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Version 1

OPERATIONAL GUIDE

EMERGENCY RESPONSE FOR ELECTRIC VEHICLES

Present situation - recommendations - perspectives

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FOREWORD

In the past decade, electric vehicles have evolved from a technological novelty into an everyday part of the transportation landscape. They bring important advantages—reduced emissions, quieter operation, greater efficiency—but also new operational and safety challenges. One of the most demanding among them is ensuring safe, effective, and professional firefighting when incidents involve high-voltage battery systems.

CTIF* Extrication and New Technology Commission has continuously monitored the development of electric vehicle firefighting methods with the aim of providing firefighters with appropriate guidance for effective extinguishment, preferably using existing techniques and equipment, which would ensure broad applicability of suitable methods.

The purpose of this operational guide is to provide a comprehensive overview of the approaches, techniques, and tactics for extinguishing electric vehicle fires, based on the latest understanding of battery technology, the behavior of lithium-ion cells, and the specifics of thermal runaway. The other objective of this guide is to provide an operational response in the event of a road accident involving electric vehicles in order to ensure the safety of the operation in the context of electrical risks.

The operational guide before you brings together practical experience from emergency response teams, research findings, and recommendations from leading experts in fire safety. The focus is not only on extinguishing fires, but also on tactical decision-making, hazard recognition, proper equipment use, and protecting response teams and their surroundings.

Electric mobility is developing rapidly—often faster than many standards and procedures can keep up. For this reason, the core purpose of this book is to offer a solid, up-to-date, and professional foundation that can serve as a guide in demanding and often unpredictable situations. I believe it will provide readers with both the knowledge and the confidence necessary for safe and effective work when dealing with electric vehicle fires.

As the President of CTIF, I would like to express my gratitude to Michel Gentilleau and his colleagues for preparing this manual, which follows the core idea behind CTIF's mission – the exchange of knowledge to ensure safer work for firefighters and a safer living environment for citizens.

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CTIF President

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INTRODUCTION

Electric vehicles have been considered as a potential new risk by fire brigades, public authorities, laboratories and private companies for several years now.

Hundreds of laboratory tests, field trials, studies, reports, and international guidelines have already been produced.

Equipment manufacturers have offered a wide range of tools designed to help rescue teams operate more efficiently and safely on this type of vehicle.

The rapid growth in electric vehicle sales (initially cars, but now increasingly also trucks and buses) has provided emergency services with valuable operational feedback from those working directly on scene.

However, this accumulated experience has not led to a general consensus on the response procedures to be adopted by fire brigades, whether during a roadside rescue operation or when tackling a fire involving an electric vehicle.

The purpose of this document is to provide an overview of the 2 main issues involved:

- -managing electrical risks during roadside rescue operations involving electrical vehicles;
- -managing thermal runaway in the event of an electric vehicle fire (lithium-ion batteries).

The sections covering basic knowledge about electric vehicles and batteries, electric risks and on thermal runaway will be addressed briefly, as extensive literature already exist on these topics.

The document will focus on reviewing the equipment and materials available to the fire brigade to manage these incidents and on proposing practical operational protocols using the traditional resources at their disposal.

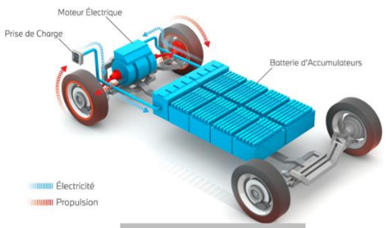
Finally, for each of the operational themes (roadside rescue and vehicle fire), we will outline the future perspectives for firefighters, particularly in light of the work currently being carried out by Euro NCAP*.

**Euro NCAP European New Car Assessment Programme*
https://www.euroncap.com/media/91774/euro-ncap-protocol-post-crash-v11.pdf

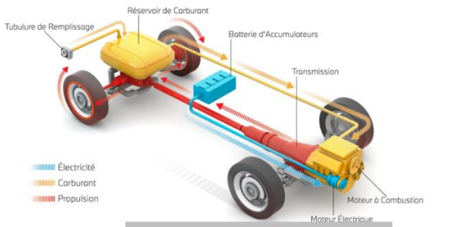
A REMINDER ABOUT ELECTRIC VEHICLES

Hybrid/electric vehicles can be grouped into four main categories:

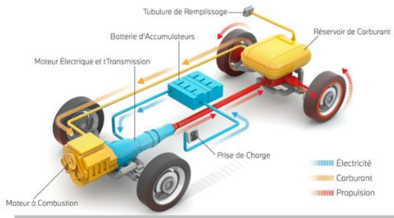
- **hybrid** electric vehicles (HEV)
- **plug-in** hybrid vehicles (PHEV)
- **electric** vehicles (EV)
- **fuel cell** (hydrogen) vehicles (FCEV)



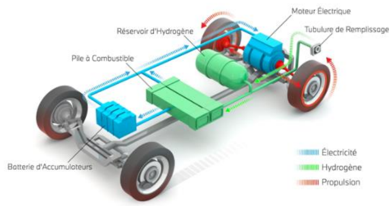
Electric vehicle



Hybrid electric vehicle



Plug-in hybrid electric vehicle



Hydrogen vehicle

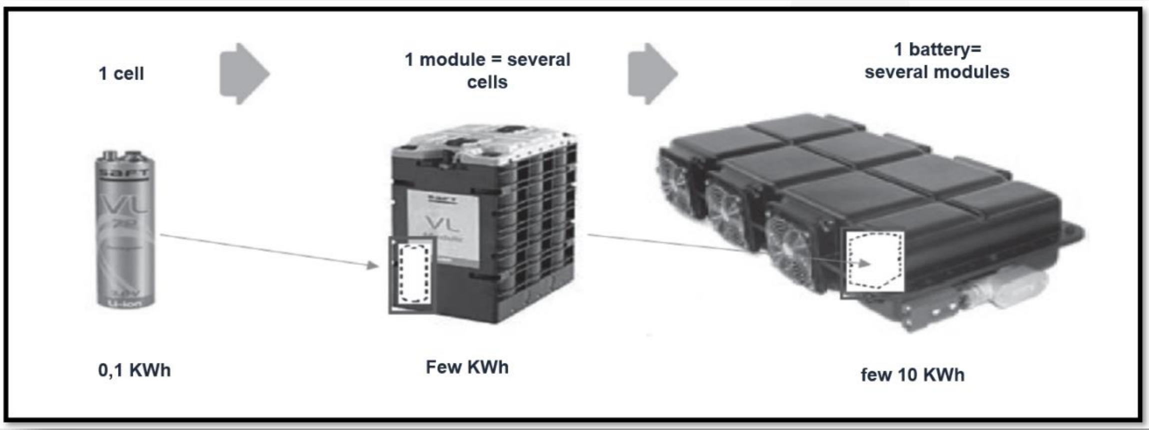
The capacity and placement of EV and HEV **batteries** vary by vehicle type :

- cars : generally under the vehicle floor
- trucks : on the sides (or center) of the chassis or behind the cab
- buses on the roof or at the rear of the vehicle



The basic element of a battery is the cell, which can be pouch, prismatic, or cylindrical in form.

A group of cells forms a module, and a group of modules forms a battery pack.



Although several **technologies** exist (NiMH, LMP, sodium, etc.), **lithium-ion** (Li-ion) remains the most common technology in electric mobility.
Vehicle battery **casings** are generally made of steel or aluminum.

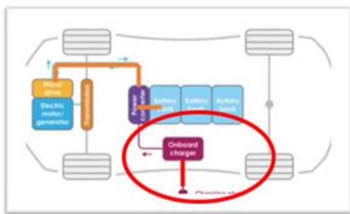
Main risks associated with Li-ion batteries are :

- **électrical**
- **thermal**
- **toxic**
- **explosive**

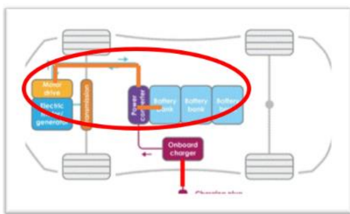
The last 3 risks are due to the **thermal runaway** phenomenon that can occur in a Li-ion battery.

Firefighters may encounter electrical hazards in several operational contexts

- **Direct contact** with high-voltage (HV) cables or batteries during **road rescue operations**
- **Direct contact** with HV cables or batteries during a **vehicle fire**, particularly **during debris removal**



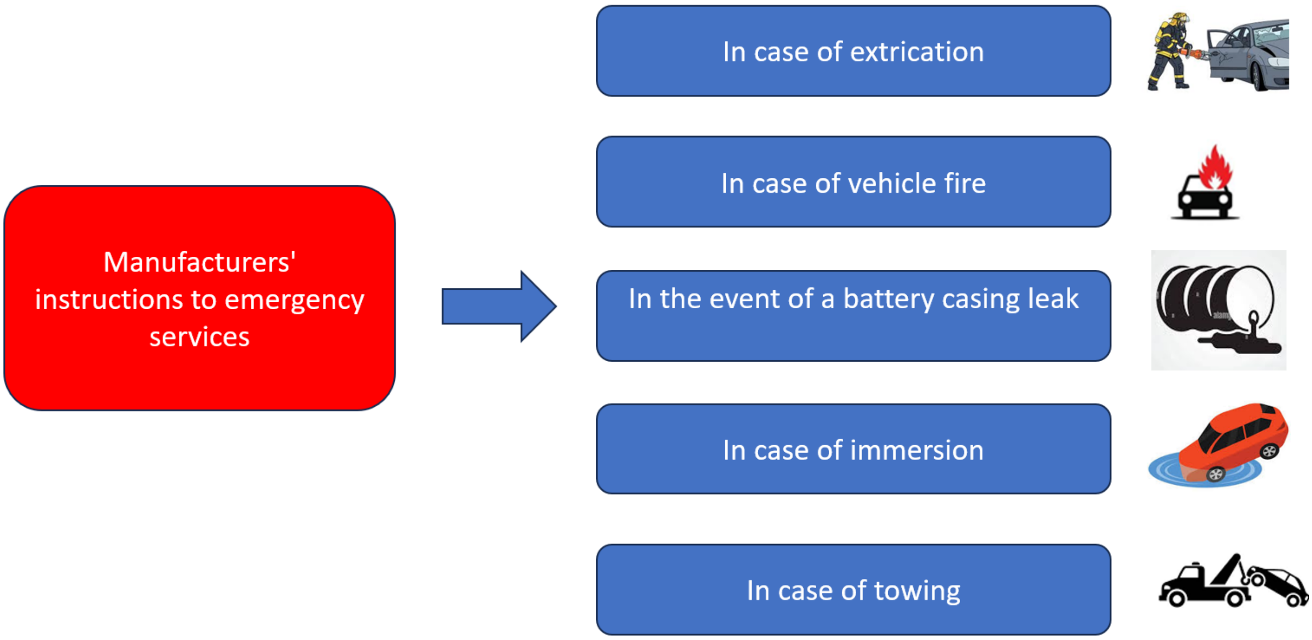
- **Direct or indirect contact** with **charging cables** during a vehicle fire, especially in the **extinguishing phase**



The electrical hazards identified in these cases are **electric shock**, **electrocution**, and the generation of **electrical arcs.**

A DECISION-MAKING TOOL FOR FIREFIGHTERS : THE RESCUE SHEETS

Rescue sheets are standardized information documents that comply with the ISO 17840 standard.
They are produced by vehicle manufacturers for use by emergency services, providing essential information and guidance for intervention in **various operational situations:**

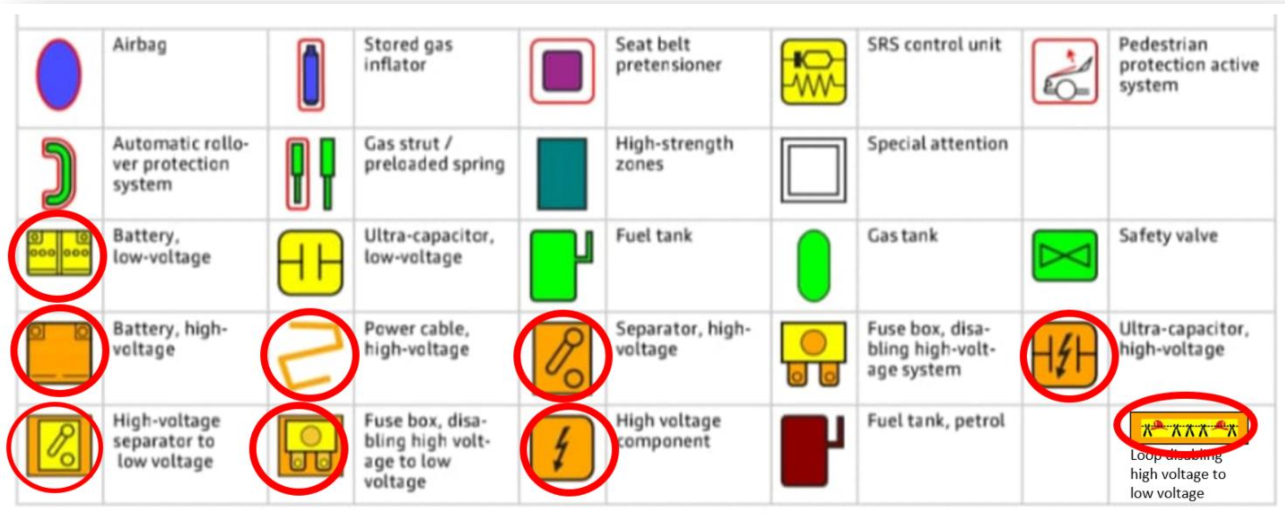


The ISO 17840 standard defines the content and layout of rescue sheets.
It is organized around two key principles :

- standardized symbols
- a standardized document structure

All official symbols are detailed in the ISO 17840 documentation.

The **most important symbols** used for identifying and managing the **electrical systems** of electric vehicles include :

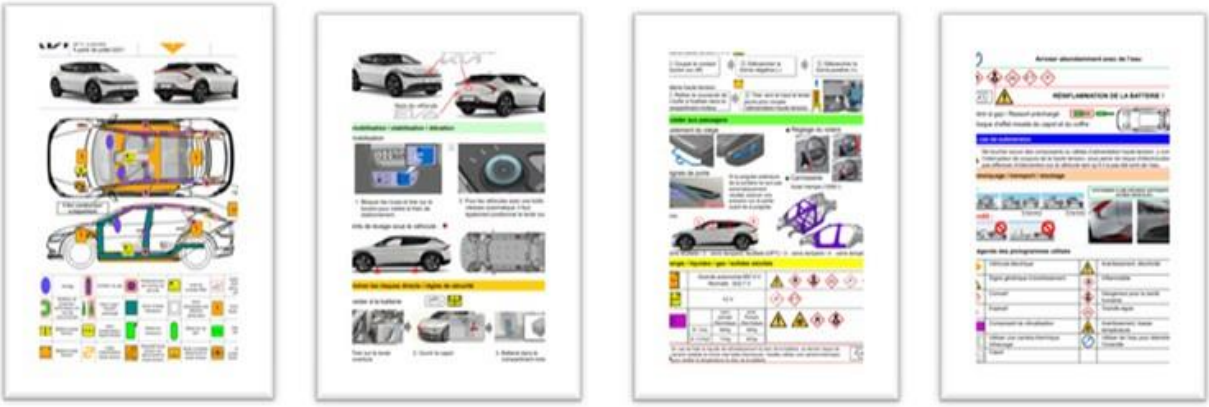


Airbag	Stored gas inflator	Seat belt pretensioner	SRS control unit	Pedestrian protection active system
Automatic rollover protection system	Gas strut / preloaded spring	High-strength zones	Special attention	
Battery, low-voltage	Ultra-capacitor, low-voltage	Fuel tank	Gas tank	Safety valve
Battery, high-voltage	Power cable, high-voltage	Separator, high-voltage	Fuse box, disabling high-voltage system	Ultra-capacitor, high-voltage
High-voltage separator to low voltage	Fuse box, disabling high voltage to low voltage	High voltage component	Fuel tank, petrol	Loop [illegible] high voltage to low voltage

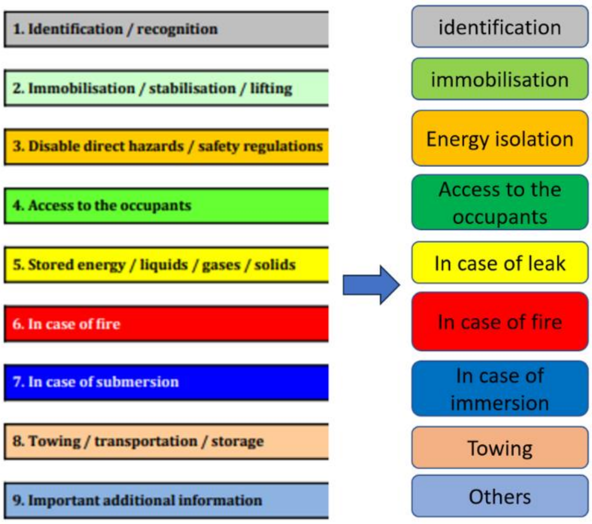
Rescue sheets are standardized documents designed for quick and easy use by emergency services.

They are **structured** according to Euro NCAP criteria, with a maximum of four pages (five pages exceptionally accepted):

- Page 1:
  - Overview of equipment relevant to emergency services
  - A photograph of the vehicle
  - A legend explaining the symbols used
- Page 2-4:
  - Operational instructions divided into chapters



Each chapter is identified by a specific color code for quick reference



Rescue sheets can be accessed through the Euro Rescue application developed by Euro NCAP.

As of September 2025, the app provides access to over 1,900 rescue sheets, which can be consulted online, when connected to the internet or offline, after downloading rescue sheets to a smartphone or tablet.

Euro Rescue

The application is available free of charge in all 22 official European languages and can be downloaded here:

GET IT ON Google play https://play.google.com/store/apps/details?id=com.euroncap.rescue&hl=fr&pli=1

Download on the App Store https://apps.apple.com/fr/app/euro-rescue/id1516807765

A desktop version is also available, which can be particularly useful for emergency response centers when identifying the correct rescue sheet before deployment : https://rescue.euroncap.com/

Car, truck and bus rescue sheets are available through these platforms.

In Australia, the ANCAP Rescue application has been developed for local emergency services. It provides access to a similar database of rescue sheets, including vehicles specific to the Australian market: (https://www.ancap.com.au/ancap-rescue-app)

ROAD RESCUE : MANAGING ELECTRICAL RISK

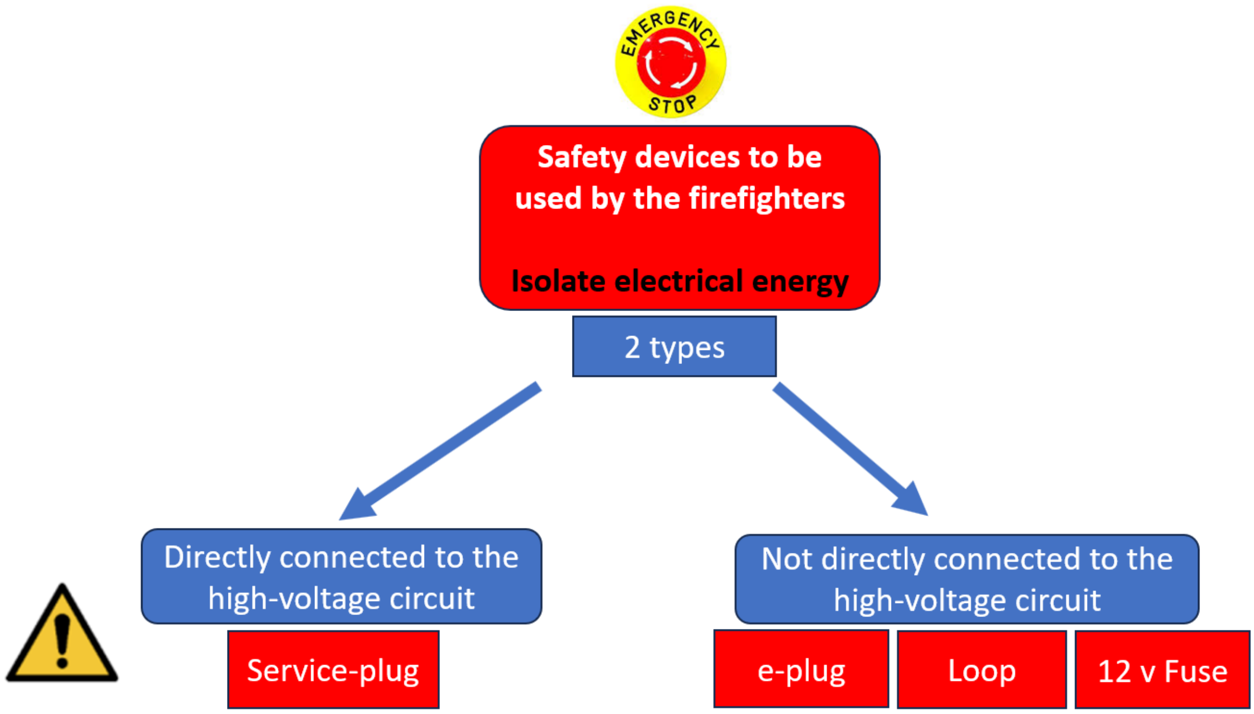
-Safety devices available to emergency services

Electric vehicles are equipped with **safety devices** that can be operated by emergency services during rescue operations.

These safety devices are specifically designed to isolate the electrical energy from the high-voltage (HV) battery, thereby eliminating electrical hazards and allowing emergency interventions to be carried out safely.

Information on the location and operation of these devices is provided by vehicle manufacturers in their rescue sheets, in accordance with the ISO 17840 standard. These operational documents provide information and instructions to the emergency services.

Safety devices can be grouped into two main categories :

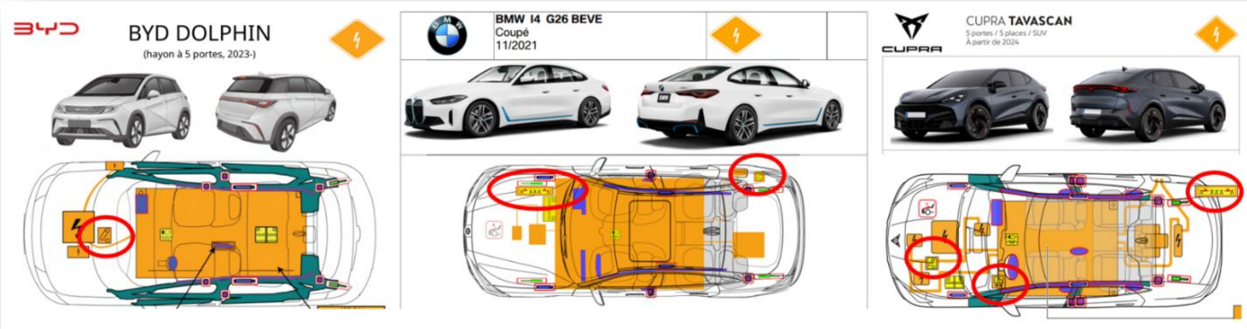


These devices can be located in different places in an electric vehicle. Each vehicle may have one to three such devices, depending on the manufacturer and model.

The placement of these devices varies by vehicle type :

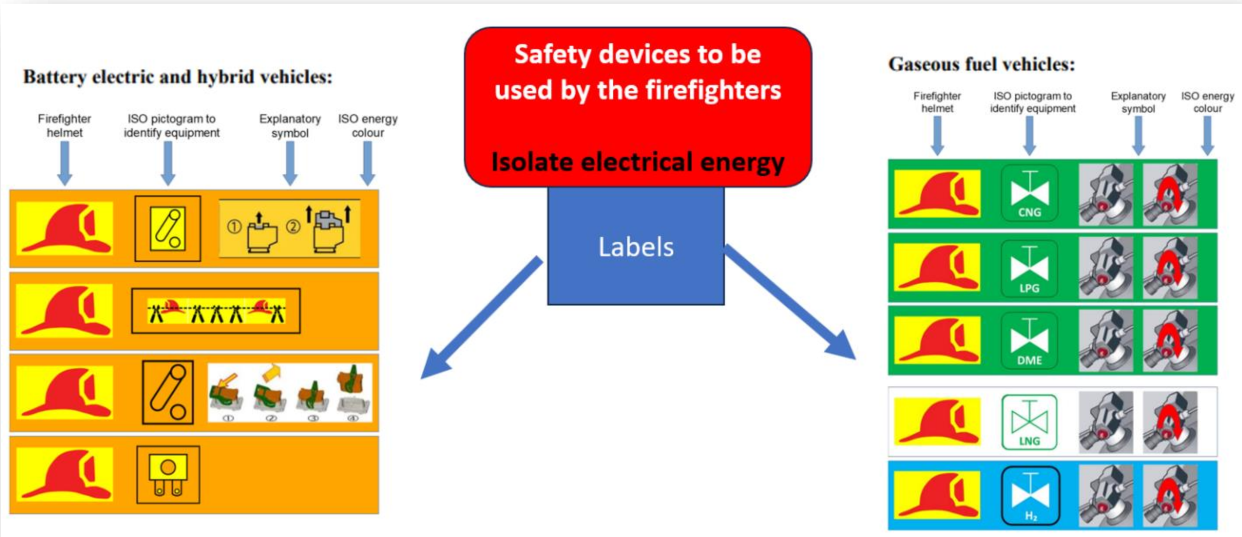
- Cars: passenger compartment, trunk, front (engine) compartment, or sometimes externally (e.g., under the chassis)
- Trucks: passenger compartment or chassis-mounted locations
- Buses: near the driver’s seat or at the rear of the vehicle

All these safety devices are identified by a specific symbol on the rescue sheets (ISO 17840 standard).



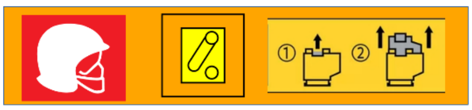
All safety devices are identified on rescue sheets using standard ISO 17840 symbols and are often physically labelled on the vehicle itself.

The label format is defined by Euro NCAP for uniformity across brands and models :



The orange color of the label is characteristic of a safety device associated with a high-voltage (HV) electrical circuit.
The presence of a firefighter's helmet indicates that this equipment is to be used in case of emergency. Note that the choice of the helmet model is left to the discretion of the vehicle manufacturer.

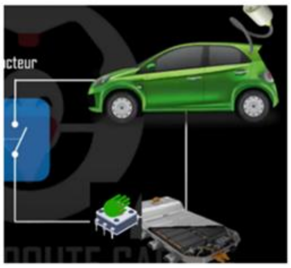
Another possible example :



The ISO symbol representing this safety device is incorporated into the label.

Finally, the diagram explaining how to use the safety equipment is left to the discretion of the vehicle manufacturer.

The « **service plug** » is a safety device located on the high-voltage circuit, often in direct contact with the HV battery.
Operating the service plug disconnects the HV circuit, making the system safe for intervention. Important : handling the service plug requires specific personal protective equipment (PPE), including insulated gloves, face protection…
These are generally used for vehicle maintenance.

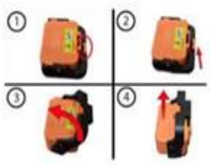


Before and after operation:
Before: HV circuit is live (energy present) / **After:** HV circuit is disconnected (safe state)

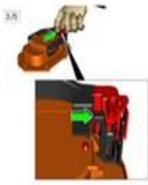
They can be of different designs and can be used in different ways :

MG 5

BYD Dolphin



MG HS



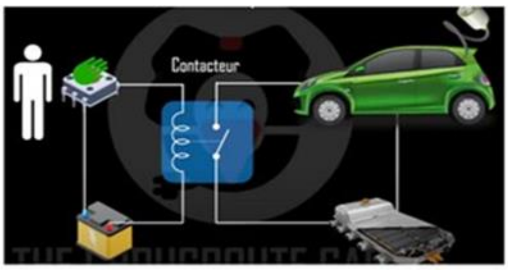
Opel ampera

Polestar 2

Service-plug standard symbol indicated on the rescue sheet (ISO 17840):
The orange color indicates safety device on high-voltage circuits.

Standardized "Service Plug" identification label as defined by Euro NCAP:

The « e-plug », « loops » and « 12 volts fuses » safety devices are located on the low-voltage (LV) circuit. They can be used to open relays on the HV circuit indirectly, thereby isolating high-voltage components.
Unlike the service plug, no special PPE is required to operate these devices.



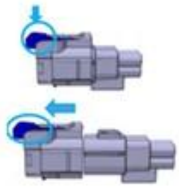
Before and after operation:
shows the HV circuit's state before and after isolation

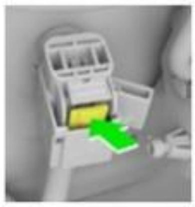
They may differ in design and operation depending on the manufacturer :

- **« e-plug »**


BMW i4


NIO EL 6


CHERY Tiggo


ORA funky cat

« E-plug » standard symbol indicated on the rescue sheet (ISO 17840) :
The yellow color indicates safety device on a low-voltage circuit.

Standardized « e-plug » ” identification label as defined by Euro NCAP :

- **Loop**

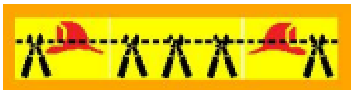

BYD SEAL


KIA EV3

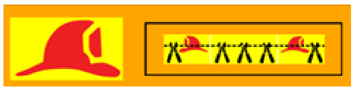

MERCEDES CLA Coupé


JEEP Avenger

« Loop » standard symbol indicated on the rescue sheet (ISO 17840):
The yellow color indicates safety device on a low-voltage circuit.



Standardized « loop » identification label as defined by Euro NCAP:



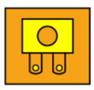
- **12 volts fuse**


SKODA Kodiak


Ford Capri


MAXUS Mifa 7

« 12 volts fuse» standard symbol indicated on the rescue sheet (ISO 17840):
The yellow color indicates safety device on a low-voltage circuit.



Standardized « 12v fuse » identification label as defined by Euro NCAP :

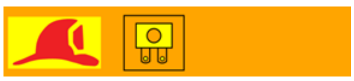
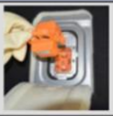


TABLE SUMMARISING ISOLATING ENERGY SAFETY DEVICES				
Type	Examples	ISO symbol	Euro NCAP labels (example)	Specific PPE
Service-plug				✔
e-plug				✖
Loop				✖
12 volts fuse				✖

- *Vehicle manufacturers' instructions*

Vehicle manufacturers provide specific instructions for the isolation of electrical energy in electric vehicles.

These instructions are detailed in Chapter 3 of the rescue sheets (as defined by the ISO 17840 standard) :

3. Disable direct hazards/ safety regulations

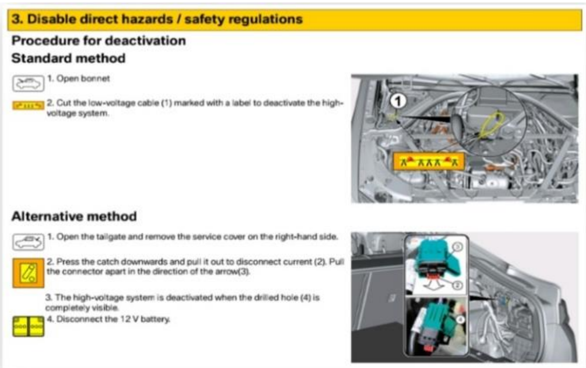
Manufacturers’ instructions typically include the following elements:

- Procedure for accessing and disconnecting the low-voltage (LV) battery (usually 12 volts for cars and 24 volts for heavy vehicles and buses)
- Procedure for accessing and operating the safety equipment used to deactivate the high-voltage (HV) system, including details of the precautions required.

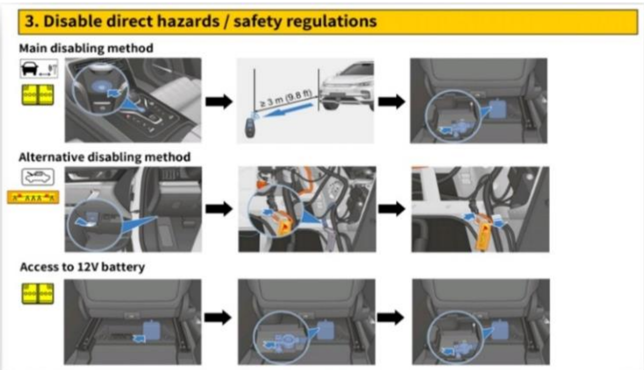
In the last case, different procedures may be proposed :

- Primary procedure (priority) – the preferred and safest method
- Alternative 1 – secondary option if the primary procedure is not accessible
- Alternative 2 – additional backup method

Each procedure may use different types of safety equipment (e-plug, loop, 12V fuse, or other HV isolation devices).



BMW



BYD

It should be noted that some vehicle manufacturer's instructions indicate that:

- the deployment of airbags is a necessary and sufficient indicator to confirm the automatic deactivation of the vehicle's high-voltage circuit

  or

- that switching off the engine is a necessary and sufficient action to automatically deactivate the vehicle's high-voltage circuit.

It is essential to refer to the vehicle manufacturer's instructions to ensure a safe and effective intervention.

Before beginning any extrication procedure on a crashed vehicle, firefighters must:

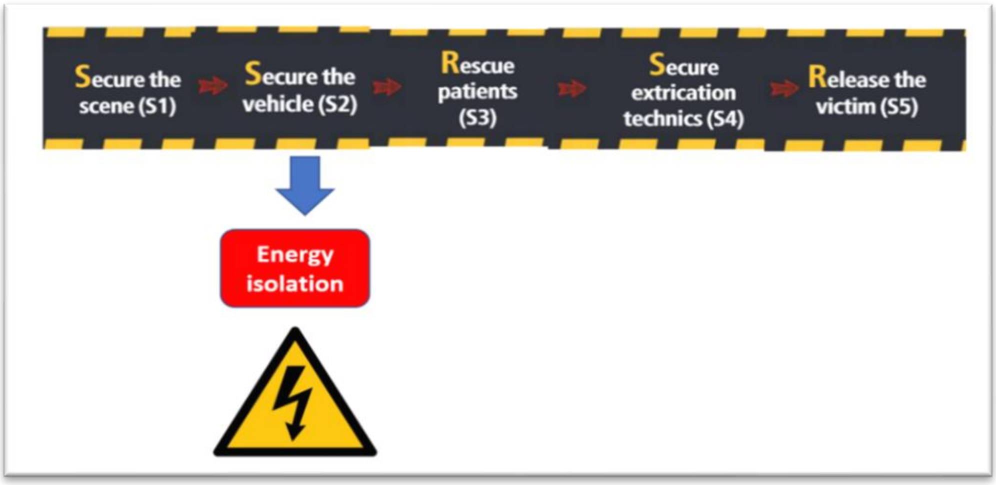
- Identify the vehicle model and type
- Locate and consult the corresponding rescue sheet

This step is a critical prerequisite to ensure that the correct isolation procedures and safety measures are applied during the operation.

It should be noted, however, that while recent rescue sheets have this type of detailed information, this is not the case for all older rescue sheets.

- Integrating of an energy "vehicle securing" phase

To properly manage electrical risks during a road rescue operation, a dedicated "vehicle securing" phase, focused on the control of on-board energy systems, must be integrated into the overall rescue procedure.
The general approach to a road rescue operation can be defined as a series of structured phases, each addressing a specific operational objective.
Within this sequence, the vehicle securing phase forms an essential step for managing electrical hazards and ensuring responder safety.
This general approach can be defined as follows:



The objective of the vehicle securing phase is to enable firefighters to intervene safely and efficiently — as in any standard rescue operation.
For electric or hybrid vehicles, this phase specifically involves:

- Immobilizing the vehicle
- Isolating the on-board energy source (in this case, the electrical system).

The vehicle securing phase must always follow this fundamental rule:

Identify the energy source, vehicle type (make, model, year) and corresponding rescue sheet

Inspect (visually) the energy source (batteries) and vectors (orange HV cables) of the HV electrical system. Check for any visible damage (damaged cables, deformed battery casings, etc.). If necessary, take the necessary precautions (for example, mark or signal damaged areas to prevent accidental contact).

Forbid to touch the orange cables and batteries (and the components connected to orange cables typically marked with yellow triangle with hazard). Report any damage found during the inspection.

Immobilize the vehicle by stopping the vehicle (ensure the vehicle is switched off), applying the vehicle brakes (mechanical or electric), placing the transmission in Park and chocking the wheels (if possible). If necessary or in doubt, refer to Part 2 – Immobilization of the rescue sheet for detailed instructions.

Isolate the high-voltage (HV) system using the procedure described in Part 3 – Energy Isolation of the rescue sheet and using, if necessary, the safety devices available to firefighters (plugs, loops, 12V fuses, etc.).

	Before this last sequence, switch off the low-voltage (LV) system (12 V or 24 V) as an immediate reflex action to be carried out (after having anticipated the electrical equipment to be used to facilitate future rescue actions: electric door handles, electric windows, electric tailgates, electric seats, etc.)
	Note that the HV isolation sequence should only be carried out when extrication techniques are required (e.g. cutting, spreading, or lifting using hydraulic tools), or if there is a clear and immediate danger to rescuers (e.g. visible damage to orange HV cables) or in a specific situation (e.g. a victim trapped under the vehicle).
	Some rescue sheets indicate that the HV battery automatically disconnects in the event of a collision. In this case, the requirement for firefighters to manually use safety devices (loops, e-plugs, …) must be clearly stated on the rescue sheet. Indication of a visual confirmation of HV disconnection (airbags deployed or warning light illuminated on the dashboard for example), will be necessary, in the event of instructions making automatic disconnection sufficient.

	Note that a battery pack separated from the electric vehicle after a significant impact (e.g. cells/modules scattered on the road) must always be considered as presenting a potential electrical hazard.

- ***Perspectives for emergency services***

  - *Emergency calls : towards optimized operational information*

Current emergency call regulations require the automatic digital transmission of key vehicle and accident data to emergency services through the eCall 112 system (implemented in 2018).
Among the mandatory data transmitted are the vehicle's VIN (Vehicle Identification Number) and the vehicle's energy type (e.g. electric, hybrid, hydrogen, combustion). These data points form the primary identification elements.

While information about the vehicle's energy type is a crucial element in the event of a road accident or vehicle fire, it remains insufficient for complete vehicle identification.
Accurate identification is essential to locate the appropriate rescue sheet corresponding to the specific vehicle model.

In contrast, the Vehicle Identification Number (VIN) can be used to identify the exact vehicle via the Vehicle Registration System (SIV) (in France, emergency services have had access to the SIV since 2022).

In this context, Euro NCAP has included in its 2030 Roadmap the priority objective of enabling rescue sheet identification through the EuroRescue application, using either the VIN and/or the vehicle registration number.

Furthermore, in its most recent evaluation protocols, Euro NCAP has decided to encourage the transmission of additional data through the eCall 112 system.

This supplementary information includes :

- ***the number of potential victims;***
- ***the direction of impact (frontal, side or rear impact);***
- ***the delta V (deceleration at impact).***

The objective, in the future, is to be able to obtain a 'severity index', defining the severity of the accident and allowing the emergency services, after receiving the emergency call at the emergency call center, to optimize the emergency resources to be dispatched to the scene of the accident.

- *Rescue sheets : making documents more user-friendly*

Rescue sheets are operational tools intended for use by emergency services during interventions. As such, they must be clear, precise, and concise.

Despite the framework provided by ISO 17840, rescue sheets are still produced in very different formats, and some remain difficult for emergency personnel to interpret and apply in the field.

To address this, Euro NCAP has introduced a set of rules and evaluation criteria to ensure that rescue sheets are as simple and understandable as possible. Points are awarded only for rescue sheets that are produced in full compliance with the Euro NCAP Technical Bulletin TB 030*, which is regularly updated based on the recommendations of the CTIF (International Association of Fire and Rescue Services).
These recommendations emphasize simplicity, clarity of information, and operational efficiency to support first responders in all situations.

EURO NCAP
www.euroncap.com
EUROPEAN NEW CAR ASSESSMENT PROGRAMME

Technical Bulletin

Rescue Sheet & Associated document Guidelines
- Passenger Vehicles

Version 2.2
November 2023
TB 030

- *Hazard isolation : simplifying energy isolation procedures*

The CTIF has identified over 70 different energy isolation protocols used across various electric vehicle models.

These differences involve diverse deactivation equipment, varying equipment locations, different procedures, and different PPE requirements — all of which make the task of first responders complex and time-consuming.

To address this, Euro NCAP, based on CTIF recommendations*, has introduced the following principles to promote simplified and standardized energy isolation procedures:

- ***Encourage simple and safe protocols that cover all possible operational scenarios.***
- ***Automatic energy deactivation is strongly recommended.***
- ***In the event of automatic deactivation, the status indicator confirming that energy has been deactivated must be clearly visible to first responders (e.g. deployed airbags, dashboard warning lights…). This information must also be listed in Chapter 3 of the rescue sheet.***

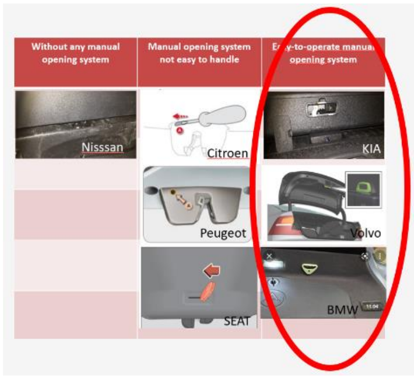
- ***if manual deactivation is required (when automatic deactivation is not possible or in specific operational cases), it must be possible from at least two different areas of the vehicle.***

- ***The operation of energy isolation devices must not require special PPE beyond standard firefighter protective equipment.***
- ***The rescue sheet (Chapter 3) must clearly indicate all deactivated risks, including high-voltage circuits, 60V systems, 12V circuits, and pyrotechnic devices.***
-

o *Tailgate and trunk : easier access in post-crash situation*

The tailgate or trunk often serves as a critical access point for firefighters — whether to reach trapped victims, perform extractions, or access key safety equipment (such as the e-plug or isolation loop).
However, post-crash conditions can make it difficult to open these components, particularly in vehicles relying solely on electric opening systems.

Because rapid access is essential during rescue operations, Euro NCAP has chosen to promote vehicle designs that allow quick and simple tailgate or trunk opening in the event of a collision.



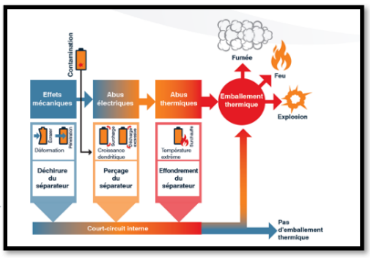
This can be achieved through guaranteed electric opening systems that remain functional after impact, or manual internal release mechanisms that allow firefighters to open the tailgate or trunk from inside the vehicle.

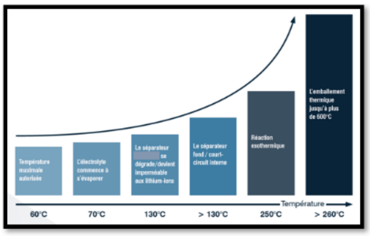
* TB030 d'Euro NCAP : https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/

* article CTIF : https://ctif.org/news/disabling-direct-hazards-vehicle-crash-what-does-it-mean-emergency-responders

VEHICLE FIRES : TAKING ACCOUNT OF BATTERY THERMAL RUNAWAY

- ***Key facts about thermal runaway***





Causes and origines ?
External heat source / internal short circuit* / overcharge / immersion

External signs ?
Flames (flares) / smoke / crackling noise

« How to read the fire » ?
similar to an inflamed (or nor inflamed) gas leak with emission of dense smoke

Critical battery cells temperature to remember :
- Between 130°C and 180°C (depending technologies used)

* After impact, defect, perforation…

The risks identified for this type of event are as follows:

- **Flares** (burns/propagation)
- Possible **projections** of molten metal (including of cells if cylindrical cells)
- **Very rapid kinetics** of thermal runaway, possible

- **Dense, toxic smoke** (CO, HF)

- **Explosion of flammable gases** (H2, CH4…) in enclosed spaces (e.g. garage, car interior)

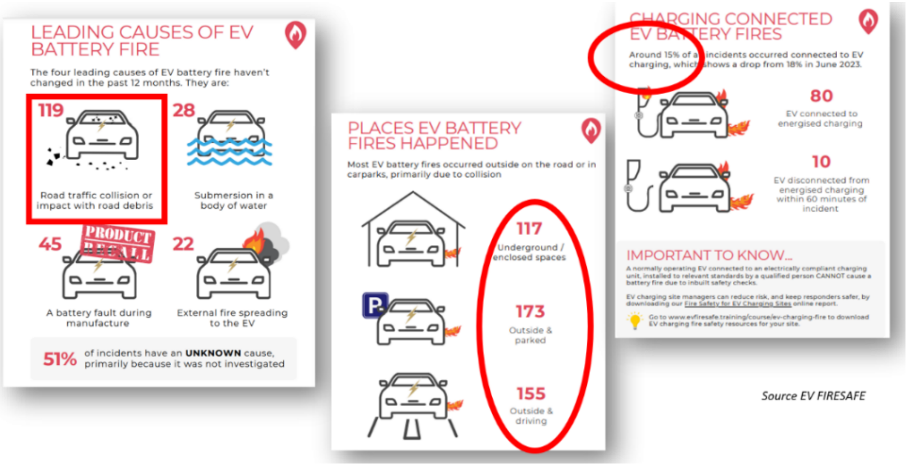
It should be noted that molten metal projections generally originate from the battery casing when it is made of aluminum.

The “missile effect” of ejected cell fragments or sparks is mainly associated with cylindrical cells, which are commonly used in light electric mobility devices such as scooters and e-bikes.

The kinetics of thermal runaway are highly variable and depend on several factors, including the triggering cause (external heat source, internal short circuit, overcharge, etc.), the battery design and architecture, the cell chemistry, and the state of charge (SOC). As a result, the process may be very slow, with several minutes before the appearance of flames, or very rapid, developing in just a few seconds

The smoke generated during thermal runaway is not only dense, but also toxic and flammable, posing significant challenges for emergency services — particularly during interventions in enclosed spaces.

Analysis of incident data reveals several important trends regarding the conditions under which thermal runaway occurs:



Source EV FIRESAFE

- A high proportion of thermal runaway events occur following a road impact, compared with other identified causes such as immersion, manufacturing defects, or exposure to an external heat source.
- A significant number of thermal runaway incidents occur in enclosed spaces
- Approximately 15% of thermal runaway events are estimated to involve vehicles that were being charged at the time of ignition.

- ***Operational aspects of thermal runaway***

Extensive laboratory testing, real-world trials, and field experience from firefighters worldwide have provided a substantial body of knowledge regarding battery thermal runaway.

This accumulated data now allows for the identification of key operational elements to guide emergency services in their response strategies.
The main points to be retained concern specific aspects of the development and behavior of thermal runaway, extinguishing strategies, and the risks and safety considerations for emergency responders :

- <u>development of thermal runaway:</u>

➢ As seen above, the kinetics of thermal runaway can vary greatly. In some cases, flames and smoke appear almost instantaneously, while in others, smoke emission precedes ignition by several minutes.

This **unpredictable onset of flames**, combined with the uncertainty regarding their point of emergence and the **potential for sudden flare-ups**, represents a significant hazard for responders operating near the vehicle. Therefore, any personnel working within the immediate vicinity of the vehicle must be protected against thermal risks. In addition, firefighters must anticipate the possible onset of thermal runaway during extrication operations.

- The **average duration** of a battery thermal runaway in free combustion (that is, without any extinction or cooling intervention) **is approximately 30 minutes**, and rarely exceeds one hour. This parameter is crucial for operational decision-making, particularly when determining whether to maintain an offensive attack, or employ an extinguishing technique in direct contact with the battery (for example, the battery perforation).

  The decision must always be based on a careful assessment of risks versus operational benefits.

- A thermal runaway **without visible flames** (characterized only by smoke emission) creates a significant **risk of explosion** in a confined or enclosed environment. During this phase, the affected battery releases flammable gases, primarily methane (CH_4) and hydrogen (H_2). When these gases accumulate in an enclosed space (such as a garage, underground car park, or vehicle compartment), they can form a potentially explosive atmosphere. In such situations, and particularly in the absence of ignition, the operational context is comparable to a non-ignited flammable gas leak.

- A battery involved in thermal runaway **may re-ignite** several **hours, or even days,** after the initial event. For this reason, it is essential to verify the absence of residual hot spots before declaring the end of operations. Whenever possible, this should be done using a thermal imaging camera, which allows for precise detection of lingering heat within the battery modules. Additionally, the use of carbon monoxide (CO) detectors may also be considered.

  It is also critical to inform law enforcement and any recovery or towing services of the type of vehicle involved (electric, hybrid, or hydrogen), and the incident context (thermal runaway with potential risk of re-ignition).

- **Battery reignitions** are relatively common occurring in approximately 13% of documented cases (source EV Firesafe).

- **Re-ignition** most frequently occurs after the **vehicle or battery has been moved**, such as during roadside recovery or post-incident towing operations. This phenomenon is typically caused by electrical contact between damaged cells and adjacent cells, or cells and metallic components within the vehicle structure (following a previous thermal runaway or after a mechanical impact from a road collision) or by cells and water contact (due to water infiltration, for instance, following the use of water during firefighting). In these situations, cell-to-cell contact or cell-to-water interaction can create a short circuit, leading to reheating and potentially a new thermal runaway event.

- <u>extinction and cooling</u>

- All available tests and operational feedback consistently demonstrate the **effectiveness of water as an extinguishing agent** in the event of battery thermal runaway. **Water is also highly effective (cooling) in preventing** thermal propagation, helping to limit domino effects between adjacent battery modules or nearby vehicles.
- However, while water is an excellent extinguishing medium, it remains extremely difficult (if not impossible) **to deliver it directly inside the battery casing**.

  This is due to the compact, sealed, and reinforced design of most high-voltage battery enclosures, which are typically waterproof and structurally integrated into the vehicle chassis, and difficult to access for emergency responders (for example, under-floor batteries in electric cars or roof-mounted battery packs in electric buses)
- During a fire-extinguishing operation, firefighters should take advantage of any **fusible or weakened parts of the battery casing** to improve the penetration of extinguishing water.

  Potential access points include : cable exits, openings or deformities created by heat, and damage to the casing, particularly when the casing is made of aluminum (melting point approximately 660°C).

  In the case of steel casings, thermal **deformation caused by heat** exposure can also create useful openings for directing water or cooling agents closer to the affected cells.

  The same principle applies to light electric mobility devices (such as electric scooters and e-bikes), where the plastic battery housings often melt more easily, allowing faster access to the cells for extinguishing or cooling operations.
- All tests conducted to date indicate that there is no **electrical hazard for firefighters** handling hoses **during the extinguishing phase of** a battery fire. However, the situation is different during the **debris removal and overhaul phase.**

  At this stage, **any contact with electrical components must be strictly avoided,** as residual electrical energy may still be present despite the apparent extinction of the fire.
- The **smoke** produced during a battery thermal runaway is **dense, toxic, and flammable**, significantly reducing visibility and hindering access to enclosed spaces. These characteristics make firefighting and rescue operations particularly challenging and hazardous for emergency responders.

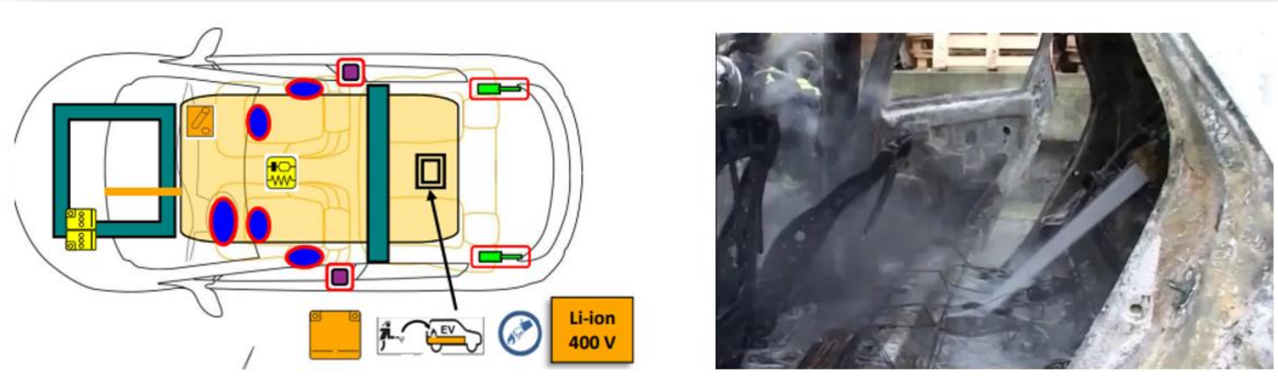
- Risks for responders

- Due to the toxicity of the smoke produced during a thermal runaway (notably the presence of hydrogen fluoride (HF) and carbon monoxide (CO)), **enhanced protection against toxic exposure** (appropriate PPE, including respiratory protection) must be ensured for responders.
- Due to the flammable nature of the smoke produced during a thermal runaway (notably the presence of hydrogen (H_2) and methane (CH_4)), **enhanced protection against explosion risks** must be ensured for personnel, particularly when operating around vehicles, in confined spaces, or when using thermal blankets.
- Due to the possibility of **flare-ups and molten metal projections** during a thermal runaway, **enhanced protection against thermal risks** is required for responders, particularly those working in direct contact with the vehicle.
- Due to the possibility of **cylindrical cells being projected** (although this is uncommon in electric vehicles / /common in the case of electric bicycles/scooters) during a thermal runaway, **enhanced protection against mechanical risks** is required for responders.

- Safety equipment available to emergency services

While vehicle manufacturers have addressed electrical risk management for emergency responders by providing electrical isolation devices (such as isolation loops, 12-volt fuses, and e-plugs), the same level of consideration has not yet been applied to the issue of battery thermal runaway.

However, some electric vehicles are now equipped with a “fireman access” device, integrated into the battery casing, which allows emergency services to inject water directly into the battery to assist in cooling and extinguishing operations.



Renault fireman access

- Vehicle manufacturers' instructions

Car manufacturers’ instructions on fire hazards for electric vehicles are provided in Chapter 6 of the rescue sheets.

6. In case of fire

These instructions rarely include specific operational advice, but generally focus on broad recommendations concerning the risk of battery re-ignition, and the use of thermal imaging cameras to monitor potential hot spots.

BYD

- Main techniques developed around the world

Based on the previously listed knowledge regarding the characteristics of battery thermal runaway, many fire and rescue services, as well as private companies, have developed techniques using different concepts.

We will address the three main approaches :

- vehicle immersion,
- extinguishing with water by perforating the battery casing
- the use of thermal blankets,

while outlining the constraints, restrictions, and limitations associated with each of them.

The presentation of these techniques does not, under any circumstances, constitute validation of their relevance or effectiveness.

- *vehicle immersion:*

  Battery immersion is one of the most effective techniques for bringing a thermal runaway under control.

  While this approach can be readily applied to isolated batteries, its implementation becomes much more complex when dealing with battery packs integrated into vehicles. Nevertheless, several fire and rescue services have adopted this principle for use with electric cars.

To achieve this, they employ immersion equipment, either improvised on-site as required, or prepared in advance as part of their operational resources, or made available through partnerships with external organizations (for example, towing companies equipped with quarantine or immersion containers).

Notes on vehicle immersion techniques :

- *In addition to a submersion container, immersion operations often require additional equipment, such as lifting or towing tools.*
  *As a result, immersion of a single vehicle is a **complex operation** that requires careful planning, coordination, and sufficient resources.*
- *Any immersion operation that requires **rescuers to be in direct contact** with the vehicle must be conducted only in the **absence of flames**. This operational constraint means that the intervention must be carefully timed according to specific phases.*

  Deploying any immersion technic, one of the following operational conditions must be met:

  - *The intervention takes place during a flame-free phase of the thermal runaway cycle, typically at the early stage of a low-kinetic thermal runaway.*
  - *A preliminary attenuation attack using conventional firefighting methods (e.g., water hoses) is conducted to reduce or eliminate the thermal effects of the runaway.*
  - *The operation is carried out after the end of the thermal runaway cycle, once thermal activity has significantly decreased or ceased.*

  Given the response times of emergency services, the first scenario (intervening at the very beginning of a thermal runaway without visible flames) is highly unlikely in real conditions
- *The **post-operation management of a vehicle** in a submersion container can present significant challenges, including transport logistics, storage location, and handling.*
- *The **management of water used in the submersion container** can also present challenges, including the need for treatment by a specialist company, disposal logistics, and associated financial costs.*
- *The use of vehicle immersion techniques is generally restricted to **light electric mobility devices** (such as electric scooters and bicycles) and **passenger cars**, and is not suitable for larger vehicles such as trucks, buses, or heavy commercial vehicles.*

- ***The effectiveness of immersing a battery*** *in a container will depend on the ability of water to penetrate the battery casing.* ***The battery's architecture*** *(whether it contains one or several modules) and/or* ***its degree of damage*** *(such as an aluminum casing that is intact or deteriorated)* ***or deformation*** *(such as a steel casing that is intact or deformed) will be key factors influencing this effectiveness.*

  If one or more of these favorable conditions are not present, immersion may be poorly effective and may require several days or even weeks

- ***Immersion of vehicles or batteries*** *that are undergoing or have undergone thermal runaway* ***does not guarantee the absence of subsequent re-ignition once the vehicle is removed from the container.***

  Re-ignitions frequently occur after the vehicle has been moved (for example, during towing or recovery operations). These movements can cause damaged cells to come into contact with one another and/or with residual water present inside the casing, leading to new internal short-circuits.

  Only the complete immersion of all cells could effectively prevent this phenomenon.

  However, following thermal runaway, battery casings are rarely watertight — deformation or damage caused by extreme heat (and even more so by mechanical perforation of the lower casing) compromises their integrity and makes total immersion impractical.

- *Extinguishing with water by perforation :*

Given that water is an effective extinguishing and cooling agent, yet difficult to introduce into sealed battery casings, several battery perforation tools have been developed to facilitate targeted water injection.
Some are manually operated, while others use mechanize systems that allow controlled perforation of the battery casing.

The main ones are mentioned here:

COBRA ColdCut

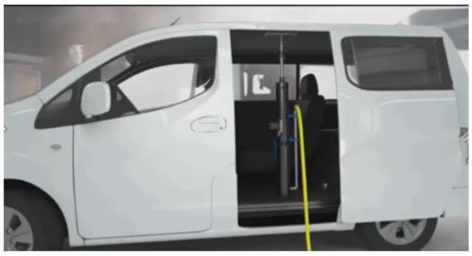
https://www.coldcutsystems.com/handling-of-lithium-ion-fires/

Murer

https://www.murer-feuerschutz.de/e-loeschlanze/index_en.php

Rosenbauer

https://www.rosenbauer.com/en/products/fire-fighting-systems-and-body-components/rfc-battery-extinguishing-system



AVL Stingray One

https://www.avl.com/en/testing-solutions/e-mobility-testing/battery-testing/avl-stingray-one

TOOL	Perforation method	Perforation energy	Main perforation zone	Flexibility of use	Rescuers in contact during preparation	Rescuers in contact during perforation	Rescuers in contact during extinction
COBRA ColdCut	High-pressure water	Hydraulics	On top				
AVL Stingray One	Rigid punch	Pneumatic	On top				
Murer	Rigid punch	Manual	On top				
Rosenbauer	Rigid punch	Pneumatic	From Below				

Notes on perforation techniques:

- *Given the capacity of the batteries concerned (which can reach up to 100 kWh) and the resulting electrical risks, it is **necessary to ensure**, with the manufacturer of the specific perforation tools, that there is **no electrical hazard for rescuers**, regardless of the weather conditions (rain, snow, fog).*
- *It will also be necessary to determine the **operational contexts** in which these tools will be **effective** (electric cars, electric buses, electric trucks, isolated batteries, etc.).*
- *As with immersion technic, the use of perforation techniques involves **the physical presence of rescuers in contact with the vehicle,** both during equipment installation and, in some cases, throughout the perforation or extinguishing phase. **This requires the complete absence of flames** around the vehicle. This operational constraint means that the intervention must be carefully timed according to some specific phases of thermal runaway (see previous section).*
- *Any operational **phase during which rescuers are in direct contact with the vehicle** must include **hydraulic protection** for personnel (e.g. maintaining a protective water hose spray) to ensure safety in the event of sudden ignition or flare-up.*
- *The **perforation of a battery casing**, especially when using rigid or mechanical punches, may **trigger the onset of thermal runaway**.*
- ***Depending on the battery architecture** (multiple modules) and/or vehicle configuration (several battery packs), it may be necessary to perform **perforations at several locations** to ensure efficient water penetration and extinguishing.*
- *Tools designed to perforate the battery from **under the chassis** can be severely limited by tyre burst — a common consequence in severe vehicle fires.*

  *When tyres burst, the vehicle often drops onto the ground (except for some high-clearance SUVs), so the **chassis contacts the ground and prevents the tool from being used beneath the vehicle.***
- *The **introduction of water into a battery casing** undergoing thermal runaway **does not guarantee the absence of subsequent re-ignition.***

  As noted previously with immersion techniques, these re-ignitions frequently occur after the vehicle has been moved or displaced.
- *A drawback of the UHD **(ultra-high-pressure device)** technique is the large amount of hazardous substances that end up primarily in the extinguishing water. Measurements show that **the UHD method can release more harmful substances** from the battery than other extinguishing methods. These mainly include heavy metals such as cobalt and nickel.*

- *Use of thermal blankets :*

The use of thermal blankets is not a method for extinguishing a thermal runaway, but can be applied either to a vehicle already affected by thermal runaway or to an adjacent vehicle at risk.

In the first case of a vehicle already undergoing thermal runaway, the objective of using a thermal blanket is to reduce thermal and smoke impact to:

- avoid domino effects
- and/or improve visibility in confined spaces
- and/or allow additional resources to be deployed safely in the vicinity of the vehicle.

In the second case, the objective will be to protect a vehicle located close to the burning vehicle.

Notes on thermal blankets techniques :

- *When used on vehicles already undergoing thermal runaway, the **operation can be difficult or even impossible** in enclosed spaces or in the presence of obstacles near the vehicle (such as other vehicles, buildings, or debris). The effectiveness of the thermal blanket depends on its ability to fully cover the vehicle, which requires sufficient clearance and floor space around the vehicle for proper deployment.*
- *In its "use on burning vehicles" application, the thermal blanket is primarily intended to control **flows of smoke and hot gases** and to **protect both the immediate and surrounding environment** from thermal and smoke exposure.*
- *When used on a vehicle already undergoing thermal runaway, the **flammable gases emitted** during the event, combined with certain types of blanket materials, **can create explosive phenomena**, either beneath the cover or during its removal.**
- *In its "use on adjacent vehicle" application, the **thermal blanket provides effective protection for the vehicle**, helping to prevent domino effects caused by heat transfer or thermal runaway from nearby burning vehicles.*

* https://www.evfiresafe.com/post/ev-fire-blanket-explosion

- Managing thermal runaway with conventional firefighting resources

When traditional firefighting resources (such as water hoses) are used to combat electric vehicle fires, a clear **operational strategy** must be adopted that considers the criteria and observations outlined above.

This strategy must be accompanied by protective measures for personnel against the thermal, toxic, explosive, and electrical hazards mentioned earlier.

Two main scenarios should be considered, each with specific objectives:

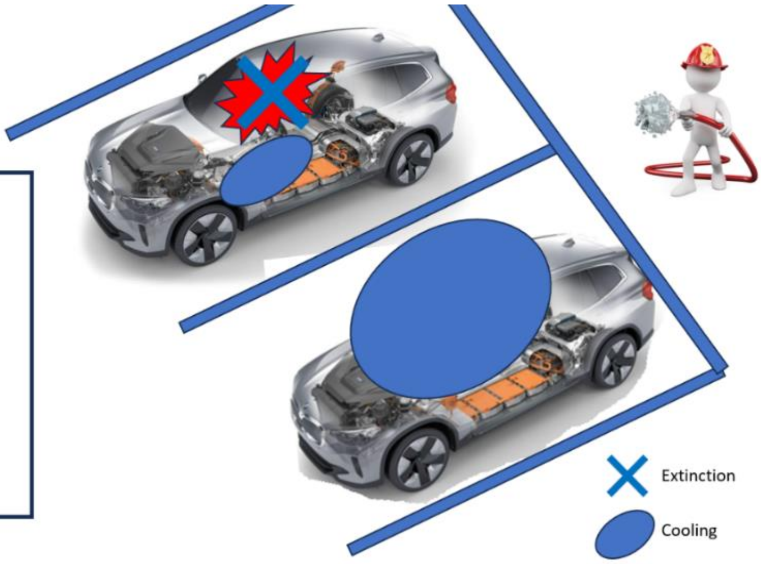
2 cases

EV fire without battery thermal runaway
=> **prevent** thermal runaway

EV fire with battery thermal runaway
=> **try** to extinguish the thermal runaway
=> **prevent** the propagation

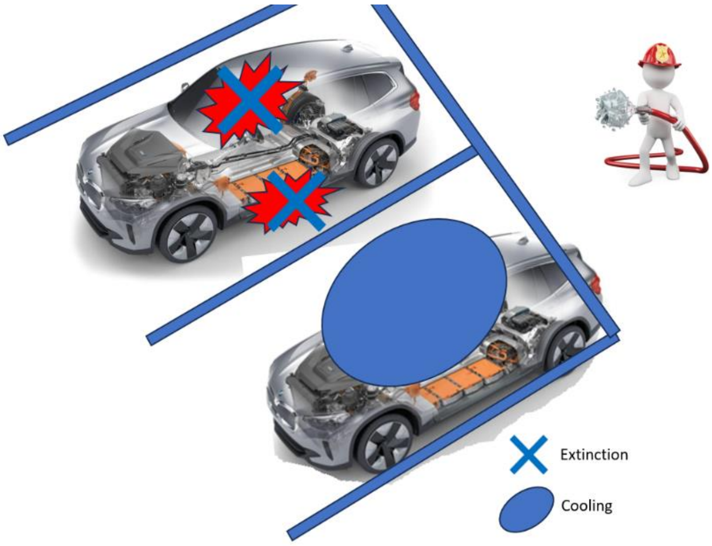
In the 1st case (EV fire without thermal runaway), the following actions must be taken:

- **Protect** rescuers (breathing apparatus)
- **Protect** the environment (people and things)
- **Extinguish** the vehicle fire
- **Prevent** thermal runaway by cooling the batteries
- **Stop all kinds of propagation to avoid thermal runaway** (domino effect) by cooling the batteries/vehicles (if there are any nearby).

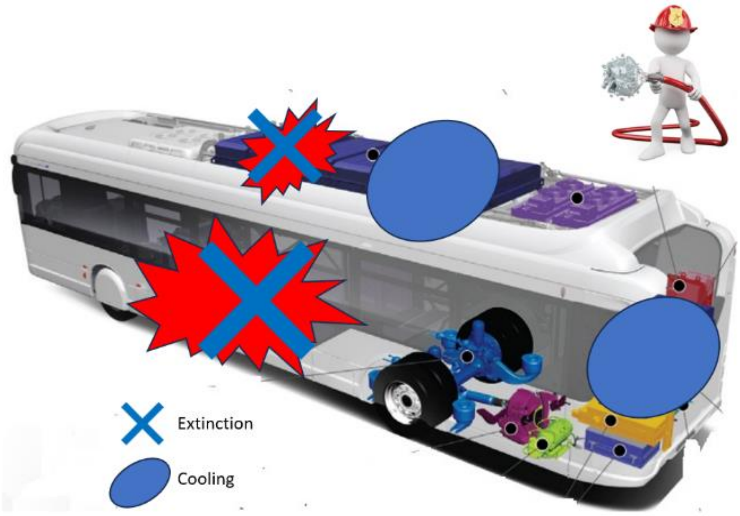


In the 2nd case (EV fire with thermal runaway), the following actions must be taken:

- **Protect** rescuers (breathing apparatus)
- **Protect** the environment (people and things)
- **Extinguish** the vehicle fire
- **Extinction** of battery thermal runaway (if effective extinction)
- If **extinguishing ineffective**, stop extinguishing procedure (**"let burn"**)
- **Prevent thermal runaway (domino effect)** by cooling the batteries/vehicles (if there are any nearby)
- Particular point : If thermal runaway « **with smoke without flame »**, take into account the **risk of explosion**
- Take into account the **possibility of re-ignition** of the battery



Electric bus example



Always include the following criteria in the operational approach :

THE COMBUSTION TIME OF A BATTERY (in free combustion), AFTER THERMAL RUNAWAY , IS ABOUT 30' ... AND VERY RARELY MORE THAN 1 HOUR!

=> **Balance of resources/risks <=> results to be expected**

The following instructions should be strictly followed by hose holders during electric vehicle fire operations :

Massive attack at vehicle contact using a **diffused spray** / 125l/min debit

Full jet attack through the fusible parts of the battery casing / flow 125 l/mn / « where the **flames exit** = possible **entry point for the water** to extinguish the fire »

If the action is ineffective => stop extinguishing the thermal runaway (let burn)
Protect the environment / prevent any domino effects,
Experience shows that after 10 minutes of trying to extinguish the fire with 2 water hoses (2500 litres of water) without any significant result, the 'let it burn' strategy has to be adopted.

The effectiveness of this offensive firefighting method can be monitored using a thermal camera, focusing on the battery casing.

The key indicator is the temperature decrease (ΔT°) over time, rather than the absolute temperature itself.

In order to illustrate several points raised in this document regarding thermal runaway (kinetics, development, extinguishing by traditional techniques, etc.), a video of tests carried out in France in May 2024 is provided.

https://youtu.be/rg8k4zyqu4M

Warning: *the test carried out with a perforating tool at the end of the video corresponds only to a very specific prototype tool. The information obtained with this equipment cannot be extrapolated to all existing models of perforating tools.*

A few specific situations need to be explained :

Electric vehicle fire during charging

Extinction procedure is only used **if the electrical power at the charging point is cut off**:

- -by emergency stop button on the charging point
- -by general power shutdown

If the **electrical power is not cut** => environmental protection **only**

Electric bus fire

Be careful of the **weight of the batteries** on the roof of the bus:
=> **risk of battery packs collapsing and falling** in the event of a general bus fire

The 2 hoses simultaneous attack is required :

- •Team 1 -– Extinguishing the vehicle
- •team 2 – Cooling the batteries and extinction if possible

Hydrogen electric vehicle fire

Extinguishing procedure **targeting cooling of the H2 tank as a priority.**

The 2 hoses simultaneous attack is required :

- -Team 1 - Cooling the H2 tank
- -Team 2 - Extinguishing the vehicle and HV batteries fire

This strategy for firefighting on electric vehicles can be integrated into a more global strategy for firefighting on vehicles of all energies * (LPG, CNG, LNG, H2) for which a specific technique is used:

- the simultaneous massive attack with 2 water hoses with the following objectives:
  - team n°1: cooling the energy source (gas tank / HV battery) to prevent escalation, delay thermal propagation and reduce the risk of explosion or thermal runaway.
  - team n°2: extinguishing the vehicle

This **technique** is performed as follows :

* global strategy with specific aspects for each energy source

- Perspectives for emergency services

- *Thermal runaway : towards greater battery stability and a post-crash alarm*

The thermal runaway of electric vehicle batteries remains a key concern for fire and rescue services worldwide, especially following road accidents.

To address this, Euro NCAP has decided to incorporate the following criteria into its test protocols:

- ***Greater battery stability after thermal runaway detection: batteries should maintain stable thermal conditions for a defined period (e.g., 20, 40, or 90 minutes) following the onset of thermal runaway.***
  This stability ensures that emergency services can intervene safely, allowing for victim extrication and rescue operations.
- ***Post-crash thermal runaway alert: In the event of a road accident, emergency services must be immediately informed if a thermal runaway has begun.***
  A dedicated thermal runaway indicator on the vehicle dashboard should be clearly visible to responders, ensuring rapid assessment and safe intervention during post-crash operations.

- *Thermal runaway : towards detection and alarm in all contexts*

The thermal runaway of electric vehicle batteries is now a critical concern for fire and rescue services in all operational contexts, including driving, parking, and charging situations.
This expanded awareness emphasizes the need for continuous monitoring and alert systems to ensure that responders and vehicle users are informed regardless of the vehicle's operational state.

To improve the safety of electric vehicles in all contexts, Euro NCAP has introduced the following criteria into its test protocols:

- **When parked (charging or not), to ensure that thermal runaway is detected and the emergency services notified as soon as possible, the vehicle owner is informed of the detected risk via a connected smartphone. In the same situation, A sound and/or warning light is activated to alert people in the immediate vicinity of the vehicle.**