an air bank have to pull out before the withdrawal signal on the device sounds.

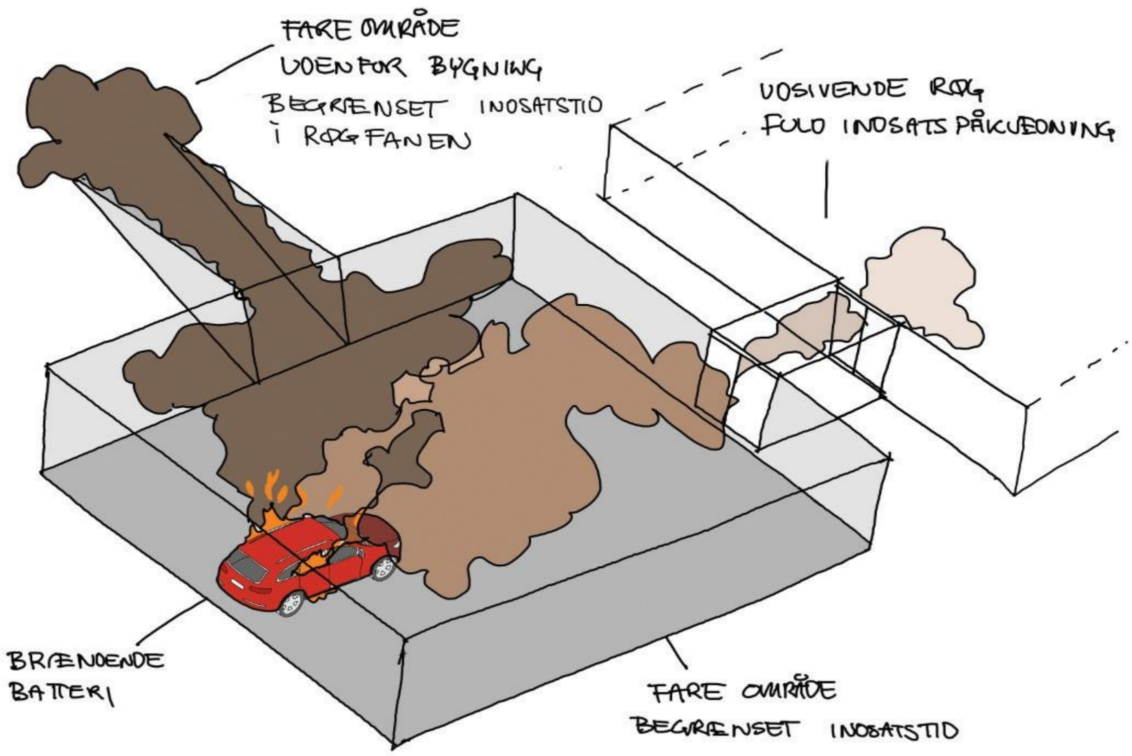


Illustration: Hovedstadens Beredskab, 2022

Overall, the deployment time (with full breathing equipment) is influenced by the firefighter's activity level. The concentration of leaking gases from the battery and smoke is likely to be lower in spaces with better ventilation, but this is of minor importance for the exposure itself, which should be managed regardless of the concentration of smoke and gases.

This will of course be a specific assessment, as conditions such as the amount of smoke can change quickly in the 'adjacent' spaces as well.

Attention should be paid as to whether there is, for example, a doorway to the hazard area - either as an access route for smoke extraction teams or a door that is left ajar to make room for the fire hoses.

It may be possible to distinguish between whether the crew in the 'adjacent' space is working, or whether it 'only' is being used as a passageway.

In general, spending time - working or walking through - smoke-filled spaces should be kept to a minimum. In this context, additional ventilation can be considered in terms of risks or benefits.

Once the EV is outside the building, the decision to use offensive or defensive response tactics should be reassessed.

QR code for video with 'thermal runaway' in a parking garage

After the response

After the fire has been extinguished, the crew should continuously assess the potential temperature development in the battery, e.g. by taking temperature measurements or monitoring the development of smoke, vapours or noises that may indicate a possible temperature change in the battery.

The battery, due to the process it has undergone, can generate heat and thereby exceed the critical temperature long after the fire has been extinguished and the electric car appears to have cooled down. This can last up to 24 hours after ignition - however, there have been cases where the battery ignites several days after the initial ignition.

In terms of personal safety, it should be assumed, as in a 'normal' fire, that the substances (fluorine compounds, metals, etc.) are present until all surfaces are sanitised.

It can be a good practice to inform emergency services and others who will be in the space about the intervention. Then they can take the necessary precautions in relation to the use of personal protective equipment (PPE) such as disposable gloves, filter mask/respirator, protective suit, etc.

Special attention should be devoted to any extinguishing water that may contain various substances that can be harmful to the environment and health. If the water is collected in a container, e.g. when the battery is immersed in water, the water may contain substances that must be handled correctly. See the 'Farlige stoffer' app.

Defensive action in the event of fire in electric vehicles

Response to electric cars on fire in the open air

In the event of a fire in an electric vehicle, a quick decision should be made as to whether the fire in the electric vehicle should be extinguished or allowed to burn out. This depends on an assessment of the specific situation.

If the electric vehicle, for example, disrupts critical infrastructure, it would make good sense to carry out a rapid and offensive shutdown with subsequent cooling and transport. The same could be true in a densely populated area where the smoke will pose a danger to people if the electric vehicle is not moved.

If, on the other hand, the electric car is parked in an isolated location, the solution may be to let the electric car burn out, taking into account the consequential pollution that would be caused by extinguishing the fire in the vehicle in that location. If a temperature increase is detected in the battery, it must be assumed that a 'thermal runaway' has been started, which must be dealt with again.

Characteristics of electric vehicles in water
Electric vehicles that are submerged in water[8] should not, as a general rule, be engaged with unless it can be done in a safe and secure manner. If possible, try to turn off the ignition so that the electric car 'shuts down' while it is in the water.

An electric vehicle that has not been involved in an accident or otherwise had its battery damaged does not generally pose a greater risk than other electric vehicles when removed from the water.

When the electric car is salvaged, it is handled in the same way as an electric car on solid ground. In this process, there is a risk of CO and HCL vapours being released. The same applies if the battery is damaged before the electric car has been driven into the water.

Fire in an electric car without fire in the battery
In most cases, when there is a fire in an electric car, it is the electric car itself that burns and not the battery. This type of car fire, therefore, should be considered a 'common' car fire.

However, it is essential that the crew is aware of the possible heat impact that this fire may have on the battery. If the battery is heat affected, there may be a longer deployment time than in the case of a conventional car fire.

Working with high voltage
Responding to incidents with electric cars involves special risks compared to responding with a petrol or diesel-powered car. Here are the risks of working with high voltage - and the use of extinguishing water - that the crew should be aware of.

According to IC/EN 61140: (International Electro-Technical Commission), the level of high voltage is above 1500 V DC (D.C.). According to IEC, when the voltage level is less than or equal to 1500 V D.C., it is not high voltage, but low voltage.

For alternating current, the level of high voltage is above 1000 V A.C. This means that, in a technical sense, there is no high voltage in the electrical system of the car.

When the term 'high voltage' is used in the theme booklet, it must be seen in relation to the voltage found in cars' 12 volt systems.

You can read more about safety and use of tools in appendix 2 and appendix 3.

Aids in extinguishing fire

Water supply for cooling and extinguishing
In the event of a fire or temperature rise in an electric vehicle's battery pack, it should be cooled effectively. It is therefore important to ensure a stable and sufficient water supply from the start of the response, corresponding to a minimum of 400 litres per minute.

Based on the 112 notification, a first response should be put together that reflects the expected water consumption.

When cooling and extinguishing a battery, it should be ensured that equipment, including nozzles, approved for extinguishing fires in electrical systems, are used.

Thermal imaging camera
The use of a thermal imaging camera can be used to check whether a high-voltage battery is affected by temperature and to monitor the effect of the initiated cooling. However, be aware of any protective cover or casing on the battery, as this can lead to significant measurement errors.

If the high-voltage battery is located at the bottom of the vehicle, the vehicle can be raised for more efficient cooling and to better measure the temperature of the battery.

Use of a fire blanket
In some cases, it may make sense to use a fire blanket. However, there are a number of things that the crew should be aware of:

- A fire blanket will not be able to extinguish the fire itself in the high-voltage battery - it will only limit flames and smoke.
- Due to escaping gases, high pressure can develop underneath the blanket, which can lift it. This is due to leaking gases that are not ignited.
- There is a risk of selective burning through the blanket due to high temperatures.
- The crew should be trained to use a fire blanket.
- Space is required around the electric car if the fire blanket is to be used correctly.

Application of a fire blanket
Photo: Østre Agder Fire Department

Use of overpressure fan
An overpressure fan can be used for several purposes. Outdoors, it can be used to vent the smoke from an area that is desired to be protected and thereby 'steer' the smoke in a certain direction. As the fan has different and limited capacities, the effect will be very dependent on the natural ventilation on site.

Indoors, such as in parking basements, overpressure fans can be used to vent smoke, thereby helping to extend the deployment time by improving the working environment and visibility as well as minimising damage to the surroundings. Its use should be assessed together with the tactical approach chosen to create a quality response.

The speed of advance of the BA teams in a building depends, among other things, on visibility.

Effective ventilation can contribute to a safer and more efficient operation. This assumes that the crew is trained in ventilation tactics, including the effect of ventilation on the course of the fire.

It should be noted that pressurisation is a defensive tactic for underground car parks, which can cause smoke to spread to stairs and exit routes, which can prove to be inappropriate.

There are a number of custom-made fans that have an increased power compared to traditional fans. An example is LUF60, which has a max. ventilation effect of 90 m^3/min.

Use of LUF 60, for ventilation and towing of an electric vehicle from underground car parks or parking garages
Photo: Hovedstadens Beredskab

Removing a car from a basement car park

In general, extinguishing efforts in basement car parks and other parking facilities should take into account long access paths through several building sections.

As part of the response, it should be considered whether it is appropriate to remove one or more cars as a preventative measure to prevent the ignition of more cars, or as a direct measure to remove the burning electric car.

In both cases, the decision on who can perform the task should be based on careful consideration of the risk to the crew, and thus whether the task can be performed by someone other than the rescue organisation.

The task of removing cars is planned and coordinated taking into account any other deployed crew and may possibly be carried out using "roller skates" under each of the wheels of the car.

In the case of longer distances or driving on platforms, ramps or inclines, towing vehicles, robots or other devices may be used.

Immersion in a container with water

Using a water-filled container is an effective way of cooling a battery. A fire extinguishing container can be designed as a tightly fitted vessel, where nozzles at the bottom and at the sides will be able to create an effective cooling of a battery.

The electric car can either be loaded with a crane or pulled in from the rear of the container with a winch. During transport to storage, etc., there should be continuous cooling of the battery.

If it is not possible to use a fire extinguishing container, an alternative would be a more low-practical solution - a standard container with a sealed base and side lining with a reinforced tarpaulin.

The cooling can be done by filling the container with water so that the battery is covered with water. Loading, transporting and unloading the electric vehicle in the container can be problematic due to the water in the container, as it is not designed for this purpose.

When recirculating the water in the container, the concentration of various substances and pH can be high. Once the work has been completed and the electric vehicle has been removed from the fire extinguishing container, the extinguishing water from the container should be properly treated in the interests of the environment and the working environment. The local environmental authority should be contacted.

Measurement of hazardous gases

New passenger cars today contain a lot of plastic, which should be taken into account during extinguishing efforts. This also applies to electric cars, which may also have a different composition of smoke due to the Li-ion battery.

There are detectors for detecting, for example, HF gas. A measurement will not necessarily be valid in relation to the situation and what you want to determine. Concentrations of hazardous substances and leaking gases may be very local.

In practice, it should be assumed that, as in other fires, dangerous substances and gases will be present. However, these can usually be handled with the use of turnout gear, full respiratory protection, other PPE and normal practices for changing into and out of protective clothing etc.

However, attention should be paid to small flames, 'explosive' puffs, leaking gases etc. from the battery, as the release of gases from the battery may well 'peak' during the course of the fire.

Contact with extinguishing water should be avoided and kept to a minimum. This is due to the general contamination of the extinguishing water.

Photo: Andreas Hillergren/TT/Ritzau Scanpix

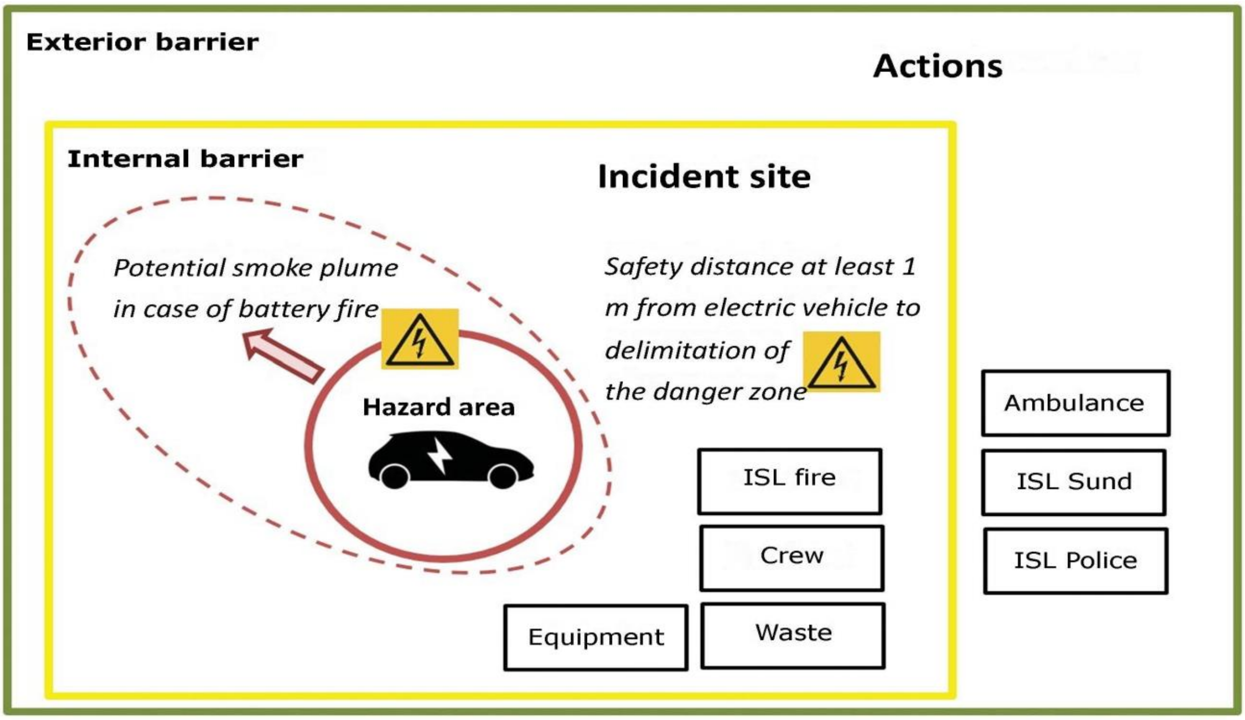
The technical leader's challenges

Construction of the incident area
Securing the work area by marking the danger area with marking tape around the danger area is important and should be done quickly. The distance to the electric car should be at least 1 m. It is important that the technical leader ensures that the inner barrier is large enough so that personnel who have not been using full respiratory protection and other emergency responders around the incident site are not exposed to any smoke.

This also applies to the location of depots (equipment, crew and waste) and emergency vehicles. Due to the risk of a fire developing in the event of damage to the high-voltage battery, there are a number of factors that the technical leader should take into account. These are:

- Need for extra manpower and equipment, as the response may be prolonged.
- Fixed or continuous water supply.
- Logistics around PPE, compressed air devices, etc.
- Cordoning off the hazard area with signs indicating high-voltage work.
- Potential smoke plume in the event of a fire in the battery pack.

Furthermore, the technical leader should be aware that the response might evolve, as the smoke from an electric car's high-voltage battery produces large amounts of HF gas and other gases. These elements should be taken into account by the technical leader when establishing the internal barrier and designing the incident site.



The structure of the scene of a road traffic accident with the need to free trapped people or risk of fire. Illustration: Beredskabsstyrelsen

Incident Challenges
Response efforts with electric cars give rise to a number of dilemmas, which differ from similar incidents in conventional cars. An incident commander should be considered. The team leader is basically the technical leader of the response, and a possible incident commander will be the tactical leader. Depending on the situation, the two roles can be adapted.

The risk assessment in particular takes up a lot of time for the incident commander and team leader, as they should focus on both the possibility that there can be a problem with voltage and the risk of fire.

The incident can be extremely complicated if it takes place in a closed environment such as a parking garage. Conditions such as high water consumption, long access path and deployment time, concentrated smoke and difficult decontamination will often make the incident more resource-intensive.

At the same time, the incident commander should consider the surrounding community, such as infrastructure and the environment, and the risk of a possible re-ignition.

When an electric vehicle is involved in a road accident - with or without injuries - the high-voltage battery is exposed to a mechanical impact that can damage it and initiate a process - thermal runaway - long after the initial response has been completed.

When it comes to the need to free trapped people, the 'Special conditions for rescue in electric and hybrid vehicles' section distinguishes between two types of intervention in road accidents based on whether the person's life is in danger/life-threatening or not in danger/not life-threatening.

Risk assessment in relation to smoke and smoke diving
It is essential that the hazard area is identified and defined so that all deployed personnel; fire, ambulance and police, are aware of where it is safe and where it is not safe. This places special demands on the incident commander's risk assessment, as the safety of the deployed personnel is the highest priority and should be balanced against the choice of an offensive or defensive approach.

In the event of a fire in electric vehicles, especially in enclosed spaces without ventilation, smoke diving should be carried out in the shortest possible time. Especially for the BA teams, there will potentially be a long access path to the fire itself, where exposure to smoke should be taken into account. Ventilation options can be considered and implemented as early as possible.

In the same way, it should be taken into account that smoke diving in large closed rooms with few exits, such as parking basements, entails a risk of prolonged withdrawal time in a smoke-filled environment, as the distances are longer.

With large rooms, there is also the risk that the BA teams do not have an overview of the development of the fire. Consideration should be given to planning smoke diving efforts so that all deployed personnel have clear and safe retreat routes and an understanding of any risks and restrictions. BA teams can use thermal imaging cameras to help detect the fire.

Special attention will always be necessary when smoke is present, and especially when there is a fire in Li-ion batteries, where both particles in the smoke as well as leaking HF gas and other harmful gases will be present.

Non-ignited gases from the battery can form the basis for an explosive environment in enclosed spaces, which should be included in the risk assessment - especially in the event that a fire has not yet occurred.

However, smoke released from an electric car with HF gas that is mixed with smoke from other components of the electric car, does not pose any additional risk than the turn out gear for fire provides protection against.

The risk assessment should include, among other things, consideration of the temperature of the smoke, the concentration of potentially hazardous substances (the number of electric vehicles/high-voltage batteries involved), the total deployment time, versus the number of BA team tours for the individual BA team, etc.

It should be noted that personal protective equipment (PPE) is used in relation to approval requirements for 1000 VAC/ 1500 VDC and the safety distance in relation to the chosen extinguishing tactics.

The smoke indicates a need for identification of hazard areas as well as areas that could potentially be affected by smoke. This is done in order to prevent other people from being exposed to smoke at an early stage. It should be noted that not all gases emitted from the high-voltage battery are necessarily visible or odorous if they are not ignited.

For operations where there has been exposure to smoke in larger quantities or concentrations, attention should subsequently be paid to whether the crew develops symptoms of exposure to smoke. At the end of the response, the crew should change their underwear and protective clothing and take a shower as soon as possible.

Photo: Hovedstadens Beredskab

Response tactics

The incident commander/team leader should assess as soon as possible whether an offensive or defensive approach is needed. The duration of the response will generally be longer, both in the acute phase and in the subsequent closing phase.

There may be additional management tasks, such as liaising with the emergency medical services about any injured people or others at the scene who have been in contact with smoke or had contact with extinguishing water, as well as handing over the electric vehicle to the transporter or police.

Expected increase in resource consumption

Responding to a fire in an electric vehicle's high-voltage battery generally requires more resources than other types of vehicle fires. To some extent, a larger amount of water is required to cool the battery pack and extinguish or limit the fire in the electric vehicle - equivalent to 400 l/min - and this can be over a long period of time.

In the event of a fire in the electric vehicle or high-voltage battery inside a building, a significantly larger number of BA teams must also be used for the incident, as there may be a relatively short working time.

The response will also be more complex than usual, as resources are used to secure the hazard area and ensure that other participants at the scene do not come in contact with the electric vehicle. There will be managerial tasks such as liaising with the emergency medical services about the injured person and handing over the electric vehicle to a transporter or the police.

Logistics in relation to relief and decontamination

Experience has shown that fires in electric vehicles can take from a few to several hours to handle, which is why it is necessary that additional resources should be requested as early in the process as possible.

The potentially relatively short working time may require more resources. There should be a focus on decontamination procedures for personnel, their equipment and PPE that follow local standard operating procedures.

The requisition of special equipment or specialists for rapid resolution of the incident or advice should also be considered as part of the solution. For example, fire extinguishing container for transporting an electric vehicle for safe storage, drone or self-propelled extraction robot, fan, etc.

Exposure to smoke or leaking gases from the battery

If the crew has been exposed to smoke or gases from the high-voltage battery during a response, the 'Farlige stoffer' APP should be consulted as soon as possible for information on the health consequences of exposure.

The Danish Emergency Management Agency's 'Farlige stoffer' app contains information about the hazardousness of substances, safety distances, health risks, etc.

Accident on the E45 with electric cars, where the effort lasted several hours.
Photo: Horsens Folkeblad

Disposal of fire-damaged electric vehicles
As part of the final response, it should be ensured that the disposal of the fire-affected electric vehicle(s) does not pose a risk of fire spreading to other buildings and the like if the battery re-ignites.

This risk can be managed in different ways. For example, it may be considered whether the car should be placed at a suitable storage site, a proper distance from buildings and other flammable materials. If the vehicle is located under a roof, consider how it can be moved to the open air in the event of a fire.

If the electric vehicle is moved, the receiver should be informed that there may be a risk of re-ignition. In addition, the technical leader should consider whether the car owner's insurance company is informed via the police if the car is removed from the fire site.

Before the scene can be handed over to the police or a transport company, they should be briefed by the person(s) involved. Attention should be paid to the following:

- Development of a fire in the battery
- Corrosive and flammable liquids
- Dangerous electrical voltage
- Avoid direct contact with the electric vehicle
- Avoid open flames

The injury site should therefore be secured with safety marking and high-voltage signs. In addition, information should be provided about the potential hazards associated with moving the vehicle, including pulling, pushing and lifting, which can cause a change in battery condition, such as a thermal runaway.

Therefore, the incident commander can benefit from entering into a dialogue with the police and the transporter to ensure that the transporter who will be removing the car is trained in towing electric vehicles. If there is any voltage in the bodywork, a specialist can be called in, e.g. from the car manufacturer, who is able to deal with this, including the further process of removal.

Safeguarding communities

The incident commander should decide early on whether to use offensive or defensive tactics when extinguishing a fire in the EV battery. As a fire in an electric car can take a long time to extinguish, the technical leader should assess whether the area around the car will be affected by a prolonged extinguishing effort to such an extent that a quick removal of the vehicle is essential.

For example, if the vehicle is located close to critical infrastructure or in an urban area where the potentially toxic smoke or gases can create a large hazard area. This can help determine whether the tactic is a prolonged cooling/extinguishing/containment of the fire or a removal of the EV under conditions that allow this.

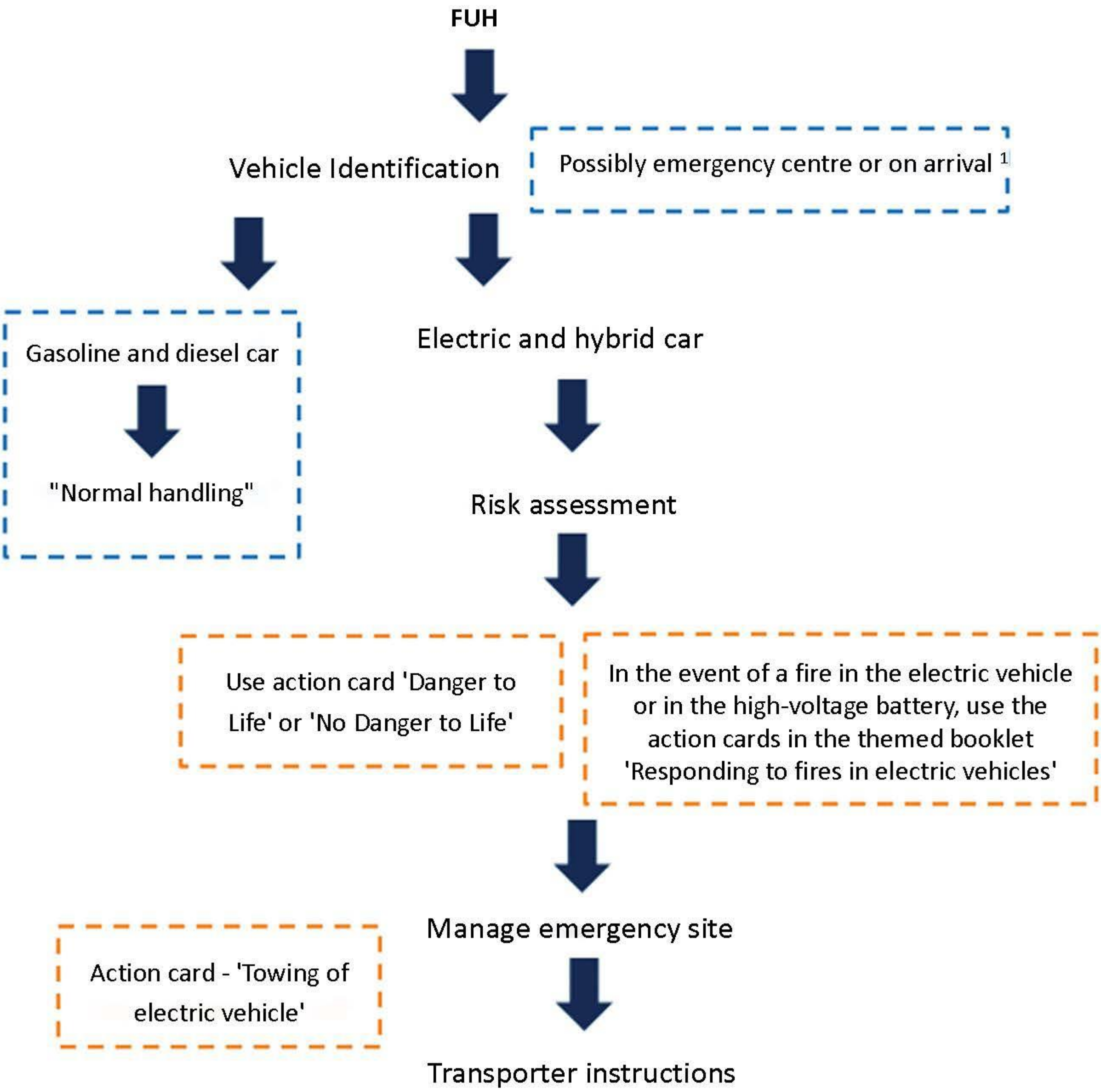
The municipal environmental authority should also be involved as well as in the planning of the disposal of extinguishing water, if this is deemed particularly polluted.

Overall flowchart for electric vehicle incidents

When handing over the accident site to the police or moving the electric vehicle, the electric vehicle should be placed in a quarantine zone with a minimum of 1 metre of yellow/black hazard tape around the vehicle, as well as maintaining the signs for high voltage, fire and chemical hazards.

You can read more about handovers, the role of the police, and health preparedness at the injury site in the appendix and action cards. If the transporter has arrived, the incident commander should explain the actions taken around the electric car, as shown in the incident flow in the illustration below. Alternatively, the information should be provided to the police so that it can be passed on to the transporter:

- It is an EV and possible a model name/number.
- Briefly about the emergency incident: firefighting, details and any cutting in the car (damage to cables).
- Assessment of the condition of the vehicle's high-voltage battery, disconnection of the main switch, voltage, damage to cables.
- The risk of 'thermal runaway' during transport to the workshop and what the transporter should do if this happens.
- The challenge of taking a voltage measurement of the car body before it is unloaded.
- The electric car should be placed at least 5 metres away from buildings and other flammable materials.



Flow chart in the event of a road accident.
Illustration: Beredskabsstyrelsen

Description of actions in action cards

Vehicle Identification
A conventional petrol or diesel-powered car has a number of characteristics, such as a fuel tank, fuel cap, exhaust pipe, radiator grille, etc. An electric car, on the other hand, may be more difficult to identify immediately, as it may have some of the same characteristics as a fuel-powered car. A number of special features may draw attention to the fact that it is an electric car, for example:

- EV, BEV or ZEV for electric cars as well AS PHEV or HEV for hybrid cars and others.
- Some car brands, for example Tesla, can be recognised by logo or name, such as the text: Zero Emission, Electric, driveE or the letter e or E.
- Presence of a charging plug cover (possibly behind the tank cover), indicator with charging mode in the dashboard, lack of engine noise, lack of exhaust and lack of cooling grille.
- High-voltage wires are orange, and warning signs will usually be placed in spots in the car where there may be a risk of coming into contact with high voltages from the battery.

Risk assessment
If cutting the car is required, please refer to the theme booklet on 'Emergency response in electric and hybrid vehicles', which describes the 5 phases of emergency rescue. Upon arrival at the site of the incident, a comprehensive risk assessment should be carried out, which should include at least the following:

<u>Risk assessment</u>
- Personal safety at the incident site in relation to the surroundings.
- Voltage in the vehicle body.
- The risk of voltage release while working on the electric car.
- The possibility of disconnecting the main circuit breaker.
- Location of ignition key.
- Securing the electric car against rolling, possibly in the form of cribbing.
- Contact with the electric vehicle with the use of rescue tools.
- Risk of 'thermal runaway'.
- Indications of fire in the high-voltage battery or electric vehicle.

<u>Equipment to support the risk assessment</u>
- Resource tools (documents, database) to identify the specific hazards of the electric vehicle.
- Thermal imaging camera.

Marking of the incident site
When working with high voltage, the hazard area should be marked, e.g. with hazard tape with clear instructions, markings or signage indicating the nature of the hazard. Seal off with an approved black/yellow hazard tape with attached signs indicating that there is a voltage hazard behind the tape. The barrier should be set up at the necessary distance from the potential danger - at least 1 m from the electric vehicle.

Main circuit breaker
In electric vehicles, there can be a main circuit breaker for the high-voltage battery. It can take different forms, such as a cable that is clipped or a plug that is pulled out of a socket. It is essential that the location of these is identified and that the main circuit breaker is disconnected.

The crew should be aware that there will typically be several batteries in the individual electric car, both batteries with high voltage and ordinary 12 V operating battery. The manufacturer's instructions for disconnection are to be followed as far as possible in relation to any deformations.

Tools, equipment and protective equipment

Only tools approved for use in high voltage (1000 V) may be used in the rescue effort. Examples of this are insulated tools or other approved tools if, exceptionally, it is necessary to apply them on live parts of the electric vehicle. Ordinary tools, hydraulic release equipment, etc. should not be used when working with voltage, which should be taken into account in the incident.

Personal protective equipment (PPE) should always be used to protect the crew against shocks when there is or is assumed to be electrical voltage in the bodywork. This applies to all participants at the accident site who come close to or in direct contact with the electric car or bodywork. This equipment includes safety gloves, turnout gear, boots and helmets with a face visor, which are approved for 1000 V.

Protection against Fire

In order to prevent a sudden fire or 'thermal runaway' during the rescue effort, safety hoses with a total water output of min 400 l/min are used, so that rapid and effective protection of persons and a possible cooling of the fire can be implemented.

Instructions to the transporter

It is essential that the transporter, who will be towing the electric vehicle away from the scene of the accident, has all the necessary information about the incident. When the electric car is placed on the transporting vehicle, twisting can occur in the vehicle, which can cause an unintended thermal runaway event or create an electrical voltage in the bodywork.

The transporter should focus on:

- Risk of fire.
- Heat production.
- Sound.
- Degassing.
- Odour.

When leaving the scene and handing over to other parties, such as the transporter or police, information about the condition of the EV and battery pack, the status of the switchgear and any safety devices should be passed on.

Signage and marking of risk of high voltage should be maintained.

Tactical understanding - chemistry

The risk assessment
The response to a fire in an electric vehicle's high-voltage battery should be considered as a fire extinguishing response. Elements from a chemical response are included when conditions around incident time and exposure to high concentrations of smoke and gases are critical.

Whether the individual vehicle is outdoors, in a garage, in a parking facility or among other vehicles should contribute to the assessment of a hazard area. This will protect the crew and other parties at the incident site from further hazards. The following three scenarios each require a different tactical response:

- Fire in an electric vehicle/battery in a parking facility or enclosed space (ventilated/non-ventilated)
- Fire in an electric vehicle/battery under a roof (ventilated/ non-ventilated)
- Fire in an electric vehicle/battery outdoors

Quickly defining a hazard area around the electric vehicle can provide the necessary overview for the response. By discussing the above-mentioned situations or a combination of them, the incident commander or team leader can plan a tactical and technical implementation of the response that takes into account the risks posed by escaping gases and smoke.

Photo 1: Fire in the battery pack; the smoke is typically white, with slight tinges of brown.

This can determine how long the crew can stay in the hazard area itself or in adjacent rooms. The hazard area is defined as the area where the concentration of smoke or gases is so concentrated that full breathing apparatuses are required. In practice, this will be inside buildings and outdoor areas where non-visible, leaking gases or smoke are suspected or detected.

It should be taken into account whether 'smoke' is smoke or chemical gases emanating from the vehicle. If no ignition has occurred, an explosive environment may exist in enclosed spaces due to the leaking gases from the battery - something that is not normally seen in cars with a combustible engine.

Photo 2: The fire in the battery pack is rapidly increasing and the fire spread to the cabin has started.

Photo 3: The fire spread is now in the electric car and adjacent cars.

The three photos show differences in smoke development in the ELBAS project, 2022
Photo: 1-3 The Danish Emergency Management Agency

BA teams' deployment time

For the crew, it will generally be sufficient to wear normal turn out gear and a full breathing apparatus and, after the deployment, adopt a focus on good practices for handling equipment and decontamination.

- In a building or enclosed space without ventilation, the deployment time should be as short as possible. This will correspond to the hazard area.
- In neighbouring spaces (lower concentrations of smoke and gases), the incident time may be extended at the discretion of the incident commander or the team leader.
- Outdoors, the incident time will be comparable to that of a 'normal' incident - provided that full turn out gear is worn, including full respiratory protection.

The total operational time for each BA team should be assessed to 1 hour. After this, washing and replacing all undergarments should be considered[10].

As a rule of thumb, one should avoid contact with smoke and gases and deploy 'with the wind at your back' in the hazard area. If work is carried out in the vicinity of the hazard area, where the rest of the crew can be exposed, for example, by a changing wind direction, the correct PPE should be used.

Understanding Hydrogen Fluoride (HF gas)

To understand the possibility of ignition of the electric car battery, it is important to have an understanding of Hydrogen Fluoride (HF gas). It is one of the gases that can escape from the battery when it is impacted by collision, deformation or an internal 'thermal runaway' overheating process.

In many cars, especially new ones, there is a lot of plastic. Chemical gases can therefore both be found in fires involving cars with a combustible engine and in EVs, albeit in different concentrations, due to 'peaks' when the battery cells in the electric car's high-voltage battery ignite.

A situation where there is only leakage of e.g. HF gas from the battery, but no ignition, and where the aerosols are tightly packed due to sparse natural or mechanical ventilation, the incident be considered a CBRN incident. However, this process can quickly turn into ignition of the gas as well as the electric vehicle. Then it will be considered a fire incident.

When working in garages and car parks/basements, there is a greater likelihood of HF gas contamination, which means that there should be an increased focus on the limited operational time. The concentration of HF gas in a more or less enclosed space will probably be higher than in a normal car fire, as the smoke from an electric car's high-voltage battery can create large amounts of, among other things, HF gas.

However, focussing on HF gas in isolation can create an unnecessary perception that the amount of HF gas poses a greater danger than the other toxic components in the smoke or gases from the battery. This can result in the crew handling the fire being more cautious than the situation requires.

Similarly, the amount of HF gas is increased by a fire in the battery of an electric car, which in connection with extinguishing water can be converted to hydrofluoric acid. The extinguishing water should be handled using a minimum of unnecessary contact, although the hydrofluoric acid is likely to be sufficiently diluted not to pose a significant hazard to the crew in contact with the skin.

The risk of leakage of large amounts of electrolyte liquid from the battery pack is considered to be minimal. In case of a leak - where there is no ignition - the leak should be handled as a chemical incident. The electrolyte manifests in both liquid and solid variants, and the liquid components vary according to the type of battery. Information can be searched for in the relevant app or from the dealer's safety data sheet for the car battery.

Cooling of battery in the ELBAS project, 2022 Photo: Danish Emergency Management Agency

Appendix 1: Characteristics of electric and hybrid vehicles

There are a number of different types of electric vehicles in the passenger vehicle category, where the fuel is completely or partly a high-voltage battery based on Li-ion technology.

The collective term 'electric car' covers both electric cars with Li-ion as the only fuel and the different types of hybrid and plug-in hybrid vehicles, which are built with both a high-voltage battery (Li-ion) and a petrol/diesel engine.

The three photos show different forms of identification of an EV logo, lack of radiator grille, lack of exhaust. Photo: Danish Emergency Management Agency

Li-ion battery and cables

A Li-ion battery in an electric car is a compact, lightweight battery with a voltage of up to 1000 V. Batteries are generally safe as long as they are original and used with the equipment they are sold with or approved for. An electric car also has a 12V battery.

The high-voltage battery consists of smaller battery cells in a battery pack. They are protected by membranes and an outer wrapping that can make them difficult to penetrate and cool. The battery pack is often located at the bottom of the car, and the electric car's motors are often located directly at the wheels to reduce transmission as well as reduce the number of moving parts.

The high-voltage battery can be connected to various components such as the heating system, air conditioning, etc. Main cables (orange) with high voltage are most often centrally located in the electric car.

In a non-intact electric vehicle, it cannot be excluded that the cables can have a connection to the chassis or the structure of the electric vehicle.

Position of the main circuit breaker under the bonnet and the orange high-voltage cables. Photo: Danish Emergency Management Agency

The booklet 'Special conditions for rescue in electric and hybrid cars' has an appendix with a detailed description of the characteristics of Li-ion batteries and cables of an electric car.

Appendix 2: Safety when working with electric vehicles

High-voltage batteries in an electric car have a high electric DC voltage and contain significantly more energy than the ordinary 12 V batteries in a passenger vehicle with a petrol or diesel engine.

During an intervention in an electric vehicle, it is essential for the crew to disconnect the main switch if possible and de-energise all the electric vehicle's systems. Electric cars typically have one or more 12 V batteries, which are disconnected in the usual way.

- The high-voltage battery cannot be de-energised. Cables and high-voltage systems will typically be coloured orange.

When the term 'high voltage' is used in the theme booklet, it must be seen in relation to the voltage normally (12 V) found in cars with conventional petrol/diesel engines.

Special risks when working with Li-ion batteries
High-voltage batteries in electric cars, which are based on Li-ion technology, store energy using chemicals. Particularly in the event of a fire involving the battery, gases are generated, such as: HF gas, CO2, CO and NOx.

Access to the high-voltage battery can be complicated due to the diaphragms in the battery pack and a further limitation due to damage to the body. This affects the operation, the tactics used to cool the battery pack and the positioning of the crew in the smoke plume. Water can be energized, so maintain a safe distance from the electric vehicle.

It is important not to cut a hole in the bonnet or cut the car's side panels, as there is a risk of hitting high-voltage components if the main switch is not disconnected.

Applicable laws, regulations and standards
The Danish Emergency Management Act applies to emergency preparedness efforts, and the theme booklet is based on some general principles for response tactics and cooperation in the field of response.

The Electrical Safety Act[11] is relevant in terms of safety regarding working methods and protective equipment, as it applies to, electrical installations where the voltage is so high or the current is so strong that it can endanger people.

The Danish Safety Technology Authority has prepared a number of relevant descriptions of protective equipment and working methods for safe work on electrical installations that are connected to a supply system or have their own supply[12].

The standard (EN 50110-1) specifies the areas for which it can be applied, including '… when working on or in, electrical installations in vehicles, electrical traction systems and experimental electrical survey work in the absence of other rules'.

On this basis, the regulations in the standard are relevant to the work of the rescue services with regard to working methods, division of responsibilities and personal protection, as no other relevant Danish regulations or requirements have been identified.

The booklet 'Special conditions for rescue in electric and hybrid cars' has an appendix with a detailed description of the risks and applicable legislation.

Appendix 3: Tools, equipment and protective equipment

Current legislation and regulations generally deal with intact electric cars and not the handling of accidental (not intact) electric cars. They are likely to pose a risk to personnel due to minor or major damage to the high-voltage battery.

By complying with the relevant rules, standards, etc. for working on, with or near electrical installations as a starting point, a safe response can be ensured in connection with the response to electric vehicle accidents. In some cases, the tactic will be based on a precautionary principle, as it cannot be ruled out that there is still voltage in parts of the electric car's components.

Depending on the size of the electric car and the performance of the high-voltage battery, many electric cars on the market in 2021 primarily use a battery voltage between 300 and 500 V. However, the trend is towards high-voltage batteries with greater voltage - between 600 and 900 V - in the new and larger electric cars that are coming onto the market.

Assessment of voltage in the electric car
In the specific incident, it will be the technical leader who must assess whether the electric car, and not least the high-voltage battery, is sufficiently intact to be secured, i.e. de-energised in accordance with the manufacturer's description.

In practice, the mere fact that the electric car has been in an accident (where emergency services are called) makes it difficult to assess whether the high-voltage battery is still intact. If there is any doubt about this, it should be assumed that no safety functions in the electric car work normally and that it is therefore assumed that 'all' parts of the electric car can potentially be energised.

Tools and marking
In electric vehicles, marking/signage is used by the manufacturer to warn crews and other emergency responders of the risk of electric shock.

This marking/signage is visible in places in the car where there is a risk of coming into contact with the high voltages from the high-voltage battery.

From a safety point of view, tools, instruments and accessories that meet DS/EN 61010-1 or have the same level of safety are used. Only insulated or hybrid hand tools are used for work on or near energised low voltage installations (1000 V AC / 1500 V DC) complying with EN IEC60900[13] or equivalent.

When working under voltage, the workplace where the electric vehicle is located must be clearly labelled in accordance with EN 50110-1. In practice, this can be done with black/yellow hazard tape or the like, on which is applied clear signage indicating electrical hazard, for example, according to ISO 7010: 2019[14].

The booklet 'Special conditions for rescue in electric and hybrid cars' has an appendix with a detailed description of tools, equipment and protective equipment.

Appendix 4: Technical conditions - batteries and charging plugs

A Li-ion battery in an electric vehicle can be described as a high-voltage battery, characterised by being a compact, lightweight battery that can withstand many discharge and recharge conditions. The batteries are generally safe if they are original and are used with the equipment that they are sold with or approved for.

Compared to a conventional petrol/diesel-electric car, a modern electric car is generally designed on the basis of a central and low-position of the battery pack, for example at the bottom of the car. The electric vehicle's motor is often located directly at the wheels, making the traditional transmission redundant and reducing the number of moving parts.

Common to all types of electric cars is that they are equipped with motor and transmission systems with voltage, as well as a smaller 12 V battery, which is seen in conventional gasoline/diesel-powered cars. For electric cars that do not have a petrol/diesel-electric engine, the risk assessment takes into account the greater dimensioning of the high-voltage battery, in addition to the live parts and the supplementary 12 V low-voltage battery. 12 V batteries can also be of the Li-ion type[15] and can be placed in conjunction with the high-voltage battery as a combined high-voltage/low-voltage battery pack.

Chargers and charging plugs
Electric vehicles utilise a high-voltage battery, which can be charged externally via a charging socket or wireless induction charging, and one or more electric motors. There can also be a charge of the battery via regenerative breaking - that is, the car recovers the energy that would otherwise normally be lost when the car brakes.

Some types of electric cars work with changing the battery. However, charging an electric car often happens at a charging station. All types of charging via a charging station will as a rule use alternating current (AC) from the mains. A charger or converter (on-board charger/OBC) located in the electric vehicle converts the alternating current into direct current (DC), as it can be charged in the high-voltage battery of the electric vehicle. The vast majority of fast chargers provide DC in the charging station, as the vehicle's on-board system has a power limit. Electric cars can be charged overnight in three different ways with power from the grid[16].

- Normal charging is carried out with one phase, below 22 kW and works by connecting the plug to the socket. Charging time is typically four to eight hours depending on battery capacity and charging level.
- Fast charging is carried out with three phases, below 22 kW. The duration of charging lasts between a half and three hours, depending on the size and state of charge of the battery.
- Very fast charging uses DC voltage up to 250 kW. The duration of charging is equivalent to a refuelling of a conventional car.

There is no one standard that describes what type of charging socket is provided. It is solely up to the manufacturer to choose in terms of the battery capacity of the individual high-voltage battery and whether AC or DC charging is used from the charging station.

The booklet 'Special conditions for rescue in electric and hybrid cars' has an appendix with a detailed description of the technical conditions.

Appendix 5: Police and emergency medical services participation at the incident site

The police and emergency medical services can benefit from reading the sections that describe, for example, an incident with acute danger to the injured person's life or health, emergency relocation, constructing the incident scene and other parties at the scene.

In road accidents involving electric cars, there is a significantly greater risk that the crew can be injured due to possible high voltage in the body, sudden fire in the battery and leaking gases.

Based on this and a risk assessment made by the first vehicle on the scene, the emergency services should be called if the following are visible to the crew:

- All kinds of high-energy accidents (the electric car is deformed).
- Visible electrical cables - orange (dangerous electrical voltage).
- Sparks, smoke, steam from the battery (hint of fire).
- Leakage of liquids and/or noise from the battery.

If one or more of the above items are present, crews should weigh the risks of working in or near the EV against available PPE.

In principle, electric cars should not be touched without proper personal protective equipment (PPE). The following list sets out European standards for different types of PPE.

Subject	Personal protective equipment (PPE)
Head	Suitable helmet - EN 50365:2003
Eyes	Suitable visor or glasses - EN 166: 2002
Body	Turn out gear - EN 61482-1 and 2
Feet/Body	ESD approved footwear - EN 15090: 2012, type F2A
Hands	Suitable gloves EN 60903: 2004

Fire and rescue services can be deployed with proper equipment and PPE. If the police or emergency medical services need to begin their response before the arrival of the emergency services - for example, in the case of emergency relocation or emergency treatment - this should be done with extreme caution.

If a person is deployed without proper PPE, there is a risk of exposure to smoke, gasses from the high-voltage battery or electric shock. The option of observation should be considered. The Danish Emergency Management Agency's 'Farlige stoffer' app contains information on dangerous substances, safety distances, health risks, etc.

The Danish Emergency Management Agency's 'Hazardous substances' app contains information about the hazardousness of substances, safety distances, health risks, etc.

Identification of an electric vehicle

In general, the first responder in an accident should be aware if an electric vehicle is involved. The alarm centre can contribute to a significant assessment made by the emergency operator at the moment of notification. When sending the required cause code, a selection must be made: Electric vehicle or not electric vehicle.

This information should be passed on to the emergency call centre or AMK as early as possible so that the emergency services can initiate the necessary procedures and tactical considerations to ensure the safety of the crew when handling the electric vehicle.

Information about a vehicle's means of propulsion can be retrieved by entering the vehicles registration number on the "motorregister.skat.dk" website under the tab "Fremsøg køretøj" (Search vehicle). However, there are exceptions to this, because registration numbers for special vehicles of, for example, the police, defence and emergency services, are not publicly available.

Resource persons or other people at the scene of an accident can, for example, by using the car brand or the full licence plate number, contribute to an early identification of whether it is an electric car.

Electric vehicles are often confused with regular gasoline or diesel-powered vehicles. A number of electric vehicles have specific features of the vehicle, which draws attention to the possibility of these designations:

- EV, BEV or ZEV for electric cars as well AS PHEV or HEV for hybrid cars and others.
- Some car brands, for example Tesla, can be recognised by logo or name, such as the text: Zero Emission, Electric, driveE or the letter e or E.
- Presence of a charging plug (possibly behind the tank cover), indicator with charging level on the dashboard, lack of engine noise, lack of exhaust and lack of cooling grille. However, this does not apply to hybrid cars, as they have both an internal combustion engine and an electric motor.

Risk of fire
Electric vehicles damaged by traffic have a risk that the battery pack may spontaneously burst into flames. Signs of this may be in the form of smoke, degassing/evaporation, leaking liquids and deformation of the electric car body. The emergency response centre can contribute to a significant assessment made by the emergency operator at the moment of notification. The emergency response dispatcher can ask about visible smoke or fire development.

In the event of a fire, hazardous fumes are emitted, and especially larger amounts of HF gas will be dangerous for people to inhale. Therefore, staying in any smoke plume should be avoided.

Barrier
In the case of damaged electric vehicles, there will be a risk of damage to the battery pack or exposed high-voltage cables, which can result in electric shock when touching the electric vehicle.

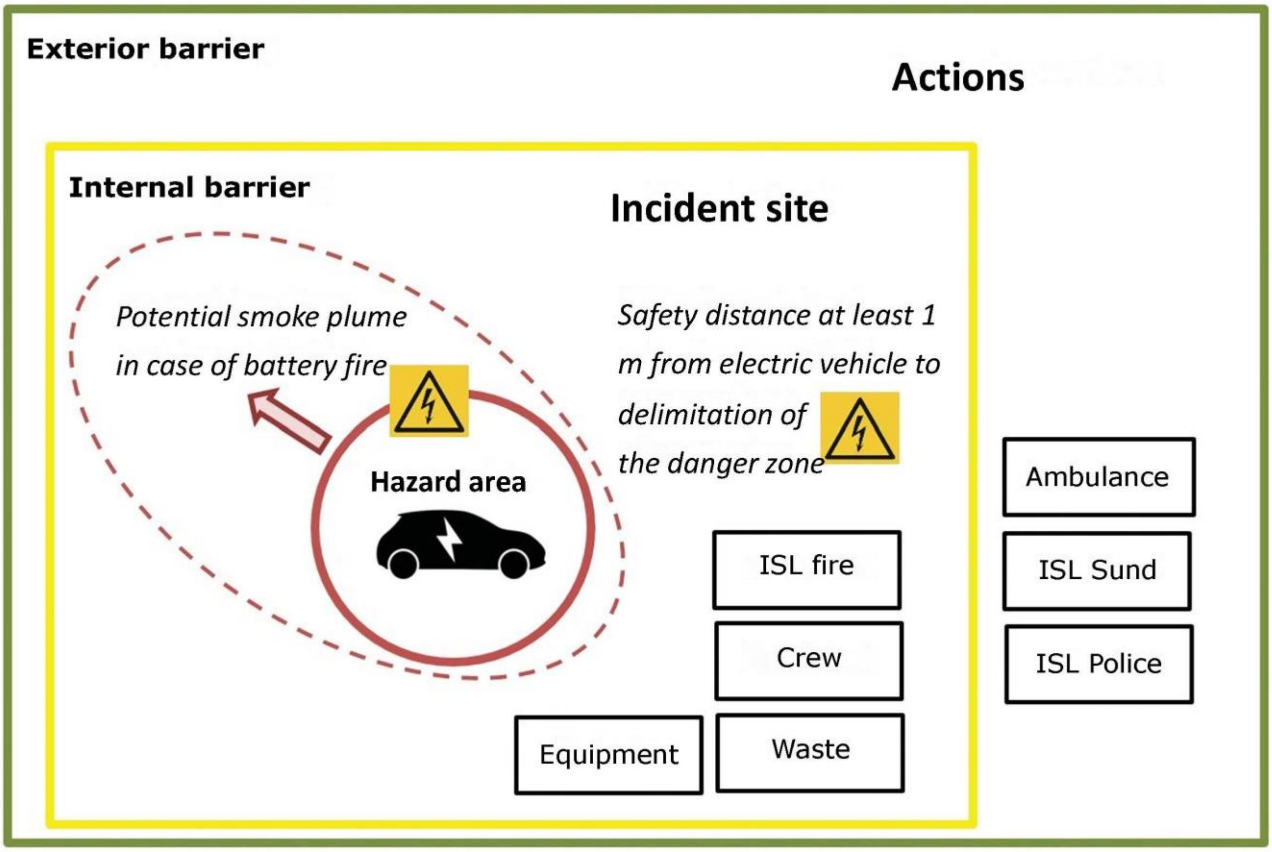
The first vehicle on the scene should set up a barrier to ensure the necessary distance to the electric vehicle (min. 1 metre), mark the high-voltage risk area and ensure that people without proper clothing and protective equipment (PPE) are not allowed near the electric vehicle.

Emergency relocation
As far as possible, only the rescue personnel should be the ones who work in and around the electric car. They are equipped with the right tools and protective clothing.

In special circumstances where an emergency movement of an injured person is required, this can be carried out if contact with the electric vehicle can be avoided and the injured person is not trapped but can be pulled directly out of the electric vehicle. For safety, a colleague should be present to help push you away from the vehicle, if necessary.

The use of approved safety gloves up to 1000 V will be able to protect against accidental contact with the electric vehicle.

See detailed description of tasks: Action card - POLICE, Action card - HEALTH EMERGENCY PREPAREDNESS



The structure of the scene of a road traffic accident with the need to free trapped people or risk of fire. Illustration: Beredskabsstyrelsen

Annex 6: Handover of a damaged electric car

After conducting a rescue operation in an EV, it is important that the incident commander provides informative instructions to the police or the transporter who will be picking up the EV. For example, towing is outside the scope of the rescue services, unless there is a risk of fire in the high-voltage battery. In general, the manufacturer's instructions for transport should be followed.

The carrier should be aware of the following:

- Development of a fire in the battery
- Corrosive and flammable liquids
- Dangerous electrical voltage
- Avoid contact with the electric vehicle
- Avoid open flames
- If the electric vehicle battery has been exposed to fire, there may be residues of toxic fluorine material (Hydrogen fluoride, Phosphorus pentafluoride, Phosphoryl fluoride).

Before moving the electric vehicle from the damage site, it should be assessed whether the high-voltage systems have been damaged. These may include high-voltage cables that are at risk of being crushed in body parts, physical damage or deformation to the high-voltage battery itself.

Marking the hazardous area with hazard tape is maintained until handover. However, the battery will always be under voltage, even if the main circuit breaker is disconnected.

Be aware that voltage can be generated when the car is towed on its wheels. In this way, the motor acts as a generator that attempts to send voltage back into the motor controller and battery. If the motor controller or battery is switched off, defective, or unable to absorb voltage, the voltage can become so high that components are destroyed. To avoid generating voltage to the battery, the electric car should be transported on a flatbed or skip whenever possible.

Even at very low speeds, wheels connected to electric motors produce voltage, which is stored as high voltage in the wheels' capacitors. Therefore, the manufacturer's instructions are to be followed.

If the electric car is parked in an inconvenient or obstructive position, it may be necessary to move the car to an emergency lane in order to clear the motorway quickly. Before such emergency movement is initiated by the emergency services, the main circuit breaker should be disconnected according to the manufacturer's instructions.

Be aware that several types of electric vehicles go into emergency mode when disconnecting the main switch, which means that wheels (depending on whether there are engines on 2 or 4 wheels) cannot move. The manufacturer's instructions will indicate which wheels are to be placed on "roller skates". If an electric vehicle is equipped with electric motor power on all 4 wheels, it may be necessary to use roller skates on all 4 wheels or lift the vehicle, if the vehicle is to be moved in an emergency.

The high-voltage battery can, if it has been exposed to a violent impact (high-energy accident) develop heat and there is a risk of 'thermal runaway' if it has not yet occurred - even in the case of non-visible damage to the battery pack.

QR code for 'thermal runaway' video while loading on a flatbed.

It is therefore important that the electric car is transported away on a flatbed or skip. There must be no unnecessary pulling and twisting in the electric car, as it can create a connection between the high-voltage battery cells. The same applies for transportation of the electric car by sea.

A damaged electric vehicle should be placed at an appropriate distance from buildings and with a proper marking for high voltage. At the final destination of the electric vehicle, it should be positioned so that a fire cannot spread to other vehicles, buildings or outdoor storage areas if the high-voltage battery or electric vehicle catches fire.

The electric vehicle should be quarantined if possible for at least 48 hours, or as the manufacturer prescribes. The repair shop or scrap dealer should be informed by the transporter about the condition of the vehicle[17].

See action card for 'Transportation of electric vehicle'.

Appendix 7: Environment

Comparison of electric cars and cars with conventional fuel
Fires in electric cars with Li-ion batteries can produce a range of gases such as CO2, CO and NOx. These also commonly occur in smoke, where crews are used to dealing with them.

Studies of burning electric cars show that more HF gas is emitted than in a normal car fire. There should be a focus on CO if the electric car, including the battery, is 'drowned' by submerging it in water. In the case of immersion, there may be a need for a measurement of excreted substances as well as the pH of the extinguishing water and a separate handling of the extinguishing water upon disposal.

To highlight the emissions of gases - and thereby knowledge of how the fire is handled - a comparison of risks with well-known fires can be made.

The emanating gases were measured at full-scale trials with electric cars and cars with conventional fuel. Many of the gases were at comparable levels as for conventional fuel cars and electric cars.

The difference in the gases lay in a larger emission of HF gas from the electric car. Based on one of the full-scale tests, it is estimated that for these types of cars with Li-ion batteries of 16.5 kWh and 23.5 kWh respectively, approximately 1.5 kg of HF gas is emitted, while a normal car fire emits just over 0.5 kg. This is equivalent to discharging approximately 1 kg more HF gas in the event of a fire in an electric car including a high-voltage battery of that size, which overall in the amount of smoke must be considered to be minimal.

It is noted that the available tests have been carried out on batteries, which today will be at the small end of the size of a high-voltage battery in an electric car. It has not been possible to find trials for larger battery packs.

Comparison fire in Li-ion battery and a plastic fire
Below is a comparison of a fire in a Li-ion battery and a plastic fire. The difference is that the plastic fire on average over time emits more HF than the Li-ion battery fire, while the Li-ion battery fire has 'peak' times with much higher amounts of HF and e.g. HCl when the cells in the battery collapse[10].

'Peak' time discharge for Li-ion batteries*: - HF: 0-6,000 ppm/kg material - HCl: 0-10,000 ppm/kg material	'Peak' time discharge for plastic fires: - HF: 0-1,000 ppm/kg material - HCl: 0-1,000 ppm/kg material
Average discharge for Li-ion batteries*: - HF: 0-1 ppm/kg material - HCl: 0-1 ppm/kg material per min	Average discharge for plastic fires: - HF: 0-45 ppm/kg material per min - HCl: 0-50 ppm/kg material per min

**The intervals for the emission of HF and HCl are given for Li-ion batteries with different chemistry*

When burning different types of Li-ion batteries alone, i.e. tests without burning a car where the smoke cannot be 'absorbed' by e.g. cavities in the bodywork and fixtures, degassing of up to 20 kg HF has been observed.

Various chemical compounds and their properties

As described, a fire in an electric car's Li-ion battery will release a number of hazardous substances, partly from the battery itself, but also from the car's components, many of which are made of plastic. Below are selected substances and their characteristics in pure form. You can read more about the substances in their pure form, conditions for action and symptoms of poisoning in the 'Farlige Stoffer' app.

The emergency response card and its information will only be valid for a concentration of 100% or the concentration indicated on the emergency response card. The chemical department should be contacted in case of doubt, for example by leakage of large amounts of gas or liquid, so that the danger area can possibly be reduced.

Fabricant	UN	Characteristics	Water
Carbon dioxide, pre-drop (CO_2)	**20** **1013**	Colourless gas/liquid and odourless. Non-flammable*.	Soluble in water. A gas plume can be dispersed with water mist.
Carbon monoxide (CO)	**263** **1016**	Colourless gas without odour. Highly flammable Toxic**.	Moderately soluble in water. Gas plume can be controlled with scattered water jet.
Hydrogen fluoride (HF gas)	**886** **1052**	Colourless gas or smoking liquid with pungent odour. Highly toxic. Corrosive.	Soluble in water (Hydrofluoric acid). Labelling at different concentrations can be seen in the tables below. A gas plume can be dispersed with water mist.
Hydrogen chloride (HCl)	**268** **1050**	Colourless or white gas/liquid with pungent odour. Toxic. Corrosive.	Soluble in water (Hydrochloric acid). A gas plume can be dispersed with water mist.

Description of selected substances from the Danish Emergency Management Agency 'Farlige Stoffer' app
**Non flammable: Chemical substances and products are perceived as non-flammable when they cannot be ignited in atmospheric air.*
** * IDHL indicates toxicity at immediately dangerous levels. Limit values in the app are calculated for 30 minutes.*

Note: Hydrofluoric acid is a colourless or brown liquid with a pungent odour, which in its pure form is very toxic. However, in connection with the effort, there will be a significant dilution in the extinguishing water, so the concentration is significantly lower than the weakest solution (< 60%) described in the app.

The two tables below[5] illustrate the labelling of hydrofluoric acid at different concentrations.

Chemical compound	Concentration			
	> 7%	1-7%	0.1-1%	< 0,1%
Hydrofluoric acid on the skin	Causes severe skin corrosion and eye damage.	Causes severe skin corrosion and eye damage.	Causes serious eye irritation.	No labelling.

Chemical compound	Concentration				
	100-10%	10-2.5%	2.5-0.5%	0.5-0.25%	< 0,25%
Hydrofluoric acid on the skin	Fatal in contact with skin.	Fatal in contact with skin.	Toxic in contact with skin.	Harmful in contact with skin.	No marking.

Labelling of hydrofluoric acid at different concentrations

Appendix 8: Working environment

Is it a fire or a chemical incident?

The response to a fire in an electric vehicle's high-voltage battery should be considered a fire extinguishing response. Although in certain periods larger quantities may be discharged, for example: HF gas and HCl in a Li-ion battery fire than in a normal car fire, the response and tactics do not change the incident to a chemical incident.

However, there can be benefits to maintaining CBRN practices, especially after the incident has ended. BA teams who have been deployed in enclosed spaces due to fire or risk of fire in Li-ion batteries - have probably been exposed to high concentrations of gases and potentially corrosive and harmful extinguishing water. At the same time, fluorine compounds must be expected on surfaces.

The tasks to be performed in the hazard zone are not comparable to the definition of 'direct contact' in the CBRN sense. Therefore, the incident can be handled with normal turn out clothing and full respiratory protection.

BA teams' operation time

During operations, BA teams wear full-coverage protective clothing and air-supplied breathing apparatuses. The maximum deployment time for BA teams in fire fumes or leakage of gases from the high-voltage battery of an electric vehicle should be as short as possible inside a building or enclosed space where there is no ventilation.

In adjacent rooms with smaller concentrations of smoke and gases, the deployment time can be longer. However, this will be a specific judgement made by the team leader or incident commander. The assessment can be based on the amount of smoke, gases, the possibility of ventilation, and whether the BA teams have to work in the room or there is a hallway to ensure the supply of equipment. Especially for the BA teams, there will potentially be a long access path to the fire itself, where exposure to smoke should be taken into account.

The total deployment time for each BA team should be assessed at the hour. This should be followed by decontamination procedures being followed.

In the open air, the operation time will be comparable to a 'normal' operation - provided, however, that full turn out gear, including respiratory protection, is used and that working in the presence of fumes or leaking gases is minimised as far as possible.

Time spent in smoke should be kept to a minimum

Particular care must be taken when working in small or enclosed spaces to minimise exposure to harmful substances. Especially for fires in electric cars, there is a risk of gases leaking from the high-voltage battery, which can occur without ignition. This risk is managed alongside the risk of the smoke itself.

If the electric vehicle is inside a building or car park, this can be achieved by using an overpressure unit (CBRN) and keeping the crew below the smoke layer as much as possible and using water mist protection, which provides additional protection from exposure to smoke and extinguishing water.

At the end of the operation, the clothing and equipment used is treated as contaminated, which means that no other operations can be carried out until the clothing is decontaminated.

Cleaning of equipment and personnel

It must be assumed that the BA teams, especially in enclosed spaces, have been exposed to smoke, possibly corrosive and harmful extinguishing water and various substances (fluorine compounds) on surfaces. Normal good practice for handling damaged (contaminated) equipment and decontamination is followed according to own operational procedures. An SOP for smoke extraction in an environment with smoke and gases leaking from the electric vehicle's high-voltage battery can prove beneficial.

In addition to the smoke inhalation itself, there should be a focus on personal hygiene, as HF gas and hydrofluoric acid can be absorbed through the skin. Therefore, a thorough wash should be carried out as soon as possible after the action.

All turnout clothing, including inner layers, should be removed at the end of the operation with minimal skin contact, e.g. by using disposable gloves and appropriate respiratory protection. Clothing is considered contaminated.

A procedure for cleaning the equipment should also be drawn up, as it is also contaminated.

Exposure to smoke

In practice, valid measurements of the presence of hazardous substances will be difficult. Since there is currently no specific knowledge of the actual toxicity of the actual concentrations in an operation, a precautionary approach should be taken to minimise the exposure to individual people.

Symptoms of poisoning with, for example, HF gas or hydrofluoric acid, when inhaled, can be coughing, difficulty breathing and pain in the airways, with contact with the skin described as burning pain and corrosive wounds. Experience of pain can be delayed up to 24 hours from contact.

In the event of signs or suspicions of intoxication, prompt personal cleansing should be initiated. Knowledge can be sought in the Danish Emergency Management Agency's 'Farlige stoffer' app or equivalent books/apps. Health authorities should be contacted for guidance and any need for hospitalisation for observation.

This also applies to any injured people and other participants in the response who have been exposed to smoke, etc.

Action card - Question guide for call centre, AMC and first responders

Input from the scene to the Emergency Response Centre and AMK plays an important role in helping to identify whether an electric car is involved in a road accident and relaying this information to the first vehicle on the scene.

The emergency call centre can play an important role in determining whether an electric car is involved. This assessment is made by the emergency operator at the moment of notification. When sending the required cause code, a selection must be made: Electric vehicle or not electric vehicle. Assessment will involve a quick assessment of electric car/non-electric car and fire/non-fire.

The emergency call centre can choose to include a medical consultant in the call (conference call). The following questions may then be asked by the healthcare professional at AMK. If the emergency operator deems it makes sense to listen in, the operator will do so. More information can be sent to the emergency services in the form of a second message (supplementary information).

QUESTIONS ABOUT INJURIES	
ARE THERE ANY INJURED PEOPLE IN THE VEHICLE? **YES** - How many? - Where are they located in the vehicle? - Are they directly trapped?	ARE THERE ANY INJURED PEOPLE OUTSIDE THE VEHICLE? **YES** - How many? - Where are they located?
IF **YES, WHAT** IS THE CONDITION OF THE INJURED PERSON? - Do they have visible injuries? - Unconscious? Conscious? - Non-contactable? Contactable? - Unstable on ABC; stable on ABC? - Can the injured person get out of the vehicle? ⇨ **Yes** - consider the risk of fire in the vehicle	**ATTENTION** - Any contact with defective/exposed cables and wires should be avoided - If you start removing injured people, there may be a risk of voltage in the car frame due to deformation of the battery pack - If the car's airbags are deployed, the cables from the battery pack may be de-energised and any first aid or emergency relocation can begin if the casualty is at risk of ABC
ARE THE INJURED PEOPLE RECEIVING FIRST AID IN THE VEHICLE? **YES** - How many people receive first aid? - What first aid is provided for the injured persons? - Can the injured person get out of the vehicle? - Are the injured trapped?	ARE INJURED PEOPLE OUTSIDE OF THE VEHICLE RECEIVING FIRST AID? **YES** - How many people receive first aid? - What first aid is provided for the injured persons? - Is first aid provided at a safe distance from the vehicle? - Have they been injured inside the vehicle or outside (hit by a car)?
IS THE INJURED PERSON RECEIVING FIRST AID IN THE VEHICLE? **NO** - Is there a reason why first aid is not being provided?	ARE CASUALTIES OUTSIDE THE VEHICLE RECEIVING FIRST AID? **NO** - Is there a reason why first aid is not being provided?

IS THERE A FIRE, SMOKE OR GAS DEVELOPMENT IN/FROM THE ELECTRIC CAR?

- Is there visible smoke or flames from the vehicle?
- Is there a hissing noise from the vehicle?
  Is there a jet like flame from approximately 1 – 2 m from the bottom section of the vehicle?
- What colour is the smoke?
  White dense smoke - speed of smoke?
- Smells or sounds from the vehicle?
  Small banging noises/noises from the vehicle all the time or occasionally?

- Is there a fire in other cars?
- Is the car located near a building?
- How many are electric cars?

Especially for hydrogen cars:

- Misfire/from hydrogen tank (hissing)
- Leaking gas from hydrogen tank (https://kemikalieberedskab.dk/)

WHAT TYPE OF VEHICLE IS INVOLVED?
Check registration number on the website motorregister.skat.dk

Visible characteristics of electric car:

- Electric car logo: Tesla; ID3; ID4 and others
- Electric car: EV; BEV; PEV; ZEV;
  Drive E; Zero emission; I-on; Electric; I-e
- Charging plug, but no tank cover
- No exhaust pipe
- No cooling grille
- No engine noise

Visible characteristics of hybrid car:

- Hybrid car: PHEV; HEV; MHEV and others
- Charging plug and/or tank cover

Visible characteristics of hydrogen vehicle:

- Hydrogen logo for example Hydrogen

QUESTIONS ABOUT THE VEHICLE

WHERE DID THE TRAFFIC ACCIDENT HAPPEN?

- Motorway - country road - urban/residential road - gravel road; in water? (lake, port, etc.)?
- Is the vehicle obstructing the flow of traffic on roads, paths, etc.
- Is it on the road? Which lane; inner, outer, middle or emergency lane; outside the roadway; located at the edge of the road; opposite roadway?
- Is it on all 4 wheels - lying on its side - upside down - opposite direction of the other traffic?

IS THIS AN ELECTRIC VEHICLE - ONE OR MORE VEHICLES INVOLVED?

- How many vehicles?
- How many electric cars are involved?
- Is the vehicle by itself or together with other vehicles?
- Has the vehicle slammed into the vehicle in front?
- Has the vehicle been hit from behind?
- Does the vehicle stay intact in a pile-up?

Visible damage to the electric car

- Damage to the front or rear
- Damage to the left or right side
- Exposed or damaged orange cables from the vehicle
- Airbags are deployed

Visible damage to the battery pack

- The vehicle is against the guardrail
- Is there leakage of liquids from the battery pack?
- Deformation of the battery pack
- Battery pack exposed

HOW FAST WAS THE CAR GOING IN THE ACCIDENT? (BEST GUESS)

- Over or under 70 km/h?

Action card - Fire in electric car
- Persons at risk in electric car/vicinity

Used in the event of an accidental fire in an electric vehicle where there is a need for extrication or other danger to life or limb.

FIRE IN ELECTRIC CAR BATTERY - PEOPLE IN DANGER IN VEHICLE/VICINITY	
Persons at risk	**Offensive operation**
The need for freeing	**Offensive operation**

TACTICAL PRIORITIES
BEFORE
Risk assessment
Switch off the power supply if the car is being charged (It can be necessary to have access to the supply cabinet for the charger)
If this is not possible, the fire should be considered a fire in high-voltage installation
Set up barriers and high voltage danger markings/signs for the charging station
Ensure that there is no high voltage in the body of the electric vehicle
Place wheel chocks at the wheels of the vehicle
Disconnect the main switch of the electric car if this is possible
Disconnect the car's 12v battery
DURING
Offensive tactic: Switch off or cool the EV battery with a high power jet and perform person rescue
For person rescue - see the booklet on rescue
After rescuing a person, the following action card is used: Fire in the battery of an electric car - no people at risk
AFTER
After rescuing a person, use the action card, 'Fire in the battery of an electric car - no people at risk'

Action card - Fire in an electric car - No persons at risk

FIRE IN AN ELECTRIC CAR BATTERY - NO PERSONS AT RISK		
Possibility of the fire spreading	Offensive efforts	Defensive efforts
No possibility of the fire spreading		Defensive efforts
Critical infrastructure	Offensive efforts	Defensive efforts
Danger to citizens (smoke development)	Offensive efforts	Defensive efforts

TACTICAL PRIORITIES
BEFORE
Risk assessment
Switch off the power supply if the car is being charged (It may be necessary to have access to the charging station's supply cabinet)
If this is not possible, the fire should be considered a fire in a high-voltage installation
Set up barriers and high voltage hazard markings/signs for the charging station
Ensure that there is no high voltage in the body of the electric vehicle
Place stop blocks at the wheels of the vehicle
Disconnect the main switch of the electric car if this is possible
Disconnect the car's 12V battery
DURING
Offensive tactic: Turn off or cool the high-voltage battery. If necessary, place the electric car in a fire extinguishing container
Offensive tactic: If necessary, use water mist to cool the surroundings and wash hazardous substances from the smoke with large amounts of water mist with as small droplets of water as possible
Defensive tactic: Let the high-voltage battery burn out. This may take more than 120 minutes
Defensive tactic: If necessary, use water mist to cool the surroundings and wash hazardous substances from the smoke with large amounts of water mist with as small droplets of water as possible
Defensive tactic: If necessary, use a fan to control the smoke plume
AFTER
Maintain barriers and signage for as long as possible
When the battery has cooled sufficiently, check that the temperature of the battery is stable or decreasing for at least 60 minutes - to below 80°C. Use a thermal imaging camera
Transport the vehicle to a suitable storage location and place it at least 5 metres away from other flammable material, including buildings
Inform the recipient that it is an electric vehicle or hybrid/plug-in hybrid vehicle
Pass information to the police, and transporter, if there is damage to the electric car or battery

Action card - Fire in an electric car – Building/closed construction

Used in case of fire in an electric car, which is located in a building or enclosed structure, for example: a parking basement where there are not necessarily any good possibilities for ventilation.

FIRE IN ELECTRIC CAR - CONSTRUCTION/CLOSED CONSTRUCTION	
Possibility of fire spread	**Offensive efforts**
Danger to citizens (smoke development)	**Offensive efforts**

TACTICAL PRIORITIES
BEFORE
Ensure efficient venting of flue gases from emergency access routes
Observe that the flue gases are not vented to areas where people can be exposed to them
Seal off any access routes to the space so that persons without proper PPE are prevented from accessing the space
Move towards the fire to minimise all contact with smoke
Switch off the power supply if the car is being charged (It may be necessary to have access to the charging station's supply cabinet)
If this is not possible, the fire should be considered a fire in a high-voltage installation
Set up barriers and high voltage hazard markings/signs for the charging station)
Ensure that there is no high voltage in the body of the electric vehicle
Place stop blocks at the wheels
Disconnect the main switch of the electric car if this is possible
Disconnect the car's 12V battery
DURING
Offensive tactic: Turn off or cool the battery. If necessary, place the electric car in a fire extinguishing container
Offensive tactic: If necessary, use water mist to cool the surroundings and wash hazardous substances from the smoke with large amounts of water mist with as small water droplets as possible
Offensive tactic: Use a fan to control the smoke plume
Pay attention to drainage and possibly collect the extinguishing water
Defensive tactic: Bring the electric car into the open
Defensive tactic: Subsequently, use the action card, 'Fire in electric car battery - no people at risk'
AFTER
When the battery has cooled sufficiently, check that the temperature of the battery is stable or decreasing for at least 60 minutes - to below 80°C. Use a thermal imaging camera
After rescuing a person, use the action card, 'Fire in the battery of an electric car - no people at risk'

Action card – Fire in an electric vehicle – Not in the battery

Used in the event of a fire in an electric vehicle where the fire has not yet spread to the high-voltage battery, but there is a risk that it could happen.

FIRE IN AN ELECTRIC CAR – NOT IN THE BATTERY	
Possibility of fire spread	**Offensive efforts**
Possibility of fire spreading	**Offensive efforts**

TACTICAL PRIORITIES
BEFORE
Risk assessment
Switch off the power supply if the car is being charged (It may be necessary to have access to the charging station's supply cabinet)
If this is not possible, the fire should be considered a fire in a high-voltage installation
Set up barriers and high voltage hazard markings/signs for the charging station
Ensure that there is no high voltage in the body of the electric vehicle
Place stop blocks at the wheels
Disconnect the main switch of the electric car if this is possible
Disconnect the car's 12V battery
DURING
Offensive tactics. Put out the fire in the electric car
Ensure that the temperature from the fire has not affected the battery of the electric car
Check that the temperature of the battery is stable and below 80°C Use a thermal imaging camera
AFTER
Check that the temperature of the battery is stable below 80°C. Use a thermal imaging camera
After rescuing a person, use the action card, 'Fire in the battery of an electric car - no people at risk'

Action card - Police

This action card provides a number of guidelines for proper handling of electric vehicles until the arrival of the fire and rescue services.

In road accidents involving electric vehicles, there is a significantly higher risk of possible high voltage in the bodywork, a sudden fire in the battery and escaping gases.

Particular attention should be paid to the following:

- All kinds of high-energy accidents (the electric car is deformed).
- Visible electrical cables - orange (dangerous electrical voltage).
- Sparks, smoke, steam from the battery (hint of fire).
- Leakage of liquids and/or noise from the battery.

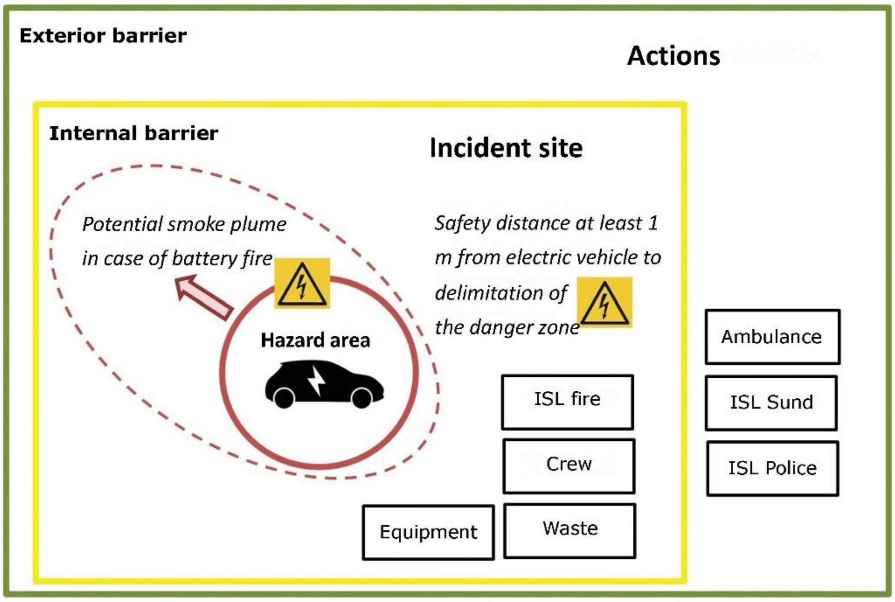
Electric vehicles should not be touched without proper PPE. If one or more of the above items are present, the first patrol car should weigh the risks of working in or near the EV in relation to proper personal protective equipment (PPE) being available.

There is a risk of poisoning if you are continually exposed to smoke or leaking gases and liquids from the battery. The Danish Emergency Management Agency's 'Farlige stoffer' app contains information on dangerous substances, safety distances, health risks, etc.

The first patrol car to arrive can be helpful in securing the incident site. This includes sealing off the area, removing people around the electric car and in a possible smoke plume. The following principle is applied when organising an emergency scene.

There is a risk of high voltage when in contact with cables/wires or live parts.

The Danish Emergency Management Agency's 'Farlige stoffer' app contains information about different substances, safety distances, health risks, etc.



The structure of the scene of a road traffic accident with the need to free trapped people or a risk of fire. Illustration: Beredskabsstyrelsen

QR code for 'thermal runaway' video while loading on a flatbed.

PATROL CAR ARRIVES AT THE SCENE OF THE ACCIDENT AS THE FIRST CAR	
Safeguarding the accident site	- Stopping the traffic - Cordoning off the accident site - Securing of own personnel and other people against any smoke plume
Overview	- Fire/no fire in the vehicle? - People in danger/not in danger? In or out of the vehicle? - Person - Unstable on ABC, unconscious? ⇨ Need to relocate in an emergency? - Person - stable on ABC, conscious? ⇨ No need to remove casualties
Fire/risk of fire	- Fire: flames or smoke (black) - Risk of fire: sounds; smells; white smoke (degassing from battery) - Avoid staying in the smoke plume or gases (without PPE)
Type of vehicle (electric car/plug-in/hybrid car)	- Confirmed/ unconfirmed electric car? - Position at the incident site - on/off road, in the water, etc. - Position of the vehicle - on its roof, on its side, etc.
Damage to the electric car ⇨ risk of shock	- Exposed or damaged cables? - Body deformations, battery? - Triggered airbags = no-voltage cables? - The battery pack cannot become voltage-free
Casualty management?	- Only if it is possible and safe: - Need to remove the injured person from the vehicle? - First aid for injured people outside the vehicle? - First aid for injured people in the vehicle without touching the electric car?
Disclosure of information to ISL BRAND, ISL SUND	- Act with reference to: - Safeguarding the accident site - Casualty overview handling? - Type of vehicle (electric/hybrid) - Fire/risk of fire - Damage to the electric car

FURTHER INFORMATION
- What type of vehicle is it - licence plate number? Electric car/plug-in/hybrid car?
- Are there any injuries in the vehicle? Are they trapped?
- Have we removed casualties as well as bystanders at a safe distance from the injury site?
- Have people been exposed to smoke (rescue personnel, injured people, other people)?
- What is the position of the vehicle (on the road, in a ditch, in the water, on its roof, etc.)?
- Is there visible smoke or gasses emanating from the vehicle?
- Sounds; Smoke development; unnatural odours or fluid running out of the battery?
- Danger of voltage on the vehicle - danger of high voltage, exposed, broken cables?

For more information about observations at the incident, see 'Action card - Question guide for call centre, AMC and first responders'.

Action card - Medical Services

There may be situations where the ambulance arrives first at the scene of the incident. This action card provides a number of points of attention for the proper handling of electric vehicles until the arrival of the emergency services.

In road accidents involving electric cars, there is a significantly greater risk that rescue personnel may be injured due to possible high voltage in the body of the vehicle, sudden fire in the battery and leaking gases.

Based on this and a risk assessment made by the first vehicle on the scene, the emergency services should be called if, (1) this has not been done on the initial call, and (2) if the one of following is visible to the responding personnel:

- All kinds of high-energy accidents (the electric car is deformed).
- Visible electrical cables - orange (dangerous electrical voltage).
- Sparks, smoke, steam from the battery (hint of fire).
- Leakage of liquids and/or noise from the battery.

Electric vehicles should in principal not be touched without proper PPE. If one or more of the above items are present, the first patrol car should weigh the risks of working in or near the EV in relation to proper personal protective equipment (PPE) being available.

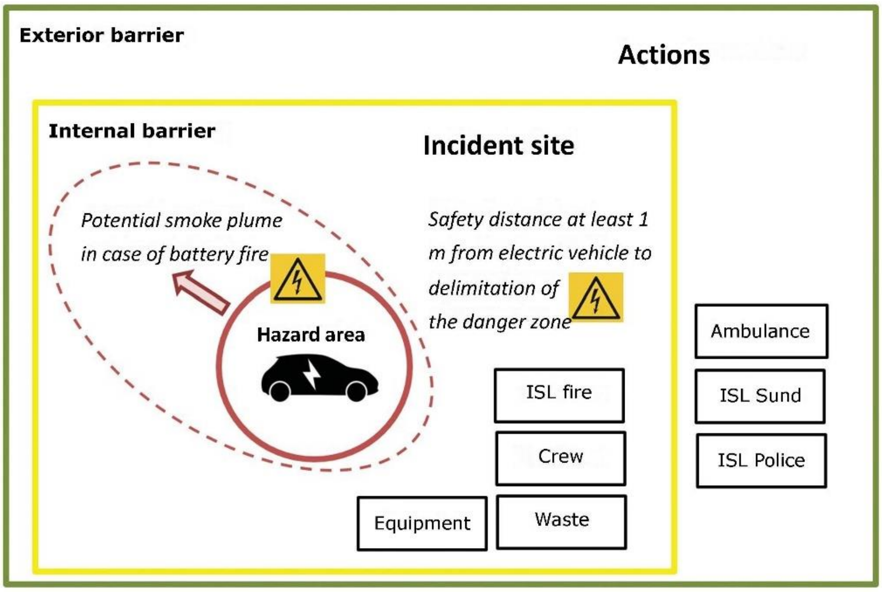
Subject	Personal protective equipment (PPE)
Head	Helmet - EN 50365:2003
Eyes	Suitable visor or glasses - EN 166: 2002
Body	Turnout gear - EN 61482-1 and 2
Feet/Body	ESD approved footwear - EN 15090: 2012, type F2A
Hands	Suitable gloves EN 60903: 2004

There is a risk of poisoning if you are continually exposed to smoke or leaking gases and liquids from the battery. The Danish Emergency Management Agency's 'Farlige stoffer' app contains information on dangerous substances, safety distances, health risks, etc.

The first vehicle can assist in securing the scene. This includes cordoning off the area, removing people from the area surrounding the electric car and from any smoke plume. Work should be carried out according to the following principle for organising an incident site:

<u>There is a risk of high voltage when in contact with cables/wires or live parts.</u>

The Danish Emergency Management Agency's app 'Farlige stoffer' contains information on the danger of substances, safety distances, health risks, etc.



The structure of the scene of a road traffic accident with the need to free trapped people or risk of fire. Illustration: Danish Emergency Management Agency

THE EMERGENCY UNIT ARRIVES AT THE SCENE OF THE ACCIDENT AS THE FIRST-RESPONSE VEHICLE (AMBULANCE, EMERGENCY VEHICLE, MEDICAL VEHICLE)	
Safeguarding the accident site	- Stopping traffic - Cordoning off accident site - Securing one's own crew and people against any smoke plume
Overview	- Fire/no fire in the vehicle? - People in danger/not in danger? In or out of the vehicle? - Stable on ABC/Unstable on ABC - Person trapped/Not trapped ⇨ Need to relocate YES - Possible and justifiable?
Fire/risk of fire	- Fire: flames or smoke (black) - Risk of fire: sounds; smells; white smoke (degassing from battery) - Avoid staying in the smoke plume or gases (all without PPE)
Type of vehicle (electric car/plug-in/hybrid car)	- Confirmed/unconfirmed electric car? - Location at the injury site - on/off road, in the water, etc. - Location on the its roof, on the its side, etc.

Electric vehicle damage risk of shock	Visible damage? - Are there one or more vehicles? - Damage to the front or rear - Damage to the left or right side - Exposed or damaged orange cables from the vehicle - Note the risk of high voltage when in contact with cables/ wires or live parts - Body deformation, battery? - Triggered airbags = no-voltage cables. The battery pack cannot be voltage-free - Is the vehicle against the guardrail? - Speed above or below 70 km/h?
Casualty management?	- Only if it is possible and safe: - Need emergency removal of injured people from the vehicle? - First aid for injured people outside the vehicle? - First aid for casualties in vehicle without contact with the electric car? Attention - Any contact with defective/exposed cables and wires should be avoided. - If you start removing injured people, there may be a risk of voltage in the car frame due to deformation of the battery pack. - If the car's airbags are deployed, the cables from the battery pack will be de-energised and removal can begin if the injured person is unstable with regards to ABC. - Insulating rubber mats and special protective equipment (PPE) should be used for the protection of personnel who will be working in and around the electric vehicle. Therefore, emergency services should be called. - A safety distance of at least 1 m from the electric vehicle should be marked, cf. EN 50110-1, where direct contact with conductive parts is defined as 'live working' and working within 30 cm of conductive parts is defined as 'near live working'.
Disclosure of information to Incident command – Fire and Medical	- Act with reference to: - Safeguarding the accident site - Casualty overview handling? - Type of vehicle (electric/hybrid). - Fire/risk of fire. - Damage to the electric car.

EVT. FURTHER INFORMATION
- What type of vehicle is it - licence plate number? Electric car/plug-in/hybrid car?
- Are there any injured people in the vehicle? Are they trapped?
- Have we removed injured people as well as bystanders at a safe distance from the incident site?
- Have people been exposed to smoke (crew, injured, other people)?
- What is the location of the vehicle (on the road, in a ditch, in the water, on its roof, etc.)?
- Is there visible smoke or degassing from the vehicle?
- Sounds; Smoke development; unnatural odours or fluid running out of the battery?
- Danger of voltage at the vehicle - danger of high voltage, exposed, broken cables?

For more information about observations at the scene of an incident, see 'Action card - Question guide for call centre, AMC and first responders'.

Action Card - Emergency site management

After the rescue team has made entry into an electric vehicle, it is important that relevant instructions are given to the transporter who will be transporting the electric vehicle away or to the police when handing over the scene of the accident, if the transporter has yet to arrive.

EMERGENCY SITE MANAGEMENT	
Manage emergency site	- Marking of hazard area with signage against high voltage - this is maintained when releasing the damage site (at least 1 m). - The accident site/electric vehicle is handed over to the police or transporter if they have arrived at the accident site when the emergency services assess that there is no longer a possibility of 'thermal runaway'. - If working earthing has been carried out, it should be ensured that an electrician or similar expert will be able to demonstrate removal of earthing upon handover of the accident site.
Instructions for the transporter	Transporters should be provided with the following information: - This is an electric/hybrid vehicle. - Briefly about the emergency response: firefighting, extrication (damage to cables). - Assessing the condition of the car's high-voltage battery, disconnecting the main switch, voltage. - The risk of 'thermal runaway' during transport to the workshop and what the transporter should do if this happens. - The electric car should be placed at least 5 metres away from buildings and other flammable materials.

Examples of hazard signs

Action card – Recovering an electric vehicle

After performing a rescue operation on an electric vehicle, it is important to provide relevant instructions to the transporter who is to transport the electric vehicle away, or to the police if the accident site is transferred to them.

Recovering an electric vehicle	
The transporter shall be informed of the following before loading the electric vehicle	- This is an electric/hybrid vehicle. - Explain the emergency response efforts. - Explain the condition of the car battery and the possible danger of high voltage.
The transporter should take care when loading the electric car	- The electric vehicle can be loaded, transported and unloaded in a safe and secure manner, including the use of personal protective equipment (PPE) by the transporter. - A safety technician must always be present when there is voltage in the bodywork. - There must be no unnecessary sudden movement of the car while it is being loaded onto the tow truck. - Be aware of any heat build-up or thermal runaway in the battery while the car is being loaded. - Noises, smoke or unnatural smells from the battery. - Fluid draining from the battery.
The transporter should pay attention to the following when moving the electric vehicle	To call 112 and provide relevant information if any of the following occur: - Fire/'thermal runaway' in the battery. - Heat generation in the battery. *Or significant changes in relation to:* - Sounds from the battery. - Smoke from the battery.
The transporter should be aware of the following when the electric vehicle is unloaded at the final destination	- The electric car should not be placed in a building/under cover. - The electric vehicle should be placed at a sufficient distance to surrounding buildings, shelters and other flammable warehouses that any fire cannot spread to this area. - The electric car should be clearly marked with barriers and signs with 'Danger - high voltage'. Call 112 and provide relevant information if any of the following occur: - Fire/'thermal runaway' in the battery. - Heat generation in the battery. - Fluid draining from the battery. *Or significant changes in relation to:* - Sounds from the battery. - Smoke from the battery. - Unnatural smells from the battery.


Dangerous
electrical voltage

References and citations

1 https://www.euroncap.com/en/press-media/press-releases/euro-ncap-improves-tertiary-safety-by-introducing-a-mobile-app-for-first-responders-in-europe

2 Euro ncap rescue sheet, free app, https://www.euroncap.com/en/about-euro-ncap/timeline/ euro-ncap-launches-euro-rescue-free-downloadable-rescue-information-for-first-respon- ders/

3 Electric car batteries: What you need to know (firerescue1.com), https://www.firerescue1. com/firefighter-training/articles/what-firefighters-need-to-know-about-electric-car-batteries- omiDv8vd87oZ9ZKs/

4 Industriens Branchearbejdsmiljøråd [The Industry's Occupational Health and Safety Council], 2016, El- og hybridbiler [Electric and hybrid cars]. Sikkerhed ved reparation og vedligehold [Safety in repair and maintenance], https://www.bfa-i.dk/media/aazlwuvr/el-og-hybridbiler.pdf

5 https://risefr.com/media/publikasjoner/upload/2017/a17-20096-03-01-fullskala-brannfor- sok-av-elbil.pdf]

6 SP Fire Research A/S, 20/02 2017, A17 20096:03-01

7 https://www.ntsb.gov/safety/safety-studies/Documents/SR2001.pdf]

8 NFPA Bulletin, September 2017

9 Informationsvideo Prehospital förmåga vid insatser med bränder i litiumjonbatterier [Information video Prehospital capability in response to lithium-ion battery fires], https://youtu.be/vaspu8f_X_w

10 Gasformig HF vid brand i trånga utrymmen – risker för hudupptag vid insatser [Gaseous HF in confined space fires - risks of skin absorption during operations], MSB 2021

11 LBK no. 26 of 10/01/2019, Bekendtgørelse af lov om sikkerhed ved elektriske anlæg, elektriske installationer og elektrisk materiel (elsikkerhedsloven) [Executive Order of the Act on the Safety of Electrical Installations and Electrical Equipment (Electrical Safety Act)], https://www.retsinformation.dk/eli/lta/2019/26

12 Sikkerhedsstyrelsen [Safety Board], https://www.sik.dk/erhverv/elinstallationer-og-elanlaeg/vejledninger/elinstallationer/l-aus-arbejde-under-spaending/arbejde-paa-elektriske-installationer, tilgået 25-01-22

13 Danish Standard, "DS/EN IEC 60900:2018 Arbejde under spænding [Working at voltage] – Håndværktøj til anvendel-se op til 1000 V a.c. og 1500 V d.c. [Hand tools for applications up to 1000 V a.c. and 1500 V d.c.]," Danish Standard, 2018

14 International Organisation for Standardisation, "ISO 7010:2019 Graphical symbols — Safety colours and safety signs — Registered safety signs," ISO, 2019

15 FDM: Hvordan fungerer en elbil [How an electric car works]? https://fdm.dk/alt-om-biler/elbil-hybridbil/alt-om-livet- med-elbil/hvordan-fungerer-en-elbil, tilgået 25-01-22

16 Sikkerhedsstyrelsen: Opladning af elbiler [Sikkerhedsstyrelsen: Charging electric cars] https://www.sik.dk/erhverv/elinstallationer-og-- elanlaeg/vejledninger/elinstallationer/elbiler/opladning-el-biler, tilgået 13-06-22

17 Håndtering af trafikskadede elbiler, SKAD – autoskadebranchen [Handling electric cars damaged in traffic accidents, SKAD - auto damage industry], https://www.skad.dk/images/Bilteknik/SKAD_guideline_skadede_el-hybridbiler_V1_2019.pdf

On the Danish Emergency Management Agency's website www.brs.dk, you can find other publications, e.g.

Guidelines and diirectives

Learning Materials

Opinions and rulings

Historical material

Graphic setup:
Graphic designer Pernille Gaarden, Publikationselementet, Korsør

DANISH EMERGENCY MANAGEMENT AGENCY

Datavej 16
3460 Birkerød

Phone: +45 71 85 20 00

Email: brs@brs.dk
www.brs.dk

EAN: 5798000201705
CVR: 52990319