Myndigheten för samhällsskydd och beredskap

GUIDANCE

Rescue operation where lithium ion batteries are present

Rescue operation where lithium ion batteries are present

Unit: The unit for fire and rescue

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Preface

This guidance aims to develop emergency services' knowledge and understanding of lithium-ion batteries, electric vehicles and other lithium-ion battery-powered applications. The guidance is based on the current state of knowledge in the area in 2023. The guidance concerns the cause, handling and response methodology for lithium-ion batteries involved in a fire.

The methods proposed in the guidance should be seen as possible methods. Development takes place quickly in the field and new ways of dealing with fires and accidents are constantly being developed. In cases where laws, rules, regulations, the manufacturer's or the organization's own instructions impose higher or other requirements, the these preferences.

With the help of routines, training, technical solutions and the right level of protective equipment, accidents can be prevented and the consequences reduced if the accident were to occur.

Stockholm, 2024-06-17

Patrik Perbeck

Deputy Head of Department, Department for Emergency Services and Accident Prevention

Summary

This guide presents overall facts about lithium-ion batteries and explains the cause and origin of thermal runaway, as well as how it spreads from battery cell to battery cell, known as propagation. The guidance also provides suggestions for response methodology in the event of a fire in lithium-ion batteries.

In recent years, knowledge about hydrogen fluoride and its impact on emergency service personnel has increased, with positive consequences. Thanks to the new knowledge, the risk of the toxicity of the battery gases is assessed to be lower than previously assessed and at the same level as other fire smoke. This means that the emergency services can handle burning lithium-ion batteries in the same way as other fires in terms of toxicity.

The risk that is least known, and perhaps most serious at the moment, is that lithium-ion batteries that thermally rush can produce flammable gases that can be explosive. This means that all volumes where gases can accumulate must be considered as having a risk of explosion. At the time of writing, there is no knowledge of which ratio between the size of battery cells and the size of room volumes is risky with regard to explosions. It is a challenge, as the guidance explains along with rough guidelines on how the emergency services personnel can think about this, before and during an operation.

An area that is current and where a lot of investigative work is currently taking place is the re-ignition of burnt or damaged electric vehicles. This guidance describes it on an overall level, as it is an important and in-demand area.
It requires cooperation between emergency services, recovery companies, garages and vehicle manufacturers, so that vehicles known to be at risk of re-ignition are transported safely and efficiently and then placed wisely to reduce the risk of fire.

The guidance develops the knowledge of handling fires in lithium ion batteries so that an intervention can take place in a safe manner. Although there are still areas that need to be developed in battery systems and emergency service methodology, this guidance will be helpful in being able to carry out operations in an effective manner. It mainly concerns battery energy storage in homes, energy storage in large systems and battery operation for heavy vehicles, together with battery systems, charging and storage of batteries for micromobility.

Content

1 Introduction

Sweden is transitioning to a fossil-free society and the use of lithium-ion batteries is becoming more and more common. Electric vehicles and other electric applications, such as electric bicycles and mobile phones, that contain lithium-ion batteries have also increased. At the same time, installations of battery energy storage in homes and offices are increasing, in order to be able to use the energy from solar power and wind power around the clock.

In recent years, authorities and other organizations have delved into the risks of lithium-ion batteries ending up in thermal runaway. This can happen in the event of, for example, mechanical damage, overheating or internal electrical faults. This is the basis for different types of solutions to deal with incidents involving lithium-ion batteries. With new knowledge comes new solutions and methods.

Fires and smoke in lithium ion batteries were assessed based on previous knowledge to require a lot of water and extensive personnel and material resources for a long time. It is hoped that the methodology described in this guide will contribute to a smoother and less resource-demanding handling of such events.

The guidance introduces the possibility of penetrating vehicle batteries with tools intended and approved for the purpose. In this way, the rescue service's time at the scene of the accident is shortened and the amount of extinguishing water is reduced. This method is based on experiments where propagating lithium-ion batteries have been extinguished in a short time by establishing an internal water flow inside a battery pack. The report[1], on which parts of this guidance are based, confirms that the in-battery water flow extinguishing technique worked on the vehicle batteries tested. Before the method presented in this guide is used, employers need to assess that it is to be used, staff need to be trained and tools need to be assessed that they are safe for the task. In the case of fires in other battery types, further tests need to be done to know the effect. However, by taking into account the security aspects we have described here, the method can be used safely.

In 2013, MSB carried out tests within the project "Räddningskedjan"[2], where we tested penetration of battery packs, among other things. Those attempts failed, something we have been able to explain in retrospect by the fact that we then tried to destroy individual burning cells with cutting extinguishers, while the later, successful attempts are based on cooling battery cells that have not yet begun to thermally rush to prevent them from starting to burn .

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[1] (MSB, 2023)
[2] (FSI, 2013)

1.1 Target group

This guide is primarily aimed at everyone who works in the municipality's rescue service within the operational work, but may also be of interest to other actors such as residual value personnel, other blue light operations and salvagers.

1.2 Purpose and goal

The objectives of this guidance are:

- to develop the rescue services' knowledge and understanding of risks and methods of handling lithium-ion batteries involved in fires
- to give the rescue services support in reasoning about the choice of extinguishing method and different tactical possibilities.

The goal is for the emergency services to be able to carry out safer and more effective rescue efforts in the event of fires where lithium ion batteries are involved.

1.3 Limitations

This guidance describes risks and methods of extinguishing fires in lithium-ion batteries based on the knowledge available at the time of this guidance is written.

The method of safely using internal application of water is based on a limited number of practical trials with vehicle batteries, based on an extensive literature study[3,4,5]. There is no guarantee that it will work for other types of batteries.

There is a risk of explosion in connection with thermal rush and there have been explosions in Sweden and the world. There is currently limited knowledge about how big this problem is, but research and development is ongoing in the area.

[3] (Bisschop, Willstrand, Rosengren, 2020)
[4] (Egelhaaf, Kress, Wolpert, Lange, Justen, 2013)
[5] (Zhang, Kaiqiang, Sun, Wang, 2022)

1.4 Concepts and abbreviations

Table 1. Explanations of terms and abbreviations

Terms and abbreviations	Explanation
Battery cell	Basic rechargeable energy storage device consisting of electrodes, electrolyte, reservoir, terminals, and usually separators. The battery cell is a source of electrical energy obtained by direct conversion of chemical energy.6
Battery energy storage	With the help of a battery energy store, for example, a solar cell plant can store the excess of energy from the day and then provide it during the night. A battery energy storage can also be used to cut power peaks in, for example, an apartment building where the peak effects can affect the electricity cost.
Battery module	Assembly of several battery cells that make up subsystems of the battery pack.
Battery pack	Energy storage device containing cells or cell assemblies normally connected to cell electronics and an overcurrent shutdown device with electrical interconnections and interfaces to external systems.7
BMS	Battery Management System. Protects the battery system from damage, monitors and increases the life and maintains the functional state.8
Cylindrical cell	Battery cell in the form of a cylinder. Often with a metal casing.
Electric vehicles	Vehicles with one or more electric drives for propelling the vehicle.9, 10, 11 Where electric vehicles are mentioned in this guide, the energy for the electric drive comes from the lithium-ion battery.
Emergency Response Guide, ERG	ERGs are documents that contain technical product information which can be used to establish procedures and methods for rescue operations for vehicles. 12, 13, 14
Explosion	A rapid process that releases energy and gives rise to a pressure wave.
Propulsion battery	Also called traction battery. Collection of all battery packs that are electrically connected to supply electrical power for the electric drive of a vehicle.15
Wheel dolly	Aids used in, for example, workshops to manually move a car without using the vehicle's own wheels.
Lithium ion battery	Rechargeable battery based on lithium ion technology and an organic electrolyte.
Prismatic cell	Battery cell with a hard cell casing in the shape of a small box (prismatic). A prismatic cell has high energy density.
Propagation	The process when a thermal surge in a lithium ion battery cell propagates from cell to cell in a battery.

[6] (ISO - International Organization for Standardization, 2019)
[7] (ISO, 2016)
[8] (ISO, 2020)
[9] (ISO, 2022)
[10] (ISO, 2022)
[11] (ISO, 2022)
[12] (ISO, 2022)
[13] (ISO, 2022)
[14] (ISO, 2022)
[15] (ISO, 2018)

Concepts and abbreviations	Explanation
Bag cell	Battery cell where the cell casing consists of laminated metal-polymer foils. A bag cell has high energy density and good heat dissipation. The battery cell has no hard casing around the cell itself and is called in English a pouch cell.
Rescue card, Rescue Sheet	Document within ISO standard 17840 that contains vehicle and model specific standardized data sheets with technical information for rescue personnel. Found, among other things, in the app Euro Rescue or CRS Crash Recovery System.
SOC	State of Charge is the available capacity of a rechargeable energy storage system expressed as a percentage of the nominal capacity.[16] The Swedish word is degree of charge.
Thermal rush	Uncontrollable condition where a battery cell overheats and reaches very high temperatures for short periods (seconds) through internal heat generation.[17]
Re-ignition	Event when an apparently extinguished material starts to burn again.

[16] (ISO, 2019)
[17] (ISO, 2024)

2 Background

In recent years, MSB has drawn attention to the risks of fires in lithium-ion batteries and the difficulties associated with rescue efforts. Technology develops rapidly and there is a need for new knowledge in the field.

For many years, MSB has received questions from the emergency services about risks and extinguishing fires in lithium-ion batteries. The questions that come up today mainly concern which electrical hazards there are, how to handle them in a safe way, as well as how to switch them off depending on the type and size of the battery. There are also risks of explosions to deal with.

In the event of fires and thermal surges in lithium-ion batteries, the substance hydrogen fluoride can be formed. A question that has previously been highly relevant is how dangerous hydrogen fluoride is. The subject has skin damaging and system toxic properties. Due to this, the Total Defense Research Institute has conducted a study[18] on behalf of MSB to investigate the risks of potential skin absorption in rescue personnel with external air packs. Overall, the results showed that the risk of potential skin absorption of hydrogen fluoride is low and that serious consequences are unlikely to occur. However, it cannot be ruled out that some pain or skin redness may occur.

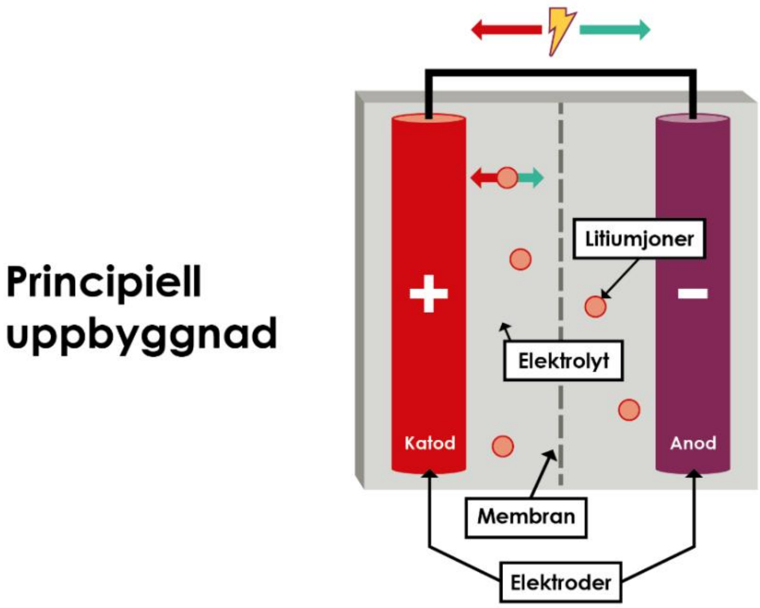
[18] (Total Defense Research Institute, 2021)

3 Lithium-ion batteries

This chapter is aimed at anyone who needs to have a basic understanding and knowledge of lithium-ion batteries, what types and appearances there are, as well as how they are constructed and function.

There are different variants of lithium-ion batteries with slightly different constituent chemical substances, which may have some significance for the risks. The guidance does not differentiate between different types of lithium-ion batteries, as the physical properties and risks are similar. Lithium-ion batteries are called the group of batteries where the battery cell's energy is extracted by lithium ions moving between the battery's electrodes, see figure 1. They have become increasingly common in society. One reason for that is they have a higher power and energy density than other types of rechargeable, also called secondary, batteries.

Figure 1. Structure of a lithium ion battery cell.



Lithium-ion batteries have good battery performance and are therefore used in, for example, hoverboards, bicycles, telephones, computers, hand-held tools and machines, cars and battery energy storage in buildings and more.

Typical shapes of the battery cells are:

- **Cylindrical.** Cylindrical battery cells are often enclosed in a larger module, but can also occur individually. They are found, for example, in certain car models, electric bicycles, hand tools, toys and laptops.
- **Prismatic.** Prismatic battery cells are shaped like cubes with hard shell. They are available in different sizes, either with standard measurements or specially

adapted to the equipment being operated. That type of battery cell is common in larger industrial batteries and in electric vehicles.

- **Bag cells.** For pouch cells, the battery cell is enclosed in a thin laminated foil. This type is common in electric vehicles, phones, tablets and laptops. The soft shell makes this battery cell more sensitive to shocks and impacts.

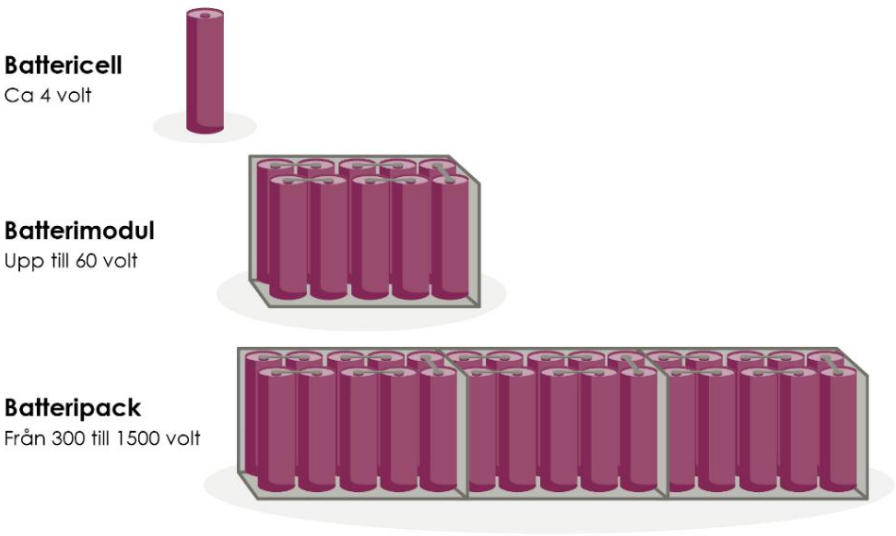
Figure 2 illustrates the different forms of battery cells and gives examples of products in which they are used.

Figure 2. Appearance and presence of lithium-ion batteries.

There is no standardized labeling on products that informs that they contain lithium-ion batteries. It can therefore be difficult to see the outside of, for example, a vehicle if it is an electric vehicle powered by a lithium-ion battery.

When talking about lithium-ion batteries in different types of equipment, the terms battery cell, battery module and battery pack are often mentioned, see Figure 3.

Figure 3. Structure of lithium-ion batteries.



A battery cell is the smallest part of the system. It can be designed, for example, as a cylindrical or prismatic battery, or as a bag. Typical voltage in a lithium ion type battery cell can be around 4 volts.

Slightly more energy-demanding equipment, such as hand tools or bicycles, contain several battery cells, often in an enclosure, i.e. a battery module.
The voltage in a battery module can be up to 60 volts. The reason why 60 volts is the maximum in modules is that they are then below a voltage that can be handled in a dry environment without additional protection.

Battery packs are used for large energy consumers. There are even more battery cells there than in a module, or several modules that are enclosed by an outer casing. A battery pack can have a voltage from about 100 volts up to 1500 volts.

3.1 Portable lithium ion batteries

Portable lithium-ion batteries refer to the type of batteries used in, for example, mobile phones, laptops, hand tools, toys, headlamps and radios.

Items with portable lithium-ion batteries often have a simpler system structure and lower quality battery cells, compared to, for example, electric vehicles that contain larger batteries. Portable lithium-ion batteries are often subjected to demanding and sometimes careless handling. In addition, they lack an equally detailed set of regulations that exist for vehicles.

3.2 Portable lithium ion batteries

Portable lithium-ion batteries refer to the type of batteries used in e.g. electric scooters, electric bicycles, hoverboards, permobiles, electric mopeds and sometimes also electric motorcycles (can also contain larger batteries). As with portable batteries, these batteries are sometimes subjected to demanding and careless handling and sometimes lack a specific regulatory framework. They usually also have a much simpler BMS system.

3.3 Larger lithium-ion batteries

Larger lithium-ion batteries have higher performance and also higher requirements and regulation. Larger batteries are used in, for example, electric cars, electric hybrid cars, electric buses, electric trucks and stationary battery energy stores.

3.3.1 Electric vehicles

Historically, larger battery installations for e.g. electric cars and stationary battery energy storage have been built with cells grouped into modules. The modules are then assembled into a complete battery, with an outer battery case of steel or aluminum forming a protective structure around the battery.

Safety in electric cars and other larger vehicles is quite well developed. There are several layers of protection that should

- prevent battery damage
- ensure that the consequences are as small as possible if the battery is still damaged.

A few examples are:

- Protection in the battery cell itself, for example pressure relief and limitation of power outlet.
- Spacing or insulating partitions between battery cells in a module and between modules in a pack.
- External mechanical protection, i.e. where the battery is located and in what.
- BMS system. It regulates how the battery cells are charged and used so that they are not damaged by incorrect voltage, over- or under-charging and temperature.

In step with technological development in the automotive industry, new types of battery designs are coming, where the battery is optimized with regard to energy density and weight. It is therefore important at an early stage of an operation to study the vehicle's rescue card or emergency response guide (ERG), for information about the battery structure in the vehicle in question.

Road vehicles are subject to regulations and international standards. These requirements and standards include, among other things

- insulation values
- physical access to electrically conductive components
- tightness requirements
- shutdown of the high-voltage system in the event of a collision.

UN vehicle legislation[19] requires type approval, which must be met in order for a vehicle model to be sold on the market. The legislation is updated in step with technological development and based on the needs identified in the market.
For electric cars, there are special requirements for electrical and battery safety[20] which include

- mechanical violence (crash) and vibrations
- different types of electrical faults and thermal exposure
- various environmental factors, such as moisture.

The Swedish Transport Agency represents Sweden in the UN working group that develops and decides on the requirements. In addition, there are test institutes with their own security requirements, to

[19] (UNECE - United Nations Economic Commission for Europe, ud)
[20] (UNECE, 2024)

for example Euro NCAP and IIHS (Insurance Institute for Highway Security), which test vehicles and rank them in terms of safety. The crashworthiness requirements placed on electric vehicles are equivalent to those for vehicles with other types of fuel, for example petrol and diesel powered vehicles.

The battery is protected both by the vehicle body and by the mechanical construction around the battery. The physical placement of the battery is important, as energy-absorbing crash zones protect the battery from physical deformation in all directions, in the same way that the vehicle protects its occupants. The battery structure ensures that the tightness requirements are met, i.e. the IP classification. This means that the battery is protected against the external environment and tested to withstand exposure to water (wading and water spraying).

The battery is controlled and monitored by a BMS system. The BMS system monitors that individual cells and the battery as a whole stay within the upper and lower voltage levels, as well as current and temperature limits, for which the battery is designed.
If necessary, the BMS system can limit the power output, to avoid deviations and in an acute risk situation, the battery is disconnected from the high-voltage system, either directly or upon restart.

Electric vehicle BMSs have many different layers of safety, which is reflected in the fire statistics when compared to other battery systems that do not have the same type of safety features.

3.3.2 Battery energy storage

Battery energy storage can be found, for example, in villas, apartment buildings, industries, schools and charging stations. Battery energy stores can also be mobile and the lithium-ion batteries are then fixed in containers or vehicles.
Battery energy storage in buildings is often in the form of lithium-ion batteries connected to solar cell systems or other renewable energy sources. They are available in sizes from a few kWh up to several hundred kWh.

It is characteristic of the large energy stores to collect many battery cells in a limited volume. Sometimes the cells are in modules which are then placed in racks and in other cases used cells from vehicle batteries which are placed in existing packs are used.

Battery energy storage has its own regulations and industry standards for battery management and safety.21, 22, 23, 24, 25

[21] (UL Solutions, 2020)
[22] (NFPA, 2023)
[23] (Standards New Zealand, 2019)
[24] (ICC International Code Council, 2021)
[25] (NFPA, 2023)

4 General risks and measures

The following risks are associated with lithium-ion batteries:

- Thermal rush
  - o Fiery thermal rush
  - o Steaming thermal rush
  - o Fire gases
  - o Explosions
  - o Jet flames
- Electrical hazards
  - o Arcs and short circuits
  - o Current pass-through

4.1 Warnings

In this guidance, we use warning symbols to highlight and classify different risks. Here follows an explanation of the meaning of the various warning symbols.

WARNING! Risk of personal injury and death.

BEWARE! Risk of material damage.

NOTE! Information to be aware of.

4.2 Thermal rush Thermal rush is a

stage when a battery cell in a lithium ion battery itself generates large amounts of heat, after the cell has been heated up by external or internal heat. The battery cell has then become chemically unstable, which gives rise to an accelerating increase in temperature that can lead to a fire in the battery. When the temperature rise has reached a level where smoke or flames come out of the battery cell at a high speed, it has become a thermal rush that cannot be stopped. At some stage during the thermal rush, there is an internal short circuit in the battery cell, which converts the electrical energy into heat. High temperature decomposes the electrolyte into various gases and can simultaneously release oxygen from the cathode material.

Re-ignition of a burned battery can mean that a fire that has already been extinguished is restarted.

Thermal rush

Thermal surge means that the electrical and chemical energy is converted into heat in an uncontrolled way. Then the temperature in the battery cell rises very quickly. The energy also breaks down the ion-conducting liquid, the electrolyte, into flammable gas.
The combination of heat and flammable gas is very dangerous. Of the gas that is formed, as much as 30% - 50% can be hydrogen gas. In addition, oxygen can be released which can contribute to a violent fire if the flammable gas is ignited.

For a battery cell to be affected by thermal surge, a situation must arise where the cell generates more heat than the battery can dissipate. This starts various chain reactions that further worsen the situation as various cell materials become unstable and break down, often into more combustible substances. Figure 4 shows the sequence of events that can lead to thermal rush.

Figure 4. Example of a sequence of events that can lead to thermal rush.

There are a number of risk scenarios that can lead to a safety incident in a battery and which in the worst case can result in a thermal runaway, for example:

- mechanical effects, for example deformation or penetration of the battery cells
- high temperatures, for example external fire
- overdischarge
- overcharging
- external short circuit
- internal short circuit

At a sufficiently high temperature, oxygen is released from the metal oxides found in many cathode materials of lithium-ion batteries. The oxygen can in turn react with the substances formed when the electrolyte decomposes into flammable gas. That reaction adds additional heat.

A battery system is characterized by voltage, electrical capacity, power and energy density. The electrical energy content is only a fraction of the total amount of energy contained in the battery. The chemical energy stored in the material of the cells is roughly five times higher than the electrical content and is released in connection with the burning of the battery.

The threshold for when lithium-ion batteries can self-generate heat that can lead to a thermal surge varies between different cell chemistries, but for some cell types can be at a cell temperature in the range of 70-100º C or higher. At temperatures of 80- At 150º C, so-called gassing/venting can occur, which is a built-in safety mechanism in the battery that is there to relieve the pressure build-up that then occurs inside the battery cell. During ventilation, before the thermal rush begins, small amounts of smoke or invisible gases may be emitted. It is possible to slow down the early process before thermal rush by cooling a battery cell further below the critical temperature.

WARNING! A battery that has been exposed to high heat must always be considered as a battery that can ignite later or have voltage left.

Cell failures in batteries are rare and difficult to detect. They affect about 1–2 cells out of 10,000,000 cells produced. Cell defects can appear after several months or years.

The battery's state of charge, the SOC level (State of Charge), is of great importance for how the cells react to all of the above causes. In general, the higher the state of charge, the more powerful the battery reacts.

Once the thermal rush is initiated in a cell, it can spread to neighboring cells. The high heat from the first cell triggers a thermal rush in the other cells as well, like a domino effect. This is called propagation.

Propagation

The process when a thermal surge in a lithium ion battery cell propagates from cell to cell in a battery.

4.2.1 Fiery thermal rush

WARNING! Jet flames.

WARNING! Health and flammable gases.

Burning thermal rush means that there is no explosion hazard in the spaces where there is fire. This means that it is possible to smoke dive and handle the fire according to standard procedures for fires in electrical equipment indoors, with the additional risks that lithium-ion batteries can entail. See also section **4.2.4 Fire gases.**

4.2.2 Steaming thermal rush

WARNING! Risk of explosion.

WARNING! Health and flammable gases.

In a smoking thermal rush, only smoke is produced, which consists of flammable gases. This means that spaces in a building that are filled with smoke can explode. How quickly it is possible to get into a flammable mixture depends on the volume of the space, ventilation, the size of the battery cells in the facility and the degree of charge and battery chemistry in the cells. The many variables make it difficult for a rescue service to know if, or when, there will be an explosion. The difference to many other flammable gases is that the smoke from a thermal rush is visible. A characteristic of the smoke is that it is light/white/grey and sometimes heavier than the surrounding air. See also section **4.2.4 Fire gases.**

4.2.3 Measures in case of thermal rush

If it is only smoking thermal rush, it should be handled like a leaking gas cylinder with flammable gas.

The best way to stop a fire in a battery pack or a battery module where a thermal surge is propagating is to cool all battery cells.
An effective way is to get water into the battery in which it is burning. Water flowing at a low rate around undamaged cells is in many cases sufficient to prevent them from heating up to critical temperatures. Similarly, the water cools the cell where there is a thermal rush. If the cells are built into modules that cannot get water into, the outside of the modules is instead cooled to prevent propagation from module to module.

> **Measures in case of thermal rush**
>
> - Cool all battery cells.

4.2.4 Fire gases

WARNING! Health and flammable gases.

The process by which a lithium-ion battery can achieve thermal runaway generates different gases depending on whether vented gases are ignited or just fumes. If it is a **smoker thermal rush** these gases mainly consist of:

- hydrogen gas (H_2)
- carbon dioxide (CO_2)
- carbon monoxide (CO)
- short hydrocarbons, for example methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) and propane (C_3H_8).

Steaming thermal rush can under certain circumstances lead to an explosion, see section **4.2.5 Explosions.** In addition, there are **acid gases** in the form of, for example, hydrogen fluoride (HF) and phosphoryl fluoride (POF_3), which are corrosive and toxic at low concentrations. If it is a **burning thermal rush,** the gases that are flammable will burn and instead form combustion products, such as carbon dioxide (CO_2) and water (H_2O). The composition of the gas depends on several parameters, such as cell chemistry, charge status and temperature, as well as whether the gas ignites or not.[26]

[26] (Rowden & Garcia-Araez, 2020)

A substance that has previously been a cause for concern is hydrogen fluoride, where the short-term limit value is stated at 1.7 mg/m3 (2 ppm), that is, an average value over a period of 15 minutes.27 The limit for perceiving hydrogen fluoride is lower than this limit value and stated to be between 0.04 and 0.13 ppm. Even at these levels, severe discomfort is experienced, like irritation. 28

4.2.4.1 Measures in case of fire gases

In the case of a lithium-ion battery fire, the probability of being exposed to concentrations of hydrogen fluoride higher than the limit values is low.29
Rescue personnel carrying alarm stands and compressed air apparatus in dense fire smoke are considered to have adequate protection against harmful exposure to hydrogen fluoride and other gases. [30,31]

4.2.5 Explosions An

explosion is a rapid increase in volume with an extremely rapid release of energy.

Lithium-ion batteries in their original form do not contain explosive substances, but instead contain flammable substances and a lot of electrical energy. Explosion and fire associated with thermal runaway in lithium-ion batteries is due to electrolyte decomposition, forming both flammable and explosive gas mixtures.

4.2.5.1 Gas explosions due to lithium-ion batteries

WARNING! Risk of personal injury and death.

BEWARE! Risk of material damage.

There have been explosions in connection with battery fires both in Sweden32 and in the world. 33,34,35,36

A thermal rush and propagation can occur without igniting gases or vapors. In these cases, both unburned electrolyte and combustible gases, which are reaction products from the cell's internal thermal rush, are vented. Many of these

[27] (Working Environment Authority, 2018)
[28] (Brock, 1999)
[29] (Ambulanssjukvården i Storstockholm AB (AISAB) and Giftinformationscentralen, 2022)
[30] (Wingfors, Magnusson & Thors, 2021)
[31] (Veen & Koppen, 2020)
[32] (Kallin & Lindahl, 2023)
[33] (The Liverpool Echo, 2020)
[34] (Schwäbische, 2022)
[35] (Agrarheute, 2022)
[36] (Arizona Public Service, 2020)

reaction products are flammable gases such as hydrogen, methane, carbon monoxide and other hydrocarbons. Explosions in connection with battery fires differ from flue gas explosions from "normal" fires. One difference is that the smoke from battery fires can contain large amounts of hydrogen[37], which has a wider flammability range and low ignition energy. The smoke may look different compared to normal fire gases. The smoke from a venting battery is usually much lighter, i.e. more white or light grey.

WARNING! The risk of explosions is greatest when thermal rush and propagation occur without igniting gases or steam.

From an operational perspective, a propagating lithium-ion battery can be equated to a leaking gas bottle with flammable gas. If the battery or electric vehicle burns with an open flame, the risk of accumulation of flammable gases is significantly reduced, as these are burned by the fire. In the same way as for other gas leaks, flaming combustion, i.e. burning thermal rush, is an advantage in reducing the risk of explosion.

WARNING! A smoking battery indoors means a higher probability of higher concentrations of flammable gas mixtures in the air. Risk of personal injury in the event of ignition.

Personal injuries can occur as a result of pressure build-up where building parts, furnishings, people or the like are thrown away. Building parts such as glass panes, doors and lightweight walls are those that have the least resistance to pressure build-up and are likely to be destroyed first. In addition, there is a risk of burns.

Smoke outdoors will mix with ambient air and is unlikely to be a flammable mixture, more so than in the immediate vicinity of the source.

NOTE! In the case of battery fumes outdoors, there is usually no risk of explosion.

The biggest possible consequence of battery fumes outdoors is that the gases ignite and turn into burning thermal rush.

[37] (Colella, Mendoza, Barry, Kossolapov, Spray & Myers, 2022)

4.2.5.2 Measures in case of explosion risk

The rescue service must assess the explosion risk and what is best from an operational perspective in each individual case. Treat enclosed spaces as if they could explode. Define risk areas and block off areas that should not be entered. Assess the risk of explosion by comparing the size of battery(s) with the volume of the room. The bigger the batteries and the smaller the room, the greater the risk. The risk of fire spreading and the need for lifesaving needs to be weighed against the risk of explosion. Experience in this regard is currently limited.

There may be openings and structural parts that can give way in an explosion, for example windows, doors, light walls or the like. By identifying where these are and avoiding being nearby, the risk of, for example, personal injury is reduced.

At the time of writing, there are many uncertainties about what methods work to make unburned gases from thermal rush less likely to ignite and cause explosion. In smaller volumes, it may be possible to add substances, such as finely divided water, carbon dioxide or nitrogen gas, which make the combustible gas mixture difficult to ignite. Another method may be to ventilate the flammable gas so that the gas mixture never reaches the flammability zone. These methods are sometimes used in combination with each other.

WARNING! During ventilation, the gas mixture can reach the flammability area and ignite. This applies above all where there is an ignition source in the form of battery cells that are about to thermally rush. Risk of personal injury.

Measures in case of explosion risk

- Treat enclosed spaces as if they could explode.
- Define risk areas and block off areas that should not be entered.
- Assess the risk of explosion by comparing the size of battery(s) with the volume of the room. The bigger the batteries and the smaller the room, the greater the risk.
- Identify where there may be openings and structural parts that could give way in an explosion, for example windows, doors, light walls or the like. Avoid being nearby to reduce the risk of injury.
- In smaller volumes such as battery energy storage, add substances (for example finely divided water, carbon dioxide or nitrogen gas) that make the flammable gas mixture difficult to ignite.
- If there is no ignition source nearby, ventilate the flammable gas (the white or light gray smoke).

4.2.6 Jet flames

WARNING! Risk of personal injury.

A jet flame is a flame that burns as a result of gases formed in connection with thermal rush being ignited and continuously released through an opening. The spread of the jet flames depends on pressure and the size of the opening.

4.2.6.1 Jet flames from prepared openings

Jet flames can escape through prepared openings for pressure relief from both cells, modules and battery packs. For example, cylindrical cells often have a bursting plate at one end of the cell, which opens at the pressure the cell has at approx. 130º C. On battery packs for electric vehicles, this type of prepared openings for pressure relief can be found. They are needed for the battery pack to meet the requirements for vehicle batteries to reduce the risk of explosions.

4.2.6.2 Jet flames from vents created by a fire

In connection with fires in battery modules and battery packs, openings may occur for various reasons. The high flame temperature in the vicinity of the battery cell can burn holes in materials that have a lower melting point than the temperature of the flame at the location in question. The temperature can be high enough to burn holes in metal. Electrical short circuits that occur due to the fire can also cause holes in the casing. It can be difficult to predict where these holes will occur.

4.2.6.3 Actions in case of jet flames

The increase in pressure that is the cause of the escaping gases follows the least resistance to get out. This means that vents that gas depressurized through once, will likely contribute to depressurization when new thermal rushes occur that cause a pressure increase inside the enclosure. This can be used during extinguishing operations to assess the progress. There is a risk that flames may enter through new openings, but places where there was jet flames at one time will probably show jet flames later in the operation.

If you are going to stay where there is a risk of jet flames, you should position yourself where jet flames have not occurred before and at the same time be prepared for the possibility of jet flames there as well. This may mean that whoever is closest to the jet flame must have a plan for where to move if a jet flame occurs.
There should be a person who is prepared to use a jet tube to cool both the person working in the risk area and the jet flame itself. This means that people should never be placed where they do not have an opportunity to move away from possible jet flames. For example, one should not be in a place where sudden jet flames make it impossible to move to a safe place.

Actions in case of jet flames

- Watch the openings where jet flames have previously come out, it is likely that new jet flames will come out in the same place. However, be aware that new openings can also form.
- Have a plan for where to move if a jet flame occurs.
- Make sure that a person is prepared to use a radiation tube to cool both the person who working in the risk area and the jet flame itself.

4.3 Electrical hazards

Electrical risks in connection with rescue operations and firefighting have previously been assessed based on the voltage present in the system. Since most electrical systems have been grounded, the assessment has been made that the current can travel through a person, via the ground, back to the power source. With the increased prevalence of DC systems, this is not always correct.
DC systems are normally free-floating. That an electricity system is free-floating means that the ground is no longer included as a part where the current is transported. It provides the opportunity for other assessments of the electrical risks than those based solely on the voltage level.

Risk assessment of electrical risks in connection with work with lithium-ion batteries is based in this guidance on whether one can become part of a closed circuit with a dangerous current.
In order to be able to carry out a safe rescue operation, you therefore need to know whether the system is grounded or free-floating. A grounded system provides more possible paths for the current to take.

Electrical systems in vehicles are referred to as high-voltage systems when they are 30–1000 volts alternating voltage (AC), or 60–1500 volts direct voltage (DC). Batteries used in electric vehicles are generally in the voltage range of 400–800 volts at the system level and are often referred to as "high voltage systems", to distinguish them from the 12 volt, 24 and 48 volt systems. For high current installations, which is what is found in buildings for example, anything below 1500 volts direct voltage or 1000 volts alternating voltage is called low voltage.

4.3.1 Electrical hazards in vehicles

WARNING! It is a risk to be in direct contact with the vehicle's electrical propulsion system or other high voltage systems. Risk of personal injury and death.

The high-voltage system in an electric vehicle is free-floating. For electricity to be dangerous, a person must become part of a closed circuit where the voltage is above a dangerous level. 50 volts and 60 volts are sometimes used to indicate such a level, but in reality the figure varies as different individuals have different body resistance. Dry or humid environment also affects how dangerous it is to humans. Since emergency services can be expected to work in a humid environment, the risk assessment needs to be primarily based on not being able to become part of a closed circuit. It is not possible to become part of a closed circuit in a free-floating system if you spray water on the object from a distance. If the vehicle is charging, it is not a free-floating system and response procedures for grounded systems apply.

A person does not normally become part of a closed circuit by spraying water on a burning electric car. The probability is very low since it is a free-floating system, and no soil involved.

Several unfortunate factors would have to work together for a person to become part of a closed circuit via the water. For example, the water jet must be in contact with one of the battery's pools to become electrically conductive, and the person applying water must also be in contact with the other pool. This could happen, for example, if the person is standing in the pool of extinguishing water at the same time as they are in contact with the other pole.

Electric vehicles have standards and legal requirements for electrical safety. According to those rules, electrical systems must be designed so that it is possible to disconnect the battery from the rest of the high-voltage system in connection with errors and deviations. However, with smaller electric products such as hoverboards and electric bicycles, there can be a risk, as they may come from manufacturers who are not required to comply with the same level of product legislation as electric vehicles. However, this type of product has a system voltage of less than 60 volts DC.

There is no electrical connection between the high voltage system and the vehicle chassis when the battery pack is undamaged.

WARNING! The risk of inadvertently creating a closed circuit is greatest when an electric vehicle is connected to charging, because the power grid is then not free-floating, but has the system's so-called neutral point connected to earth.

WARNING! If it is not possible to disconnect the earth connection, no intervention should take place where you enter the battery pack with tools.

NOTE! A rescue operation in an electric vehicle that does not involve work with the high-voltage system itself does not normally involve any electrical risk.

Since the battery is free-floating in relation to the bodywork itself, there is no electrical contact between any of the battery's poles and the car's chassis. Both poles of the battery normally have no contact with the vehicle's metallic structure. One forced shorting of the battery therefore requires that a conductive object or person must come into direct contact with the battery's internal circuit. It does not have to involve any work environment risks either to bring in an extinguishing tool or for one of the poles to come into contact with the battery case, provided that you work with tools that are intended for the work and have training and well-thought-out routines. Normally, there is no need, for example when extinguishing a battery fire or when rescuing a traffic accident with electric vehicles, to work in direct contact with components with harmful voltage other than the battery pack itself.

NOTE! The high-voltage system in an electric vehicle is automatically disconnected if the vehicle has been exposed to violence that triggered the airbags.

Usually if airbags have deployed, the battery has also been disconnected and the occupant protection systems may have deployed. This means that within a few seconds the high-voltage system is separated from the battery, by opening the contactors and the high-voltage system outside the battery is drained of residual energy to low voltage levels. However, the battery, inside the contactors, still has full voltage and energy.

Normally, the car battery is not in contact with the exterior of the car. But what happens if the car is deformed after, for example, a collision? Then there is a risk that a battery terminal came into contact with conductive materials and the car body. It is called for insulation failure.

Despite this, emergency personnel can touch the body, for example, to evacuate people from the car without becoming part of a closed circuit. To become that requires contact with both poles at the same time.

An unusual example of when it can become dangerous is if emergency personnel were to touch a broken orange high-voltage cable while touching the body if there is an insulation fault in the battery.

The internal circuit is in contact with the drive system during operation and the contact is maintained by a 12-volt system on passenger cars.

in Measures in the event of electrical hazards

vehicles 4.3.1.1 The charging cable for an electric vehicle must, if possible, be disconnected from the mains socket before a rescue operation. It is not enough to cut off the power to the charging point in the electrical center, because the outer casing of the battery and the chassis of the car are still connected to earth. Disconnect the charging glove according to the instructions in the Emergency Response Guide (ERG) and in the Rescue Card, or at the other end towards the mains socket.

In connection with rescue efforts, one must not be in direct contact with the vehicle's electrical propulsion system or other high-voltage systems, unless one has specially designated knowledge, equipment and procedures for this.

Measures in the event of electrical hazards in vehicles

- Disconnect the charging cable of an electric vehicle before a rescue operation.
- Avoid direct contact with the vehicle's electrical propulsion system or other high voltage systems.

4.3.2 Arcs and short circuits

WARNING! Arcs and short circuits can create strong flashes of light and heat that can melt metal or start fires.

BEWARE! Risk of material damage.

Arcs are a continuous powerful electrical discharge through air, which ionizes the air that has become electrically conductive. Short-circuiting means that the electrical current takes a shortcut that is not intended. Short circuit can occur both for direct voltage and alternating voltage systems.

Arcs and short circuits that occur in connection with a fire, or that cause a fire, may remain or re-emerge even if the flames are extinguished.

WARNING! An electrical installation with residual energy, which is broken, for example due to fire, can re-ignite as long as it is not discharged or disconnected.

When a plant is discharged or disconnected, there is no electrical voltage left in the broken parts of the plant.

NOTE! Arcs and short circuits occur closest to the place where the electrical short circuit occurs, or where a direct current electrical circuit is closed or broken. In connection with fire extinguishing of electric car battery packs, this can happen where electrically conductive tools enter the battery pack. The risk then becomes local.

4.3.2.1 Measures in case of risk of electric arcs and short circuits

Measures in case of risk of electric arcs and short circuits

- Disconnect the charging cable from the battery before a rescue operation.
- Have a plan for where to move if arcs and short circuits occur.

4.3.3 Current pass-through

WARNING! Risk of personal injury and death.

In the case of current flow, the current usually goes between hand and foot or from hand to hand, but it can be difficult to determine what is actually input and output when the body becomes part of the current circuit. In order to appreciate the damaging effects, it is important to form an idea of the current's path through the body. The heart and skeletal muscles are the most sensitive and can cause heart rhythm disturbances and muscle contractions. Passage of current often gives rise to muscle cramps, with prolonged current exposure as a result of the person getting "stuck" and means that the current circuit must always be broken.

4.3.3.1 Measures in case of risk of current passing through

The emergency services' alarm stands are often not required to withstand electricity, but properties that are included in the requirement specification can still provide some protection.

Actions in the event of power failure

- Break the tension.
- If you cannot break the voltage, pull the clothing with one hand or double grip at one point to remove people from the power source, alternatively use a non-conductive object. Do not touch the skin of the injured person, then you can electrocute yourself.
- Check the casualty's condition, especially pulse and breathing.
- Summon help from the surroundings and call 112.
- Start cardiopulmonary resuscitation if necessary.
- Consult medical care even in the case of a less serious current breakdown.

5 To plan and prepare a rescue operation

When alerting, it can be difficult to find out if lithium-ion batteries are involved in the incident, except in specific objects. There may therefore be a need to have reinforcement resource plans for certain events. For portable and transportable batteries, the procedures are no different from other types of fires. For large facilities with battery energy storage and other special objects, it is an advantage to have prepared alarm plans and methodology.

On MSB's website there is a compilation of fires in electric vehicles and others installations.[38]

5.1 Planning for rescue operations in the event of fires in portable and transportable lithium-ion batteries

For fires in portable and less transportable batteries, the operation probably requires no special planning compared to other types of fires.

5.2 To plan for rescue efforts in the event of fires in electric vehicles

Use the same initial procedure as for a fire in a vehicle fueled by gasoline or Diesel. A fire in an electric vehicle or in the immediate vicinity of an electric vehicle needs handled in different ways depending on the situation around the vehicle. There need to be plans, instructions and routines to manage extensive fire spread to and between vehicles, to protect the surroundings and finally to extinguish the fire.

5.2.1 Alarm plans

In many cases, a fire in an electric vehicle will be reported as a fire in a vehicle, because the person reporting does not know what type of fuel the vehicle has. The vehicle fire alarm plan may need to be supplemented with additional resources when it turns out that the burning vehicle is powered by a battery. Modern vehicles, regardless of fuel, have a higher energy content, which means an increased risk of fire spreading and in some cases an increased complexity in terms of tactics and extinguishing methods. This means that certain vehicle fires may require an extended alarm plan with material and management resources, which were not previously associated with fires in vehicles. A vehicle fire may need to be handled in different ways depending on the situation around the vehicle. Alarm plans

[38] (MSB, 2024)

therefore need to be able to adapt to the location of the burning vehicle and what is threatened.

5.2.1.1 Resources

The extinguishing effort for fires in electric vehicles where the battery is involved can be shortened, if it is possible to make holes in the battery pack to let water in. Alternatively, it is possible to use holes that have occurred due to fire. There is adapted equipment to take hole and bring in water. In cases where it is the battery in electric vehicles that burns, it can be a solution to have tools available in the form of a regional resource.

From a management perspective, there may be more tasks to perform than in the event of a fire in a vehicle that runs on gasoline or diesel. For example, management should search information about the vehicle. There may also be a need for collaboration with more people parties, for example experts from the automotive industry, which may mean that there is a need to strengthen the management organization.

NOTE! Via the vehicle's rescue card, it is possible to find out more about the vehicle's fuel, construction and risks in connection with rescue efforts.

5.2.1.1.1 Human resources and rescue vehicles

A fire in an electric vehicle may be protracted in time or non-existent upon arrival.
The flames from a battery fire can affect vehicles or surrounding buildings so they may need to be protected, which may require different resources than a traditional vehicle fire. Actions that may be needed on site are to:

- move the burning vehicle
- move surrounding vehicles
- protect surrounding vehicles and buildings
- establish water flow in the battery pack.

5.2.1.1.2 Technical equipment

Examples of technical equipment that may be needed are:

- vehicle fire blanket to protect the surroundings or, after carrying out a risk assessment, put out a fire
- curtain system with jet pipes that create a water curtain to protect the surroundings
- equipment for moving surrounding vehicles, for example wheeled dolly
- lance, jack, fire extinguisher or other equipment approved for the purpose to get water into a burning battery pack.

NOTE! Equipment for getting water into a burning battery pack must be intended for that particular purpose.

The manufacturer of the equipment for getting water into a burning battery pack must have approved it for the purpose. Alternatively, the employer must have carried out a risk assessment of the equipment. The employer must also have developed the necessary training and routines for using the equipment.

5.3 Planning for rescue efforts in the event of fires in battery energy storage

A fire in a building with a battery energy storage, in a stand-alone battery energy storage or in the immediate vicinity of a battery energy storage needs to be handled in different ways depending on the situation and how the surroundings look. A burning or smoking battery energy store can, if lithium-ion batteries are involved, be handled in the same way as gas cylinders with flammable gas that burn or leak. There need to be plans, instructions and routines to deal with extensive fire spread, to protect the surroundings and finally to extinguish the fire. In the case of larger battery energy storage, the emergency services together with the owner or operator should draw up an action plan.39

5.3.1 Alarm plans

A battery energy storage, either freestanding or housed in a building, can be a complex facility that requires a well-thought-out action plan. Planning requires knowledge of where any lithium-ion batteries are located, whether there are special devices for monitoring, extinguishing, emergency stop and ventilation, etc.
The information can, for example, be with the business and the property owner as well as in action plans.

Some fires may require an extended emergency plan with equipment and management resources. Alarm plans also need to be able to be adapted to the location of the burning battery energy storage and what is threatened.

5.3.1.1 Resources

From a management perspective, there may be more tasks to perform than in other types of fires in buildings. There may also be a need for collaboration with more parties, for example experts from the industry, which may mean that there is a need to strengthen the management organization.

A fire in a battery energy storage can be protracted in time. The flames from a battery fire can affect surrounding buildings so they may need to be protected.
Resources may therefore be needed for a longer period of time than in other types of fires.

[39] (Grönlund, Quant, Rasmussen, Willstrand & Hynynen, 2023)

At the time of writing this guidance, there is not enough knowledge about battery energy storage fires to provide guidance on the specific resources required in an effort.

5.4 Protective equipment

The rescue service's clothing is not classified for electrical work, but studies have shown that under certain conditions, including that they are not wet, they can offer limited protection. It has also been shown that the emergency services' alarm stands are more impervious to gases than previously thought. This means that it is possible to make an internal effort when using equipment intended for smoke diving.

WARNING! Work must always be done in a way that means that a person never becomes part of a closed circuit with dangerous voltages/currents.

Ensure through knowledge, risk assessment and that established methods for rescue operations are followed that the work always takes place in a way so that a person never becomes part of a closed circle.

In the market for electrical safety equipment, there are electrical safety gloves that protect against 1000 volts, which are used during electrical installation work directly on live parts. That type of direct contact with high-voltage parts is not normally relevant during a rescue operation on an electric vehicle. However, it may be relevant for other types of objects, such as solar cell installations or smaller battery energy storage.

5.5 Environmental factors in rescue efforts

Fire extinguishing water from burning lithium-ion batteries can be harmful to the environment. Runoff extinguishing water must be handled in accordance with the current state of knowledge. 40

[40] (MSB, 2023)

6 To carry out and end a rescue operation

6.1 Response to fires in portable and transportable batteries

NOTE! First read the chapter General risks and measures.

WARNING! Risk of explosion.

WARNING! Electrical hazards.

WARNING! Health and flammable gases.

BEWARE! Risk of material damage.

Equipment:

- Full personal protection with breathing apparatus.

Instruction:

- **Disconnect the power source.** If the item is charging, cancel it by turning off and disconnecting the power source. If it is not possible to disconnect the power source, then consider the battery as energized with the voltage present in the source.

- **Consider the risks of heavy smoke development in closed spaces.** Heavy smoke without visible flames may pose a risk of explosion. The size of the room volume in relation to the battery is decisive for whether an explosion can occur.

- **Use breathing apparatus.** Whether it's smoke or not breathing apparatus must be used then even burnt fire gases that cannot be seen contain dangerous substances.

- **If possible, move the object into the open air.** If it is uncertain whether the battery-powered equipment has burned out, it may be good to take the equipment out through the nearest opening instead of transporting it through a building.

- **Cool with water.** Fires in small lithium-ion batteries are extinguished and cooled with water or other suitable extinguishing agents. A small battery that fires can be difficult to extinguish, but burn out relatively quickly. Placement in a water bath can stop the fire.

6.2 Response to fires in electric vehicles

NOTE! First read the chapter General risks and measures.

WARNING! Risk of explosion.

WARNING! Electrical hazards.

WARNING! Health and flammable gases.

BEWARE! Risk of material damage.

A fire in an electric vehicle or in the immediate vicinity of an electric vehicle needs to be handled in different ways depending on the situation around the vehicle. There need to be plans, instructions and routines to manage extensive fire spread to and between vehicles, to protect the surroundings and finally to extinguish the fire. Use the same initial procedure as for a fire in petrol or diesel powered vehicles.

6.2.1 Electrical hazards during a vehicle extinguishing operation

WARNING! Always use personal protective equipment.

WARNING! Only use tools that the manufacturer states are intended for the purpose.

WARNING! Be prepared for increased thermal activity in the battery adjacent to the drilling area, including vigorous ignition of local gas accumulations.

NOTE! If possible, use already existing holes into the battery to lead water in. Some vehicle models have a design solution with an inlet, fireman's access, where water can be injected. Other options could be the battery vents or openings created during the thermal event.

The probability that emergency personnel will be injured by leakage currents in flowing extinguishing agent is low.[41] Current prefers the simplest path, but if there are several paths can be divided between them. This means that current preferably flows where there is direct contact between the poles. If there is a low resistance in other ways, such as by using tools not intended for the job, or extinguishing agents that are electrically conductive, however, current can take paths that become dangerous to emergency personnel.

6.2.1.1 Electric vehicles in water

If an electric vehicle is flooded with fresh water, this probably causes insulation failure after a while, when water has leaked into the battery. Insulation failures are not considered to be an immediate safety risk in themselves, but increase the risk that further electrical failures could lead to serious incidents. Since the current-carrying parts of the battery itself are electrically free-floating, no circuit can be closed in the event of contact with bodywork or high-current components. However, care must be taken to avoid direct contact with the battery or components with harmful voltage.

[41] (Hoffman, 2014)

WARNING! Always ensure that no one comes into direct contact with battery or components with harmful voltage during an operation.

If an electric vehicle is flooded, water can enter the battery. If it is salt water, a process can begin where the battery's energy is discharged, which is visible in the form of bubbles, as if the water is boiling. The gas bubbles develop due to an electrochemical reaction where salt water is broken down (electrolyzed) into oxygen, hydrogen gas and possibly chlorine gas. The evolution of gas can continue for varying lengths of time depending on the battery's state of charge and the battery's construction, as well as how much water has penetrated and what salt concentration (conductivity) the water has. It can be hours to several days. Pockets of trapped explosive gas can be ignited by sparks and cause gas explosions. Salt water that has leaked into battery packs can also cause thermal runaway in battery packs, due to the rapid discharge it can cause.

WARNING! Risk of fire when the vehicle is lifted from the water and transported away from the accident site, in cases where there is electrical energy left in the battery.

6.2.1.2 Electrical hazards when the battery has burned

WARNING! Always treat a battery, regardless of condition, as live and be prepared to deal with re-ignition.

After the battery has burned out, there may still be large amounts of electrical energy and capacity remaining. There is a risk of re-ignition after battery fires, but it is unclear how great the risk is.

6.2.2 Risk of explosion during an extinguishing operation by vehicle

WARNING! Risk of personal injury and death.

BEWARE! Risk of material damage.

In the case of electric vehicles, there are mainly three spaces where gases can accumulate and explode:

1. **Battery pack.** The battery pack is built to handle fast burn of flammable gases. There are built-in pressure equalization devices that relieve pressure and release expanding gases to prevent an uncontrolled explosion in a battery pack.

2. **The passenger compartment and the luggage compartment.** If flammable gases accumulate in an explosive mixture in the passenger compartment or trunk, it will probably ignite during the course of the fire. If the gas mixture is explosive, in connection with ignition it will push out what can withstand the least increase in pressure. It can be glass, shutters, doors, removable roofs and other things that are flung outwards and upwards.

3. **The building where the electric vehicle is located.** Unburned fire gases that accumulate in a building and ignite can result in an explosion if the building is closed and the room volume is the right size in relation to the build-up of fire gases.

6.2.3 Combustion products in the event of fires in vehicles

WARNING! Hazardous gases. The fire gases produced during vehicle fires are hazardous to health regardless of whether the vehicle is powered by electricity, petrol or diesel.

In the event of a fire in a petrol or diesel-powered vehicle, a number of different types are formed combustion products that come from the combustion of the vehicle's components, including plastics, various rubber compounds and textiles. Common combustion products include:

- water vapor (H_2O)
- carbon monoxide (CO)
- carbon dioxide (CO_2)
- soot
- polycyclic aromatic hydrocarbons (PAHs)
- hydrogen chloride (HCl)
- hydrogen cyanide (HCN)
- hydrogen fluoride (HF)
- hydrogen bromide (HBr)
- acrolein (C_3H_4O)

- nitrogen oxides (NO_x)
- sulfur dioxide (SO_2)
- ammonia (NH_3)
- polychlorinated dibenzodioxins (PCDDs)
- benzene (C_6H_6)
- volatile organic hydrocarbons (VOC).

An electric vehicle contains similar components as a petrol- or diesel-powered vehicle and therefore largely the same combustion products are formed in the event of a fire, see also section **4.2.4 Combustion gases.** If the battery has gone into thermal runaway, gaseous substances are formed which spread out into the surroundings.

In order to understand the toxicity of individual gases, so-called limit values are specified, which are indicative. Limit values for substances hazardous to health can be studied in the regulations of the Swedish Work Environment Authority[42].

6.2.4 Impact on structures in the event of fires in electric vehicles Modern vehicles, regardless of fuel, are often larger and generally contain more combustible products than older vehicles. Modern passenger cars have become wider and taller without parking pockets in garages increasing in size to the same extent.
In addition, there are more combustible materials in modern cars than in older ones. This can give rise to faster fire progress and faster fire spread between vehicles.
This is something that matters in closed spaces such as garages, regardless of vehicle type and fuel. Rapid fire spread and increased fire load are examples that can have an impact on a building and any people and property in it.

In burning thermal rush, there is no indication that the likelihood of building damage or building collapse is greater if electric vehicles are parked in the garage than if they are gasoline or diesel powered vehicles. A garage fire with electric vehicles involved where there is a burning thermal rush should therefore be treated in the same way as a garage fire with petrol or diesel-powered vehicles in terms of fire spread. This is based on the fact that electric vehicles do not contribute more to the development of the fire than petrol or diesel powered vehicles.

NOTE! A garage fire with electric vehicles involved where there is a burning thermal rush should be treated in the same way as a garage fire with petrol - or diesel powered vehicles in terms of fire spread. However, a risk assessment should be carried out in each individual case.

42 (Working Environment Authority, 2018)

A difference between electric vehicles and petrol or diesel powered vehicles to consider is that electric vehicles can generate jet flames that spread the fire quickly to the nearest vehicle, while gasoline or diesel-powered cars can spread fire through flowing liquids that, depending on the slope of the ground, can reach several vehicles. Each type of fire spread may need to be handled in different ways with regard to response methodology and completion of the response.

6.2.5 Risk of fire in traffic accidents and removal

WARNING! Risk of the battery starting to catch fire. Make an action plan.

WARNING! Risk of the battery starting to catch fire. Have equipment intended for the purpose in front of you to be able to start the operation.

In traffic accidents where there are people trapped in the vehicle and where the battery pack is affected by the collision, the battery may start to catch fire, even if there are no signs of it on arrival. Compare with being prepared for fuel leaks that can ignite in accidents with petrol or diesel vehicles
vehicle.

Make sure that equipment intended for the purpose is available so that, in the event of a fire in the battery, you can immediately start an operation and get flowing water into the battery pack, as well as make a quick extraction of the injured.

NOTE! Read on the rescue card where the battery pack is located.

WARNING! Health and flammable gases. Have tools and protective equipment at the front.

A damaged battery pack can produce large amounts of carbon monoxide even if no smoke is visible from the battery pack. Gas measurement, a fan that ventilates the passenger compartment and respiratory protection can be tools to manage the risk.

WARNING! Risk of the vehicle catching fire. Prepare for quick extraction.

Equipment that may be needed is:

- **Respiratory protection for the trapped person.** A carbon monoxide meter with it jammed can also provide an early indication of thermal activity in the battery pack. Carbon monoxide can form in quantities dangerous to health, even if a thermal rush does not yet occur. Carbon monoxide is both a sign that the trapped person needs to be protected with a respirator and that it can be an indicator that a thermal rush is approaching.
- **Water and fire blankets** to protect the person during extrication.
- **Correct protective clothing.** You shouldn't have to cancel a release if that's the case begins to burn. At least one safety person must be dressed for work in smoke and fire. If it is a heavily crash-damaged battery, it is especially important to be prepared to deal with a rapid ignition.

WARNING! Fire hazard. Oxygen should not be used.

If the medical service considers that the victim needs oxygen, inform that there is a fire risk. If oxygen must be used, a risk reduction measure may be to use a PPV fan to ventilate the compartment. Healthcare should follow its guidelines for oxygen and fire.

WARNING! Risk of jet flames. Prepare to protect those who work.

Be prepared to protect those working in front of the vehicle by being able to cool them if they are located where jet flames are coming out.

WARNING! Risk of thermal rush. Appoint a person who constantly monitors the heat development in the battery pack.

Designate a person to continuously scan floor plates and the parts of the battery pack that can be seen. If there is an increase in heat, it is a sign that can be interpreted as a thermal rush will soon occur. Leakage of coolant can damage the vehicle's battery cooling system, which can lead to temperature rise and thermal runaway.

6.2.6 Calling out the alarm and approaching

In connection with incoming emergency calls, information is needed if it is an electric vehicle that is on fire and if the battery pack is involved in the fire, in order to be able to alert the right resources. Many factors will be unknown in connection with raising the alarm, for example:

- **Type of vehicle.** If the vehicle type or model is confirmed, check the associated rescue card and Emergency Response Guide for specific guidelines when responding.
- **Abnormal sound.** If a "popping" sound has been heard from the vehicle, and if at the same time more smoke has developed, it is probably an electric vehicle with a fire in the battery pack.
- **Abnormal smell.** Battery fire has an odor that irritates the respiratory system.
- **Where there is fire.** It is important to ascertain if there is a fire in the passenger compartment or in the underside of the vehicle. If the flames come from the underside of the vehicle, there is probably a fire in the battery pack, if the vehicle has been identified as an electric vehicle.
- **Fire or smoke.** Check to see if there is fire coming from the underside of the vehicle or if it is just smoke. If it is smoke, the color of the smoke can provide clues as to whether the battery is involved.
- **Location.** Check where the vehicle is located.
- **Spread risk.** Check if there is anything that could start a fire in the immediate area.

These factors can provide information about whether it is an electric vehicle and which resources may need to be alerted. In many cases, it is unknown which fuel the vehicle has. It is important information for the alarm center to find out as soon as possible.

Use the information from the emergency center while driving to the scene of the accident, for example to request more resources or to mentally prepare the intervention.

6.2.7 Arrival and immediate measures

Establish a correct situational picture and make a risk assessment upon arrival.

6.2.7.1 Vehicle location upon arrival

Position emergency vehicles in the same manner for all types of vehicle fires. Always take into account that parts of the burning vehicle can be thrown and that the smoke from the fire is toxic.

6.2.7.2 Read the accident and make a risk assessment

There are several observations that can form the basis for planning the further action:

- **Fuel type.** In all vehicle fires, the type of fuel is decisive for one correct risk assessment and planning of an effective and safe intervention. There are several ways to find out the fuel type. Among other things through the vehicle register or the equivalent via the vehicle's registration plate. The progress of the fire in the vehicle can also provide clues.
- **Fire in the cabin.** A compartment fire can last a long time and be extinguished without the fire spreading to the battery pack. Note if the battery pack also catches fire.
- **Nothing visible upon arrival.** If an alarm comes in about smoke from an electric vehicle and no flames are visible upon arrival, there are three possible scenarios:

  1. The development of smoke does not come from the battery pack, but can for example be due to a short circuit somewhere in the electrical system.
  2. The battery pack's safety system handles the thermal surge which been and nothing more will happen.
  3. Heating occurs by adjacent cells, which starts a thermal rush in one or more cells, so-called propagation. There is then a high probability that the fire will start again with smoke or flames erupting from the lower part of the vehicle.

- **Abnormal sound.** If the fire starts due to a faulty battery cell there may be a "popping" sound from the vehicle. In connection with this, smoke may come from the underside of the vehicle. When the emergency services arrive at the scene, there may have been a thermal surge in a battery cell. At this stage, plan for the thermal rush to continue, take measures to prevent fire from spreading to the surroundings, and develop equipment to get water into the battery pack if there is more smoke and fire.
- **State of charge on the battery pack.** The degree of charge, SOC, plays a role in how powerful and lasting the fire will be. It is not possible to define any exact limit values, but high and low charge levels can provide clues as to how a fire may develop. If information about the current charge level is available, note it in the event report. Vehicle owners can see what charge level the vehicle has, for example through information in their app.
- **Fire in the battery pack.** It is important to be able to establish whether the battery pack is involved in the fire. See the fact box below.

Check if the battery pack is involved in the fire

See

How the fire behaves in the vehicle will be the first indicator for emergency personnel upon arrival. If it's an electric vehicle, check the car's battery pack. Pay particular attention to possible deformation of the battery casing, breakage and smoke generation. A typically visible reaction to the battery being involved is a changing color of the smoke, from black to white.

Listen

An involved battery emits a hissing and crackling sound. The sound comes from the formation of excess pressure inside the battery module during increased heat due to, for example, mechanical deformation, and at a certain pressure the gas will be released through the intended ventilation openings, creating a characteristic sound.

Smell

One of the first impressions of a broken battery pack that is on fire may be an unfamiliar, sweet, solvent-like smell, which is typical of electrolyte that evaporates quickly in the event of a leak. Note that the gases may be toxic.

Measure

The temperature of a lithium-ion battery is a good indicator of its condition in terms of safety. It can be difficult to get truthful temperature using thermal imager, but it is a good tool. Use it continuously to appreciate and follow the trend of heat development.

Source: Wöhrl, Geisbauer, Christoph Nebl, & Schweiger, 2021.

NOTE! MSB does not recommend smelling at risk of toxic gases. However, the smell is characteristic and difficult to avoid.

6.2.7.3 Zones and levels of protection in case of fire in vehicles with lithium-ion batteries

A sign that the battery pack is on fire may be that it shoots smoke or flames (jet flames) from the vehicle in a way that is not characteristic of a vehicle with an internal combustion engine.

WARNING! Risk of jet flames. Find out where on the vehicle the flames or smoke shot out earlier in the process before approaching the burning vehicle.

WARNING! Make sure no one stays in areas where there have been jet flames and smoke from the battery pack.

Continue to observe where flames and smoke appear once the extinguishing effort has begun. It is likely that flames and smoke will continue to take the same ways. Even if smoke or flames temporarily stop coming, these areas can still be assumed to be risk areas. Flames may appear later in the operation even from areas of the electric vehicle where only smoke has come out.

WARNING! Note if new holes appear in the battery pack casing.

Adjust risk areas after new areas of fire and smoke are discovered. It may be wise to appoint a person responsible for observing and informing about the progress of the fire.

WARNING! Risk of gas cloud ignition with resulting explosion or fire.

If the vehicle is located indoors and there is a fire in the battery pack that only generates smoke, the gases in the smoke must be assumed to be flammable. The risk areas for this are handled in the same way as in the case of a gas leak of flammable gas.

Apart from the risks in the direct vicinity of the burning electric vehicle and

the risk of flammable gases being produced can be handled by zoning the damage site as in the case of a fire in petrol and diesel-powered vehicles.

6.2.7.4 **Immediate measures** A burning

electric vehicle is no different from other events in terms of immediate measures. Examples of immediate measures are saving lives by moving victims and preventing fire from spreading to the surroundings by cooling with water.

The vehicle manufacturer's rescue card or ERG describes for each model how the vehicle's high-voltage system is structured and guidelines for a possible rescue effort. There is information on what is important to think about and know for the emergency services in the event of a traffic accident, for example if there are 12 V batteries that need to be disconnected, where the airbags are located and in which areas one should not mow. The ERG for the current car model is also available in a free application called the Euro Rescue app.

- **Check the vehicle's model-specific rescue card for guidelines and procedure** for disconnecting the charging cable. If it is not possible to follow the guidelines, the other end towards the mains socket can be released. An alternative is to activate the emergency stop on the charging station, if available exists.

- **Check the vehicle's model-specific rescue card for the vehicle construction** when removing that requires tools.

WARNING! Do not place supports, spreaders and the like so that they press against the battery pack.

WARNING! Never push or cut against the battery pack.

- **Take damage control measures.** The battery pack's security system means that any propagation can take time. In the meantime, the emergency services can take measures to, for example, prevent the spread of smoke in buildings, prevent the spread of fire to other objects and prepare an effort to introduce water into the battery pack, if the situation requires it. To prevent the risk of explosion, the emergency services should divert any gases outside the passenger compartment.

- **Scan with a thermal imaging camera.** Beyond direct visible observations are regular thermal imaging scan a good way to know the approximate location of the thermal rush and whether the event is escalating or waning. Images from thermal cameras, to compare temperature development at fixed measuring points together with observations of smoke and noise, can provide clues as to whether the event will increase or decrease in intensity.

- **Carbon monoxide content.** Measure the level of carbon monoxide around the vehicle and in the passenger compartment. If there are no visible signs of fire, but carbon monoxide is measured, this may indicate a fire or thermal runaway in the battery pack.

6.2.7.5 Status reports

As soon as it is confirmed that it is the battery in an electric vehicle that is on fire, it is important to report it. A burning battery in an electric vehicle can take longer to deal with and require other resources. The protracted process may affect the preparedness for any other alarms. Apart from the above, the need for status reporting is no different from other events.

6.2.8 Implementation of the effort

NOTE! In all cases, start with an assessment of whether the benefits of extinguishing outweigh the benefits of letting it burn out.

The following instructions apply in cases where extinguishing is to take place. If possible, carry out the operation with the wind at your back.

6.2.8.1 Fire in the compartment

Equipment:

- Full personal protection with breathing apparatus
- Jet tube
- Thermal camera
- PPV fan
- Hand fire extinguisher
- Fire blanket.

Instruction:

- **Extinguish the fire according to standard routine,** in the same way as in the event of a fire in petrol and diesel vehicles.

- **Prevent spreading to the battery pack.** It takes a relatively long time to reach a high enough temperature to initiate a thermal surge in the battery pack from an external heat source. When the fire in the cabin is out, it may therefore be advisable to try to cool the outside of the battery pack near the heat source. You should also cool all sheet metal adjacent to the battery pack as soon as possible.

- **Use thermal imaging continuously.** The thermal camera can provide information about the battery pack being affected. Observe temperature increase and size of hot areas simultaneously with the development of smoke and noise.

6.2.8.2 Fire in the battery pack

If there is a fire in the battery pack and the thermal rush propagates, the assessment of which method to use also depends on the location of the electric vehicle and the intensity of the fire.

When it is established that the fire in the battery pack will not self-extinguish, and the benefits of extinguishing outweigh the benefits of letting it burn out, getting water into the battery pack is an effective method.

WARNING! Make sure no one stays in areas where there have been jet flames and smoke from the battery pack.

NOTE! A fire where smoke only comes out of the battery pack on occasional occasions can mean that the battery extinguishes itself. Do not puncture the battery pack in that position, unless there is an obvious risk with the unburned flue gases from a health or explosion perspective.

If you hit an undamaged battery cell when cooling into a battery pack, it will go into thermal runaway. Continued inflow of water means that the thermal rush occurs with less risk to the surroundings.

NOTE! There may be parts of a battery pack that are more difficult to penetrate than others. Then try making a new hole a few centimeters from there.

Equipment:

- Full personal protection with breathing apparatus
- Jet tube
- Thermal camera
- PPV fan
- Tool for making holes in the battery pack, intended for the purpose.[43]

Instruction:

- **Scan with a thermal imaging camera to find the heat source.** Scan continuously during the entire extinguishing operation until the temperature has stopped at .C ÿ50
- **Make holes in the battery pack where the thermal camera indicates the hottest the area.** A thermal rush is probably going on here. The objective is to find a point where it is possible to get water in close to the source of the fire and in the same volume where the thermal rush occurs. A vehicle's batteries can be divided into several battery packs or parts, where water cannot flow between them. A hole far from the thermal rush but in the same part may work, but a hole close to the thermal rush but in a different part will not.

[43] (Working Environment Agency, 2020)

NOTE! If you enter from the underside, it can be difficult to access battery cells that are not in direct contact with the underside of the vehicle. Cooling takes place even if the inflow of extinguishing water takes place in the vicinity of the burning battery cells, as long as the same physical part of the battery pack is cooled. The image of the battery's layout in the vehicle's rescue card can provide good information about where it is appropriate to make holes with the tool.

- **Flow water into the hole until no smoke or fire is emitted and the temperature is lower than 50ÿ C.** It may take a few minutes before it has an effect, because the water must fill up the battery pack to a level where the battery cells that were threatened are cooled by the water and then no longer risk propagating. If water comes from openings high up in the battery pack and there are no longer any thermal surges in more battery cells, watering can also be terminated. Note if there is smoke or is obviously hot anywhere. In such cases, resume watering until the heat and smoke subsides. If, after a reasonable time, it has not given any result, it may be because the flow has been established in a physically separate part of the battery. In such cases, try to take over by making a new hole in one other place.

- **Continue to observe the battery pack visually and with a thermal imaging camera.** A battery pack that is filled with water probably needs a shorter observation time than one where the water drains out through holes in the bottom. Note that re-ignition can occur after several hours or days from the time of the fire. 44 Currently, we are unsure how long the observation period needs to be.

- **Position the vehicle in a safe manner before leaving the site.** Manage one possible subsequent re-ignition by positioning the vehicle so that it cannot lead to the spread of fire or personal risks.

[44] (MSB, 2023)

NOTE! At the time of writing this guide, experience is limited to fires extinguished using this method. Therefore, all actors in the rescue service need to continue to seek knowledge about the necessary observation time.

WARNING! Re-ignition can occur after several hours or days from the time of the fire. Handle electric vehicles and batteries that have burned with great care.

6.2.8.3 Fire in both the passenger compartment and the battery pack

WARNING! Make sure no one stays in areas where there have been jet flames and smoke from the battery pack.

- First put out the fire in the compartment according to the instructions in chapter 6.2.8.1 Fire i the compartment.
- Extinguish the fire in the battery pack according to the instructions in chapter 6.2.8.2 Fire i battery pack.

6.2.9 Blocking off, evacuation, containment and VMA

Burning vehicles outdoors will in most cases be uncomplicated events to handle. Interventions with vehicles that are positioned so that they are difficult to access for emergency service personnel can, however, become more complicated and long-lasting.

Blocking off, evacuation, containment and VMA should be handled in the same way as for vehicle fires in general.

6.2.10 Risks that may remain after a rescue operation

WARNING! Electrical hazards.

Unburned battery cells can still contain electrical energy after a fire is extinguished. If the voltage in the undamaged parts is high enough, there may be an electrical hazard in case of physical contact.

WARNING! Risk of re-ignition or smoke development.

After the fire is extinguished, under certain circumstances fire or smoke development may occur again.

WARNING! Risk of fire spreading.

WARNING! Health and flammable gases.

WARNING! Risk of explosion. Leave windows in the passenger compartment open for ventilation.

Flammable gases may be formed. Make sure there is ventilation in the passenger compartment to reduce the risk of explosion.

6.2.11 Ending the rescue operation When you have finished giving water and observation has taken place for the time deemed reasonable, the rescue operation can be ended. It can happen when the propulsion battery has a confirmed steady and stable low temperature (below 50 ÿC). It is then advisable to place the vehicle in a safe place, where life, the environment or property are not at risk of being damaged by a possible re-ignition.

6.2.12 Residual value work and remediation In residual value work, remediation, accident investigation and similar tasks after a fire, there are residual risks. Battery cells, undamaged or damaged, that remain in spaces must be considered as possible sources of toxic gases and the level of protection selected accordingly.

WARNING! Personnel working with lithium-ion batteries need to be aware of the risks and have a plan for a possible re-ignition.

WARNING! Extinguishing water and sooty surfaces contain dangerous substances. Personnel who work with this need to have the correct protective equipment and training for the purpose.

6.2.13 Responsibility for the work environment in connection with the end of the effort

According to current legislation45, there is a responsibility to hand over information about risks to the actors who will work later in the process. This is to ensure that no one can be injured due to risks discovered during the work.

NOTE! What distinguishes a burned-out electric vehicle from gasoline- and diesel-powered vehicles is mainly the risk of re-ignition and the fact that there may be electrical energy left in the battery pack.

NOTE! Always provide information about the risk of re-ignition when handing over a fire-damaged electric vehicle or lithium-ion battery to, for example, a tow truck, a workshop or a scrap yard.

There is a risk of re-ignition after battery fires, but it is unclear how great the risk is. Reignition is probably not the responsibility of the emergency services according to the LSO. Based on the knowledge available at the time of writing this guidance, together with the low frequency of events, there may be reason to escort recovery vehicles with rescue vehicles in some situations when transporting EVs at risk of re-ignition. In the first place, however, it is the responsibility of the salvage companies to have equipment so that they can handle transports without an escort by the rescue service. Vehicle workshops have a responsibility to have prepared staging areas as well as an organization and equipment that can handle heating in battery packs, so that this heating does not have to lead to measures from the emergency services.

45 3 ch. Section 7 g of the Work Environment Act.

6.3 Response to fires in battery energy storage

NOTE! First read the chapter General risks and measures.

WARNING! Risk of explosion.

WARNING! Electrical hazards.

WARNING! Health and flammable gases.

BEWARE! Risk of material damage.

There is currently limited experience of fires in battery energy storage[46]. In large battery energy storage facilities, there have been a total of less than 100 such fires in the world up to and including 2022. More than half of these have occurred in connection with the start-up of the facilities and during the first year of operation. The intervention methodology that is proposed is based on a limited amount of experience and can be changed and improved based on future experiences.

Battery energy stores can be structured in different ways. Seemingly similar exteriors can accommodate completely different technical solutions on the inside. For example, battery cells can sometimes be placed in open racks, sometimes they can be placed in closed modules, and sometimes they can be used vehicle batteries that are reused. These characteristics influence the prerequisites for success of an effort and what may be relevant measures. Common to the various designs is that it is important to take into account explosion risks, electrical risks and possible extinguishing water.
The explosion risk is strongly linked to whether battery gases can accumulate somewhere and the electrical risks vary depending on the voltage and whether there is an earthed system in the same space as the battery energy storage.

[46] (EPRI, 2024)

6.3.1 Electrical hazards when extinguishing battery energy storage

WARNING! Electrical hazards.

WARNING! For battery energy storage, the electrical risks become special as there may be a connection between the free-floating batteries and the fixed, earthed, property or power grid.

WARNING! Initially, handle the systems as if they were grounded, and work with the proper protective distance.

The electrical risks depend on how large the facility for energy storage is and how it is constructed. In general, however, you should always assume that there is voltage in the battery part. In contrast to electric cars that are not charging, for energy storage in buildings there can be a protective ground in what is included in the property's or building's electrical system. Then safety distances and assessments of electrical risks also need to be based on the part that belongs to the building's grounded electrical system.

6.3.2 Risk of explosion when extinguishing battery energy storage

Both small and large battery energy stores can cause explosions in the event of fires. Gases produced during a fuming thermal rush contain flammable gases that can ignite if accumulated. The electrical energy in a battery also adds heat through a gradual heating of surfaces or sparks in connection with short circuits. Hot surfaces and sparks can act as ignition sources and if the gas mixture is within the flammability range, an explosion can occur.

Large independent energy storages are often built into steel containers that are used, among other things, in shipping. In explosions that have occurred, heavy metal parts have been hurled up to 25 meters47.

Smaller energy stores in properties have caused explosions that pushed out doors, windows and affected the construction, for example by demolishing walls and beams.

Despite installed and triggered extinguishing systems, there have been explosions. If the emergency services assess that it is not possible to approach the battery energy storage in a safe way, a possible measure is to make a defensive effort, where you limit the spread of fire to the surroundings and let the battery energy storage burn completely.

[47] (The Liverpool Echo, 2020)

6.3.3 Combustion products in case of fires in battery energy storage

WARNING! Health and flammable gases.

Just like any other fire smoke, the gases from both a burning and a smoking thermal rush contain toxic substances. Building construction, placement of energy storage and placement of people determine the type of intervention that needs to take place to protect people's lives and health. The big difference to "normal" fires is that the more invisible smoke from burning battery gases also contains dangerous substances, which means that it is not how thick the smoke is that determines whether it is dangerous or not. Likewise, carbon monoxide is produced before thermal rush and for a long time after a visible fire, which also needs to be considered.

The emergency services' alarm stand and breathing apparatus provide adequate protection against them possibly additional substances in combustion products from battery fires, in the same way as against fire smoke from other types of fires.

The gases that can be formed during a steaming thermal rush and which are flammable include hydrogen, carbon monoxide, hydrocarbons and other hydrogen compounds. 70% of what is formed can be of this type of flammable gases.

6.3.4 Impact on structures in the event of fires in battery energy storage

BEWARE! Risk of material damage.

Structures in buildings can be affected differently in battery fires than in fires in materials that normally burn in buildings. There are two characteristics of battery fires that can distinguish them from other fires.

In battery fires, the flames can have a higher speed than in normal fires. These so-called jet flames can cause a greater local impact on surface layers than in the case of ordinary fires.

Explosions can cause damage to a building that destroys the existing fire protection in the form of room and fire cell division, which can spread a fire in a way not foreseen by the building's fire engineering design. It can also affect the building's construction and load-bearing capacity as, for example, walls and beams may have been moved or disturbed.

6.3.5 Calling out the alarm and approaching

For battery energy storage that is located in a building, it is not certain that the caller knows that it is a battery energy storage that is on fire. The color of the smoke can give an indication of whether batteries are involved. If the color is light gray or white, there may be a risk of thermal rush. For other types of battery energy storage, it may be more clear what is burning.

In order to handle fires in both smaller and larger battery energy stores, the same type of resources are probably required as in the case of corresponding fires where the batteries do not burn. It will therefore be the burning object and what is threatened that needs to control which resources are alerted.

Abroad, there has been an ignition of smoke from battery fires on several occasions, during the time from when someone called the emergency center about the fire until the emergency services arrived. The ignition can cause an explosion, which in turn affects the building and people in the building. The risk of explosion is important to include as a possible scenario in case of emergence. There may also be reports of explosions during the approach. Likewise, it is important to keep in mind how the risk of explosion can affect the operation if there is only smoke and no flames coming from the batteries.

6.3.6 Appearance and Immediate Actions

Lifesaving can be done in the same way as for other fires in the corresponding object, with an extra attention to whether there is an internal smoking thermal rush and the risk of explosion that accompanies it. The color of the smoke gives an indication of whether batteries are involved and can be useful to include in a feedback report. If the color is light gray or white, there may be a risk of thermal rush.

Unlike other fires, where you can gain advantages from containing the fire by closing doors and other openings, due to the risk of explosion, you should be careful with battery fires. It may be beneficial to open up and ventilate instead, but given the increased risk of fire spreading, it is important to make an assessment on a case-by-case basis.

Things to do immediately when you come to a burning battery energy storage:

- If the fire/smoke is **well ventilated,** keep it so that the explosion risk does not increase. Do not close the fire.
- Handle a **smoking thermal rush** as a gas leak with, for example, hydrogen gas, which can ignite at low ignition energy.
- **Identify windows, doors, lightweight walls and the like** that can be pushed away in an explosion.

- Is there **an emergency stop?** Use it, or otherwise shut down as much of the electrical system as possible. (Unless there is an action plan that says otherwise.)

- The commander often needs **to obtain more information** in order to plan a well-thought-out operation. The facility owner may have information that is critical, and it may be possible to obtain live data from the facility's battery management system.

- Activate fire protection and fire extinguishing systems if possible exists. Some systems can be designed so that the emergency services can supply water via a dry pipe system to the batteries. Do this in agreement with the plant owner if there is one.

- In the meantime, it may be advisable for you to stay in a **safe place** and from there try to **prevent the fire from spreading** to the surroundings.

6.3.7 Implementation of the effort

WARNING! Risk of explosion.

NOTE! In all cases, start with an assessment of whether the benefits of extinguishing outweigh the benefits of letting it burn out.

Battery energy storage in residential buildings or in buildings with operations is handled in the same way as another fire in the corresponding building, but with extra attention to the risk of explosion that exists if there is a smoking thermal rush from the batteries.

- Approach and open doors only if it does not involve too great a risk for yourselves.

- Consider letting the warehouse burn and focus on limiting spread.

NOTE! Fires in larger facilities with battery energy storage, for example containers, can burn for several days.

NOTE! There are facilities that are designed so that the emergency services can affect a fire. There are also facilities with extinguishing systems that require that you do not open up the room where there is a fire.

The owner needs to give the emergency services information about the construction and possible extinguishing systems so that there is a chance to influence the course, for example through an intervention plan. Injecting water into a large energy storage can have disadvantages in the form of a prolonged time for extinguishing and contaminated water to deal with. It is possible that the best course of action is to limit the spread of fire to the surroundings while the batteries in the burning battery energy storage are allowed to burn out. It is important to consider the risk of explosion even for these large battery energy stores, even if there are extinguishing systems in the space.

6.3.8 Blocking off, evacuation, containment and VMA

Blocking off, evacuation, containment and VMA should be able to be handled in the same way as for fires in general, with the addition that if the risk of explosion has not been eliminated, it should be taken into account in terms of cordoning off, evacuation and containment.

WARNING! Take height for any remaining explosion risk when cordoning off, evacuating and housing.

6.3.9 Risks that may remain after a rescue operation

WARNING! Electrical hazards. Always handle the batteries in a battery energy storage as live, regardless of the condition of the battery.

WARNING! Have preparedness to deal with re-ignition.

WARNING! Risk of explosion.

WARNING! Health and flammable gases.

There can be residual electrical energy in batteries that have burned out, and it is not always easy to see on a battery if it has completely burned out or only parts of it. This electrical energy can both create electrical hazards and the risk of re-ignition.

It may be possible, and good from an emergency services perspective, to move a smaller battery energy storage out of a building to ensure that a re-ignition does not create a new need for a rescue response. A person with electrical competence then needs to do the actual disconnection.

In larger independent energy stores, there is the same risk of re-ignition and probably greater electrical risks. Since the energy storage is independent, there is probably no benefit from a rescue service perspective to work inside these electrical hazards. Residual energy can make a re-ignition likely.

Of the many gases that can form in connection with thermal runaway in batteries, carbon monoxide is the one that can probably be detected the earliest before the fire[48] and the longest after a fire. Before the thermal surge, when the battery cell vents, and after a thermal surge, chemical reactions take place that emit carbon monoxide and thus can be hazardous to health, but not explosive. It is therefore good to measure carbon monoxide to assess what type of respiratory protection is needed in different phases of the post-work.

[48] (DNV, 2019)

6.3.10 Ending the rescue operation

Apart from the possible residual energy and the risk of re-ignition, a fire in a battery energy storage is no different from other fires in terms of ending a rescue operation.

6.3.11 Residual value work and remediation

At the time of writing this guidance, there is not enough knowledge about residual value and remediation after fires in battery energy storage.

6.3.12 Responsibility for the work environment in connection with the end of the effort

There is a responsibility according to current legislation[49] to hand over information about risks to the actors who will work later in the process so that no one can be injured due to risks discovered during the work. What is special about fires in battery energy storage is the residual energy that can create electrical hazards, fire hazards, gas hazards and explosion hazards.

49 Chapter 3 § 9 LSO.

7 Incident report and accident investigation

There is much to learn from the occurrence of lithium-ion battery fires. The emergency services have an obligation to reasonably investigate the causes of the accident, the course of the accident and the execution of the rescue operation. Important experiences documented in incident reports and accident investigation reports contribute to the development of safe and effective rescue operations.

In order to obtain a good basis for the incident report and possible accident investigation, it is important to continuously document the effort. Both film/photo as well as notes from the development of events and implemented measures can be important data for subsequent investigation and documentation.

Up to and including the year 2022, there have been few accidents with lithium ion batteries in Sweden and there is a large lack of experience from this type of events both nationally and internationally. Therefore, it is especially valuable to obtain good documentation of experiences and lessons learned from the accidents that occur and the rescue efforts that are carried out. It may also be justified to carry out an accident investigation, in addition to the mandatory documentation in the rescue service's incident report.

Important experiences from accidents and rescue efforts that included lithium-ion batteries can be disseminated to authorities (for example the Swedish Electricity Safety Agency, the Swedish Transport Agency, the Swedish Work Environment Agency and MSB), other rescue services, property owners and manufacturers/dealers.

7.1 Event report support

In all rescue operations with lithium-ion batteries, the following information should in particular be collected to the extent possible and documented in the incident report.

- Describe the type of product, machine, vehicle, battery energy storage or similar that the battery was used for or intended for.
- State whether the battery was charging.
- State if there was a smoking or burning thermal surge in the battery.
- Describe where the fire started and possible fire spread. For example, if the fire started in the battery and spread to other combustibles nearby or vice versa.
- Describe if there was any explosion in connection with the accident.

7.2 Support for accident investigation

In cases where an accident investigation is carried out, there are greater opportunities to deepen the investigation and analysis and then one or more of the following aspects may be valuable to investigate.

1. How was the fire discovered in the product, machine, vehicle, energy storage or similar and what early indications were there.
2. The battery's energy storage capacity in Wh, kWh or MWh.
3. Battery level of charge (SOC) at the time of the accident.
4. Causes of the fire.
5. How the fire has spread.
6. Risk of explosion during thermal rush indoors.
7. How long the fire has been going on and when the battery was affected by the fire.
8. Extinguishing and cooling methods used in case of fire or thermal rush inside the battery.
9. How assessments have been made prior to the end of the rescue operation.
10. Any recommendations from the emergency services to those handling the damaged lithium ion batteries after the rescue operation.

8 Reading tips

Below is a compilation of reading tips regarding lithium-ion batteries. Some of the tips have already been referenced in the text above.

- Recommendations for how the crashed electric car should be handled at the scene of the accident[50]
- Instructions for salvagers on transporting damaged electric cars[51]

[50] (Electric car info, ud)
[51] (Electric car info, ud)

9 References

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651 81 Karlstad Phone 0771-240 240 **www.msb.se**

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