How and with What Should Electric Vehicles Be Extinguished?
(A Comparative Analysis of Methods for Suppressing Electric Vehicle Fires)

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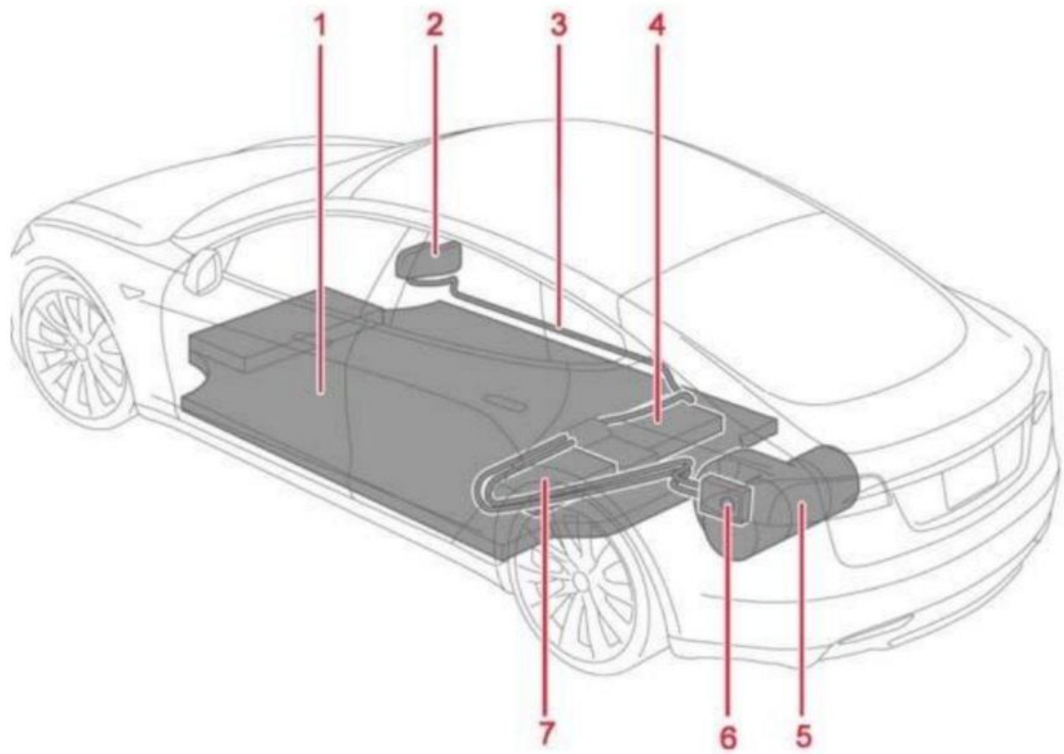
The results of scientific and technological progress, intended to serve humankind, may, on the reverse side, cause significant socio-economic damage and even lead to injury and loss of life. Numerous examples of such consequences exist, including the accident at the Chernobyl Nuclear Power Plant. A contemporary manifestation of the negative effects associated with new equipment and technologies is the issue of fire safety of electric vehicles.

In his address of October 2024, the President of the Republic of Kazakhstan, K.-J.K. Tokayev, noted that countries possessing advanced science and technology are global leaders and that, in order not to remain on the margins of progress, Kazakhstan must become a nation of technocrats. This directive of the Head of State, together with national policy promoting the introduction of environmentally friendly transport, places upon the State fire-safety system the task of developing, on the basis of relevant research, practical measures to address emerging risks associated with all stages of the life cycle of electric vehicles.

Unlike conventional vehicles, methods and strategies for extinguishing electric-vehicle fires have specific characteristics. As with ordinary vehicles, the principal approach involves the use of water for fire suppression. If combustion of the traction battery pack is not involved, the burning of the vehicle itself and the corresponding firefighting tactics differ little from those applicable to vehicles equipped with internal combustion engines. Moreover, the combustible load potential of an electric vehicle is lower than that of a conventional vehicle due to the absence of liquid fuel, coolant, and lubricants. Whereas the use of air-mechanical foam is common practice when extinguishing fires involving internal combustion engine vehicles, the manufacturer Tesla does not recommend the use of foam for electric-vehicle fires. Where the battery pack is involved in the fire, the key objective becomes its cooling in order to prevent, slow, or terminate thermal runaway (**a chain reaction within the battery leading to a rapid increase in temperature and pressure**). It is essential to reduce the temperature of adjacent battery cells below the critical ignition threshold to minimize further heat transfer. This task is complicated by the presence of a metal casing that protects the battery.

1. Battery pack;
2. Power converter;
3. High-voltage cables (orange-coloured);
4. Integrated primary onboard charger, 10 kW capacity;
5. Drive unit;

6. Charging port;
7. Auxiliary onboard charger unit, 10 kW capacity.



Typical Arrangement of High-Voltage Components

Halting thermal runaway is extremely difficult, as it requires intensive and highly localized cooling of each individual battery cell. In addition, the use of lithium in batteries may lead to explosive reactions associated with the release of flammable gases during lithium combustion, primarily hydrogen and methane.

Electric-vehicle manufacturers are undertaking efforts to improve battery design from the standpoint of safety and to facilitate the work of fire and rescue services. For example, in Tesla electric vehicles such as the Model 3 and Model Y, a comparatively simple method is employed to prevent or slow battery thermal runaway. The battery is enclosed in a steel casing, while the lower section consists of a thin aluminium plate. As temperature rises due to thermal runaway, the plate melts upon reaching critical thresholds (the melting point of aluminium is approximately 660 °C), allowing individual battery cells to fall out of the enclosure.

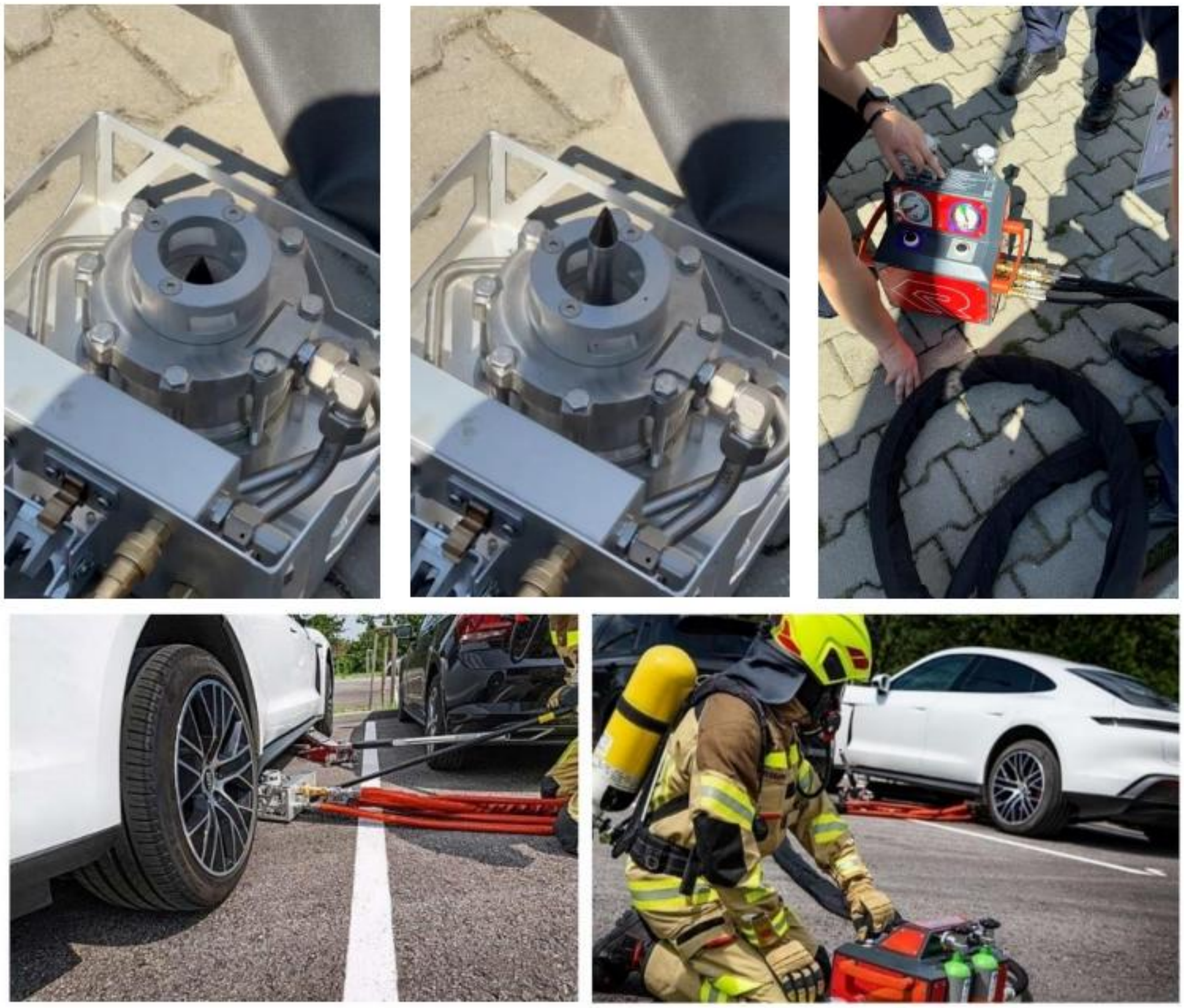
This design feature facilitates firefighting operations compared with other types of electric vehicles. In an actual electric-vehicle fire, the melting of the aluminium plate allowed battery cells to fall to the ground, after which firefighters concentrated on localizing the seat of the fire outside the vehicle. Although the vehicle was completely destroyed by fire, the primary objective of this design solution is to prevent the spread of fire to the vehicle body before the battery elements reach the ground.

Most electric-vehicle manufacturers, in their emergency response and firefighting guidance, recommend a suppression strategy based on intensive cooling of the battery using large quantities of water. However, other methods also exist that help prevent escalation of thermal runaway. The following sections will examine a number of recommended and applied methods for extinguishing electric-vehicle fires. At this stage, the discussion concerns fires occurring in open areas. Subsequently, the issue will be considered in relation to fires in enclosed parking facilities, including the dynamics of hazardous fire factors, firefighting tactics, and the development of design solutions to ensure fire safety.

Cooling with Water Using Mobile Fire-Service Equipment

The traditional method of cooling a battery during fire suppression is the use of a large volume of water. For effective cooling, water must be directed immediately onto the battery; in practice, however, this may be difficult. The battery is typically located in the lower part of the vehicle and protected by a durable metal casing designed to prevent mechanical damage. In the event of a fire, such protection may hinder the delivery of water to the burning elements. Effective cooling therefore requires a water supply from a source located as close as possible to the fire scene. On open stretches of roadway this presents a challenge, as a standard fire engine in Kazakhstan carries only about 2 m^3 of water.

On urban highways equipped with external water-supply systems, these difficulties do not arise. According to recommendations, water reserves should ensure a flow rate of 20 l/s for 90 minutes, which is equivalent to 108 m^3 of water. In the absence of an external water supply, this corresponds to more than 50 fire tankers. At present, special technical devices have been developed to deliver water beneath the underside of an electric vehicle directly to the battery pack. Among the most widely known are the products of Rosenbauer. This is a thin device placed under the chassis of the burning vehicle and equipped with a special spike capable of piercing an opening in the battery housing, through which a large quantity of water is supplied under pressure. The device allows the extinguishing process to be controlled from a distance of up to 10 metres and reduces water consumption by more than four times.



Advantages:

- The procedure is simple and well known to fire services personnel.
- In the absence of specialized devices and trained personnel, standard firefighting equipment may be used; no special equipment is required.

Disadvantages:

- A significant volume of water is required for suppression.
- Notable environmental impacts due to large quantities of contaminated runoff entering the environment.

Access to the Battery via a Fire Service Access Hatch

A French automobile manufacturer has introduced a patented technology предусматривающую оснащение electric vehicles with a dedicated fire-service access hatch allowing water to be supplied directly to the battery. The concept, developed in cooperation with fire services, employs two heat-sensitive elements located on the chassis and the battery casing. In the event of a fire, these elements melt, creating an opening that provides access to the battery. Through this opening, emergency responders can introduce water directly into the battery, enabling the fire to be localized within a short time using a minimal volume of water.

In essence, this is also a water-cooling method, but implemented through the passenger compartment directly into the traction battery; this constitutes the principal distinction from the Rosenbauer device described above. The approach also illustrates the importance of cooperation between the vehicle manufacturer and fire services in creating conditions that facilitate fire suppression.

Advantages:
- An effective method of ensuring direct access to the battery.
- A simple and rapid suppression solution.

Disadvantages:
- Direct insertion of a fire hose into the opening must be avoided due to the risk of electric shock.
- The system is located inside the vehicle, beneath the rear seat, which may complicate rapid access for firefighters.
- At present, the technology is used by only one manufacturer.

Use of a High-Voltage Immersion Container

One method of extinguishing electric-vehicle fires is the use of a high-voltage immersion container, essentially a large tank designed for passenger cars. After the visible fire in the vehicle body has been suppressed, and where damage to the battery cannot be ruled out, the electric vehicle is placed into such a container. The *Red Box* container, developed and patented by a German company, is made of sheet steel and has a volume of 23 m³, sufficient to accommodate a passenger car. Using a crane, the vehicle is lifted into the container or pulled inside by means of an integrated net and electric winch. The container is then filled with water through designated connections equipped with couplings for firefighting hoses, ensuring full submersion of the vehicle and cooling of the battery.

Vehicle manufacturers do not recommend this approach for the following reason: if thermal runaway occurs in a single battery module, the remaining modules may remain undamaged. Full immersion of the battery pack in water may cause damage to those intact modules. While the battery remains submerged, ignition is prevented; however, there is a risk of fire occurring several days or even weeks after its removal. In the worst case, immersion damages otherwise safe modules, which may lead to a subsequent fire. It is impossible to predict with certainty whether a fire will occur after immersion or when it may happen.

Advantages:

- The container is equipped with acid-resistant rubber seals, ensuring tightness and preventing leakage of contaminated water into the environment.
- It may be used not only for electric vehicles but also for other purposes.
- The vehicle may remain in the container without immediate filling with water until the risk of ignition has been eliminated, in accordance with manufacturers' recommendations. In the event of ignition, the container can be filled with water at any time.

Disadvantages:

- After the battery has stabilized, the contaminated water is pumped out; however, disposal may be costly depending on the level of contamination, and issues of liability for disposal remain unresolved.
- The high cost of the system and its transportation to the fire scene further increase overall expenses.

Use of a Piercing Nozzle

Another method for extinguishing electric-vehicle fires is the use of a piercing nozzle, which is inserted into the battery casing either manually or pneumatically, depending on the manufacturer. The nozzle is typically made of stainless steel and equipped with small outlets at the tip, through which extinguishing water is delivered directly to the battery cells. A manual piercing nozzle includes a hose connector and an electrically insulated handle to protect against electric shock.

During testing, a manual piercing nozzle was evaluated on a test bench. The fire was extinguished 700 seconds after ignition, with the battery itself remaining uninvolved in the combustion process—the voltage stayed at 400 V, and the internal battery temperature remained low (around 25 °C). This demonstrates good casing protection and the potential effectiveness of the battery management system.

When a fire was deliberately initiated within the battery, a sharp voltage drop occurred at 825 seconds, indicating the onset of thermal runaway. The temperature began rising rapidly, exceeding 400 °C. Suppressing the vehicle body fire alone had no effect on battery heating. Once the fire in the vehicle body was contained and safe access to the car was secured, the piercing nozzle was applied. Its insertion into the battery using a sledgehammer proved challenging and required skill. Potential risks—such as jet flames or short circuits capable of causing electric arcs or shock—must be carefully considered.

Although temperature readings at certain sensors showed localized cooling, a drop to 100 °C may be insufficient to fully halt thermal runaway. Temperatures in other parts of the battery remained high and continued to rise. The cooling effect can be localized depending on the battery's design. Furthermore, testing demonstrated that re-ignition can occur after removal and reinsertion of the nozzle due to internal short circuits. At this stage, the discussion does not focus on the specific design or manufacturer of the device, as many models exist and can be adapted relatively easily to address this type of fire risk.

Advantages:

- Battery cooling begins within one minute of nozzle insertion.

- A relatively small amount of water is required for suppression. The use of wetting agents can further reduce water consumption by improving wettability, a technique well known in Kazakhstan for extinguishing fires involving solid combustible materials. By altering surface tension, water penetrates more freely into all openings.

Disadvantages:

- Effective use of the piercing nozzle requires precise knowledge of the battery's location and the necessary insertion depth. Incorrect positioning may require adjustment.
- Cooling may be localized and not extend to the entire battery.
- Firefighters must approach close to the burning vehicle, increasing risk.
- The method requires specialized training and skill, making it most suitable for professional fire-service units or specialized teams.

Fire-Resistant Blanket

A fire-resistant blanket is used for extinguishing fires at an early stage and for suppressing smoke generation. Made of silicone fiberglass, these blankets are designed to cover passenger vehicles and can be particularly useful in road tunnels, assisting with evacuation and preventing the spread of fire to other vehicles.

In fire tests, BRAFA used a blanket measuring 6 × 8 m. The battery-induced fire developed rapidly, and the blanket was deployed eight minutes after ignition. By that time, however, the fire had already engulfed the entire vehicle. Despite correct deployment, flames and smoke emerged from beneath the vehicle due to thermal runaway in the battery, complicating efforts to keep the blanket in place.

According to the manufacturer, the blanket should remain on the vehicle for at least 20 minutes, but in practice it could only be maintained for two minutes because of the difficulty of use during an advanced fire. The blanket size proved insufficient, even for a compact vehicle. Moreover, despite claims of reusability, the blanket began tearing under high temperatures.

The manufacturer asserts that the blanket seals the vehicle and prevents oxygen access; however, this does not apply to electric vehicles, as combustion of the electrolyte inside the battery releases oxygen. While the blanket reduced temperature and smoke emission, complete fire suppression was not achieved, as evidenced by high CO levels detected by sensors.

For fires in open areas, the limited effectiveness of the blanket is less critical. For fires in enclosed parking facilities, Kazakhstan possesses firefighting equipment designed to remove and suppress smoke. Effective methods include smoke exhaust fans, vehicles supplying finely atomized water, temperatureactivated water mist (so-called “water fog”) from APM *PiRo* vehicles, and gas–water suppression vehicles. As noted previously, these firefighting tools are well known in Kazakhstan and, even if not applied directly at the fire source, can quickly create conditions for more effective firefighting in a parking garage scenario.

The focus is on identifying ways to maximize the operational potential of fire-service units. At the same time, it is recognized that existing procedures need to be updated or new methods developed to adapt current equipment to the realities of emerging types of fires.

The use of respiratory protection is critically important, particularly because the combustion of batteries produces highly toxic substances, including carbon monoxide, hydrogen fluoride, and hydrogen cyanide (prussic acid).

The presence of these hazardous compounds clearly necessitates careful planning for the deployment of comprehensive measures to protect the respiratory health of both personnel and the public from their harmful effects.

Advantages:

- The blanket reduces smoke emissions, which can be beneficial during the initial stage of evacuation.

Disadvantages:

- Difficult to use during advanced fires.
- Ineffective in the event of thermal runaway (flames escape from beneath the vehicle).
- Requires trained personnel for proper application.
- Limited durability under high-temperature conditions.

In this material, five methods for extinguishing electric-vehicle fires have been reviewed:

1. Water cooling
2. Battery-access hatch
3. Immersion in a water container
4. Use of a piercing nozzle
5. Fire-resistant blanket

Summary

1. Water Cooling with Mobile Firefighting Equipment

- The most acceptable and effective method for cooling the battery to stop or limit thermal runaway, and currently the only viable way to suppress battery fires.

- Requires a large volume of water; the use of wetting agents to reduce water consumption has not been sufficiently studied.

2. **Battery-Access Hatch**
   - A simple and effective method providing direct access to the battery.
   - Currently implemented by only one manufacturer.
   - The system's implementation is not yet fully optimized.

3. **Immersion in a Water Container**
   - Provides good protection against battery re-ignition.
   - High cost of the container and potential generation of large volumes of contaminated water make this a last-resort option.

4. **Piercing Nozzle**
   - Demonstrated effectiveness against thermal runaway, with temperature sensors showing rapid cooling after application.
   - Requires extensive training due to high-voltage hazards.
   - Variation in battery layout and design across vehicles complicates its use.

5. **Fire-Resistant Blanket**
   - Effective during the first few minutes of ignition, reduces smoke spread.
   - Difficult to handle and ineffective against thermal runaway due to oxygen release from the electrolyte.
   - Can be applied in underground parking facilities if personnel are properly trained.

The methods reviewed provide a general overview of electric-vehicle fire suppression techniques; however, further research and international experience are required to draw definitive conclusions, as EV fire-fighting remains a focus of active study worldwide.

Currently, the most common and familiar strategy for firefighters remains cooling the burning battery with standard water. Despite high water demand and limited cooling efficiency, this method is simple and does not require specialized equipment. Other methods are, in essence, also forms of water cooling, differing mainly in technique and the use of specialized equipment. The potential use of wetting agents to reduce water consumption warrants further investigation. Additional studies are also needed to determine the optimal water flow rates for cooling electric vehicles with various hose and nozzle configurations. The critical battery temperature at which thermal runaway ceases remains an open question. Development and implementation of a field-testing program are necessary to address these challenges.

Other important directions include updating departmental regulations on fire suppression and safety procedures when working with highly toxic substances, high-voltage systems, and areas of intense thermal exposure.

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