CONSEQUENCES FROM LARGE EV FIRES IN A TUNNEL – A DACH RESEARCH ACTIVITY

[1]Daniel Fruhwirt, [1]Alexander Kores, [2]Robert Galler, [2]Robert Wenighofer, [3]Bastiaan Lotmann, [4]Simon Frey, [5]Christian Thienert, [5]Frank Leismann, [6]Christoph Schneider [6]

[1]Graz University of Technology, AT
[2]Technical University of Leoben, AT
[3]ILF Consulting Engineers Austria GmbH, AT
[4]HBI Haerter AG, CH
[5]Studiengesellschaft für Tunnel und Verkehrsanlagen – STUVA – e. V., DE
[6]WSP Switzerland, CH

DOI 10.3217/978-3-99161-087-8-036 (CC BY-NC 4.0)

ABSTRACT

In recent years, battery-electric vehicles have reached a significant market share. Although this statement mainly refers to passenger car applications, meanwhile e-mobility has also reached heavy duty vehicles and buses. Many research activities have been conducted in order to evaluate the fire characteristics and the hazards posed by EVs. Available data from full-scale testing of small BEVs show no significant increase of risk compared to fires of conventional vehicles. However, there is only little information available about the fire risk of large EVs. For this reason, the DACH research area has initiated a dedicated research project in order to evaluate the fire characteristics of battery-electric trucks and its consequences for road tunnel safety. A key element of the DACH research activity is to perform a full-scale fire test of an EV truck in a road tunnel environment. Thereby, assessing both the consequences for tunnel users and the tunnel structure. This paper provides a comparative overview of today´s EV landscape and an introduction to the eTRUCK-DACH project.

1. INTRODUCTION – THE EVOLUTION OF VIDEO ANALYTICS

E-mobility is a key element of the transition of mobility towards more sustainability, by eliminating tailpipe emissions. In recent years the number of battery electric vehicles on European roads has steadily increased. In 2025 the share of newly registered EV passenger cars was 20%. The total number of registered EV passenger cars in the European Union has reached 7.7 million and another 5 million for plug-in hybrid vehicles.

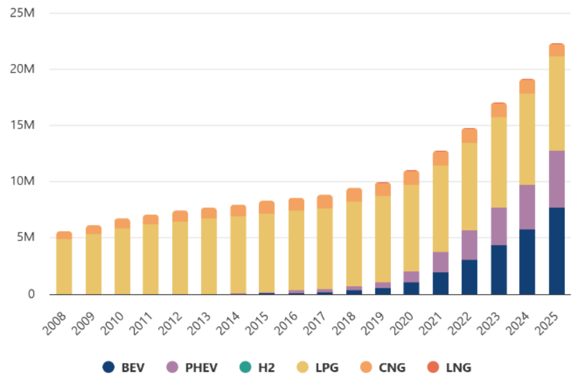

Figure 1: Number of registered alternative fuel vehicles in the European Union - passenger cars [1]

The number of large BEVs on European roads is significantly lower, although the number of newly registered vehicles strongly increases. According to the European Alternative Fuel Observatory [1], in 2025 12.300 BEV trucks have been registered, leading to a total number of 26.000 registered vehicles.

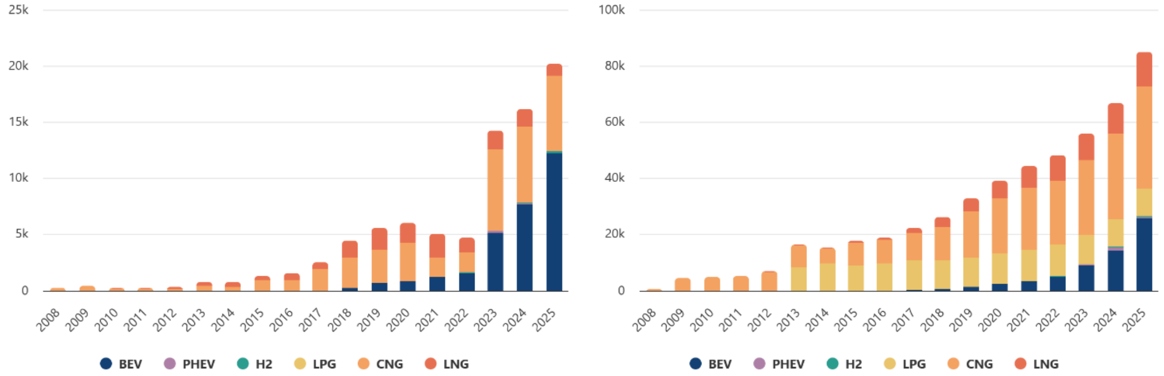

Figure 2: left – new registrations of alternative fuel trucks in the European Union,
right – total number of registered alternative fuel truck in the European Union [1]

These numbers showcast the trend in European mobility and highlight the need for an evaluation of safety concepts, which are mainly based on experiences with incidents involving conventional vehicles. Therefore, the D-A-CH region, who comprises the transport authorities of Germany, Austria and Switzerland has initiated a dedicated research project in order to scientificly investigate the fire characteristics of EV trucks in a road tunnel.

2. CHARACTERISTIC OF LARGE BATTERY-ELECTRIC VEHICLES

2.1. Battery technology

Modern electric vehicles predominantly use lithium-ion batteries because they offer higher volumetric energy density (capacity per cubic meter) and much lower self-discharge than legacy chemistries such as lead–acid, nickel–cadmium, or nickel–metal hydride. A lithium-ion cell comprises a negative and a positive electrode (whose roles as anode/cathode swap between charge and discharge), an electrolyte that enables lithium-ion transport, and a separator that electrically insulates the electrodes. The most common cathode chemistries include lithium iron phosphate (LFP), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium nickel cobalt aluminum oxide (NCA), and lithium nickel manganese cobalt oxide (NMC/NCM). NMC variants are defined by their Ni:Mn:Co ratios, for example NMC 111/333 with equal thirds and NMC 811 with an 80/10/10 split.

Compared with LFP, NMC cells typically provide higher nominal voltage and energy density. Nominal cell voltage is about 3.3 V for LFP and 3.7 V for NMC. Volumetric energy density is roughly 190–300 kWh/m³ for LFP versus about 325 kWh/m³ for NMC, while gravimetric energy density spans about 90–120 kWh/t for LFP and roughly 150-280 kWh/t across NMC variants (111/333, 622, 811). As a result, for the same size, NMC batteries offer approximately 10–70% more capacity at lower weight. Cost differences remain: in 2023, LFP averaged about $100 per kWh versus about $132 per kWh for NMC (roughly 30% higher), reflecting manufacturing complexity and the use of critical raw materials. Safety, however, favors LFP, which is more chemically stable and less prone to severe reactions under abuse.

Thermal runaway data from multiple studies (e.g., [2][3]) show lower onset temperatures for NMC cells, typically around 150–200°C, compared with about 270°C for LFP. At the module level [2], NMC modules initiated runaway near a surface temperature of approximately 370°C and propagated completely within about 390 s, whereas LFP modules initiated around 435°C and took roughly 1,850 s to fully propagate. These differences underline that battery chemistry strongly influences the fire hazard profile of BEVs. Market adoption also varies by region: in Europe, NMC dominates with roughly 95% of installed capacity, while globally NMC accounts for about 60%. OEMs deploy both chemistries (e.g., LFP by Mercedes and NMC by MAN).

2.2. System architecture

Battery technology has developed rapid in recent years and has reached all road applications. Nevertheless, the requirements on the battery technology differ significantly between passenger cars and trucks. This mainly refers to the required battery capacity to reach acceptable ranges. While the battery capacity of a common passenger car is 35 – 90 kWh, EV trucks require significantly larger batteries of 300 – 1000 kWh. In consequence, the system architecture of the applications varies. First of all, the battery of a EV passenger car commonly comprises one single battery pack, installed between the front and the rear axle. As an example the battery pack layout as well as the system layout of the AUDI etron is depicted in **Figure 3**

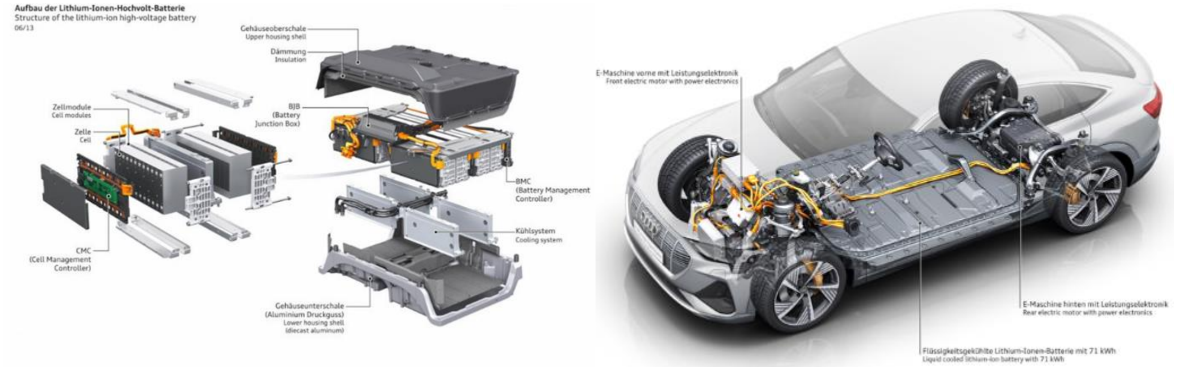

Figure 3: left – layout of a battery pack for passenger car applications,
right – system configuration of the AUDI eTron [4]

In contrast, the battery of an EV truck usually is divided in several battery packs installed at different positions. The exact layout is subject to manufacturers preferences. As an example, **Figure 4** illustrates the layout of a MAN battery pack and the arrangement of packs on an MAN eTGX truck. Battery packs of trucks are usually arranged in multiple layers. This is due to limitations in available space and to achieve highest possible battery capacity. The MAN truck depicted in **Figure 4** comprises six battery packs (either NMC 622 oder NMC 811), one situated beneath the cabin, one rear the cabin and four more packs at the location of the tanks of conventional trucks. The total battery capacity is 480 kWh.

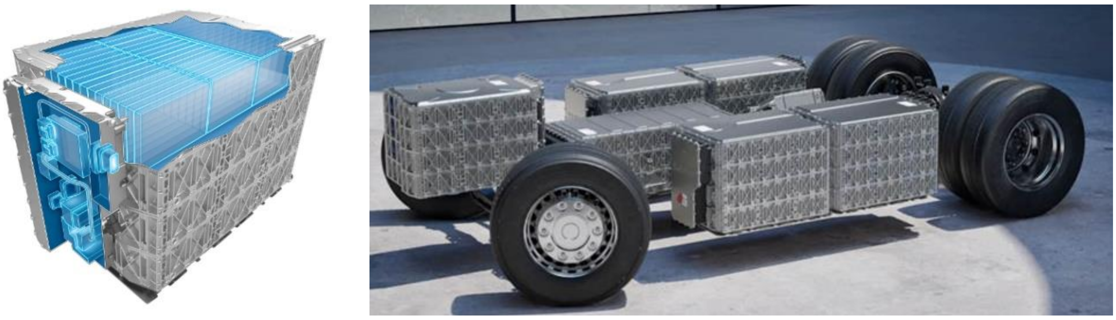

Figure 4: left – Battery pack layout, right- arrangement of battery packs on a MAN truck [5]

AS a comparison, **Figure 5** shows the EV trucks of Designwerk (member of Volvo Group) as well as the Mercedes eActros 600. Both trucks comprise three battery packs. However, the capacity of the Designwerk is 1017 kWh (NMC) and the capacity of the eActros is 621 kWh (LFP). Another difference of these vehicles is the arrangement of battery packs. While the Designwerk has its packs installed rear the cabin and laterally between the first and second axles, the eActros follows a contrary architecture by having the battery packs installed between the axles and 90° to the truck´s longitudinal axis.

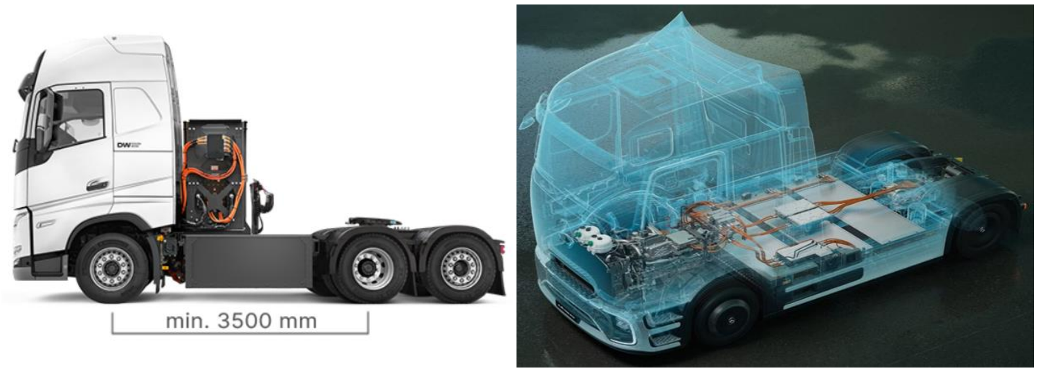

Figure 5: left – system architecture of a Designwerk truck [6],
right – system architecture Mercedes eActros 600 [7]

The presented trucks already demonstrate the variety of system configuration of EV trucks, which already suggest that different fire development can be expected for these trucks. Furthermore, large differences in system architecture make firefighting more difficult.

2.3. Hazards posed by large EVs

2.3.1. Fire dynamics

The heat release of a vehicle fire can be assessed theoretically and experimentally. Theoretical derivations (e.g., [8], [9]) are highly sensitive to assumptions about fire spread between battery modules and, for trucks in particular, about fire spread to the cargo—areas where data are scarce, making predictions uncertain. This approach is discussed in detail in Chapter 2.3. Experimental work to date has mostly focused on single battery modules or vehicles with battery capacities smaller than those of heavy-duty trucks. These tests indicate that heat release rates (HRR) of battery electric vehicles (BEVs) and conventionally powered vehicles are not fundamentally different; however, more recent programs [10][12]have reported up to 30% higher peak HRR for BEVs, a difference suspected to stem from the higher battery capacities [3].

When considering total heat release (THR), a clear correlation with battery capacity emerges. As a first-order estimate, 1 kWh is approximately 50,000 kJ of total released heat. Thus, an electric truck with a 600 kWh battery would yield roughly 30 GJ of THR, excluding any contribution from cargo. By comparison, conventional truck fire tests [11] measured total heat releases of 87 GJ, and 64 GJ in a follow-up test without the tractor. While the setups are not directly comparable, the implied contribution of the tractor unit in the conventional scenario is of a similar order of magnitude to that of an electric tractor unit (about 23 GJ versus approximately 30 GJ). These findings underscore both the dependence of HRR/THR on battery capacity and the importance of robust assumptions about fire spread when projecting outcomes for heavy-duty BEVs.

2.3.2. Toxic release

Multiple studies including [12] on combustion gases from large-scale EV fire tests, [13] on the effect of heating rate on degassing and combustion of cylindrical Li-ion cells, [14], and [15] show that BEV fires produce higher concentrations of hydrogen fluoride (HF; hydrofluoric acid in aqueous form) and elevated levels of battery-specific metals such as cobalt, nickel, and manganese when compared with internal combustion engine (ICE) vehicle fires. Special attention is required for extinguishing and cooling water, which can become a significant vector for dissolved HF and metal contamination. Despite these battery-related toxicants, carbon monoxide (CO) remains a critical hazard for tunnel users in BEV fire scenarios, similar to conventional vehicle fires.

2.3.3. Challenges in fire fighting

For practical firefighting, the vehicle’s propulsion type (ICE versus BEV) is not the primary determinant of incident response strategy. Equally important are the typical timelines between incident onset and the start of effective suppression—often up to 30 minutes, depending on access and the duration of external rescue phases. By that time, thermal runaway in the battery is largely complete and the event has typically transitioned from a battery fire to a conventional vehicle fire. Nevertheless, directly introducing water into the battery can create additional hazards for responders. Correctly identifying the vehicle as an EV and knowing the battery’s location and compartmentalization remain critical. Fully extinguishing a battery fire is generally not feasible, but cooling can significantly reduce reaction rates; flooding the battery with water is the most effective approach. Batteries positioned deep within the vehicle diminish the effectiveness of traditional hose streams as well as sprinkler or water-mist systems. Post-incident, the vehicle wreck and especially the battery require special handling. In Switzerland, the Federal Roads Office (ASTRA), together with Auto-Strassenhilfen-Schweiz, has issued guidelines for dealing with EV wrecks [16].

2.3.4. Resilience of tunnel infrastructure

Existing studies [14][15] do not indicate an inherently higher risk to tunnel infrastructure from battery electric vehicle (BEV) fires compared with conventional vehicle fires; however, this conclusion is based on tests with battery capacities far smaller than those of electric heavy trucks (about 80 kWh versus 600-1,000 kWh). Owing to the substances released during BEV fires, more extensive treatment of extinguishing water and more comprehensive post-incident cleaning are required, which directly affect the need for retention basins and increase the duration of tunnel downtime. Moreover, the potential impact of flames emerging in the underfloor area on cut-and-cover tunnel structures—particularly the structural stability of the central wall—and on utility ducts beneath the roadway remains an open question to be addressed by the eTruch-DACH research project.

3. DACH RESEARCH PROJECT

The DACH research track is a joint Germany–Austria–Switzerland initiative that prioritizes harmonized, practice-oriented research with direct utility for operators, regulators, and industry. Its core principles include cross-border collaboration and shared funding, standardised methods to ensure comparability and reproducibility, and scalability from laboratory to full-scale trials. It emphasizes evidence-based risk assessment, safety and resilience of critical infrastructure, and rapid knowledge transfer into guidelines and standards. The program fosters open dissemination, stakeholder involvement across academia and industry, alignment with European and international standards, and technology-neutral, sustainability-focused solutions that can be implemented consistently across the DACH region.

Originating from the DACH research call 2024, eTruckDACH represents a research project with focus on the consequences of an EV Truck fire in a road tunnel. The project´s aim is to provide detailed information about the fire characteristics and ist consequences for tunnel users and tunnel structure based on experimental data derived from full-scale testing, thereby answering a set of research questions.

3.1. Research Questions

The fire load of a truck strongly depends on the cargo, which in most cases is decisive for peak heat release rates (HRR) as well as total energy released (TER). The powertrain itself and in particular the energy carrier most likely contributes to the fire growth and fire dynamics, but is not the dominant element for HRR and TER. Obviously, the main research question in eTruckDACH is:

Are traction batteries oft rucks a gamechanger in terms of fire propagation towards the cargo?

Attached to this question, several other questions have been raised in the context of large EV fires in road tunnels:

- What can/must be considered “proper firefighting,” and how do fires involving large electric vehicles differ from fires involving electric passenger cars under various tunnel conditions?
- How can the protection of responders and the load-bearing tunnel structure be ensured during hard-to-extinguish large fires involving batteries? Which boundary conditions must be considered for potential rescue measures in fires involving large electric vehicles (ventilation fundamentals, tunnel geometry, risk of intermediate ceiling collapse, smoke spread, etc.)?
- How does battery fire propagation to potentially fire-prone cargo with high fire load occur, and which preventive measures can be taken in advance to avoid such spread (e.g., simultaneous battery cooling and prevention of spark transfer to the cargo during recovery, possible tractor/trailer separation devices)?
- How can recovery and removal of accident vehicles be ensured in confined environments (while simultaneously implementing stabilizing measures for the battery)?
- Battery fires generate toxic gases and thereby deposits (especially heavy metals) on tunnel structures. This gives rise to the following questions:
    - Which additional measures, beyond those already in place, can be provided to protect the environment from contamination?

    - By what means can fires involving large electric vehicles—or their impacts—in tunnels be fundamentally prevented/limited/combated (from adaptations to respiratory protection to the use of retention basins, etc.)?
    - What role do location (urban or rural) and/or tunnel design play in the choice of possible protection or firefighting measures?
    - Existing technical developments for passenger cars to contain battery fires include, for example, containers/cooling bags or piercing lances for water injection into the battery housing. What is the state of such measures for fires involving large electric vehicles in tunnels?
- Which factors must be considered for tunnel closures/permits for large electric vehicles? Do these differ from those for general transports and/or hazardous-materials transports with combustion-engine vehicles?

eTruckDACH aims at answering all aforementioned questions by conducting a full-scale fire test including advanced analysis methods, comprehensive risk analysis, analysis of structural impact, interviews with firefighters, etc.

4. CONCLUSIONS AND OUTLOOK

Past research activities have demonstrated that EVs do not cause a severe increase of risk in the context of road tunnel safety. However, this statement is limited to passenger cars, as for large EV applications no published solid data exist. In order to keep the safety of road tunnels on a high level, the DACH research track has initiated a dedicated research project that will provide evidence-based statements regarding the consequences for tunnel users and tunnel structure posed by a EV truck fire. The key element of this research activity is a full-scale fire test in a road tunnel environment, which aims at investigating the development of a fire starting in the batteries. The main question in that context is, if the batteries accelerate the fire propagation to the cargo, thereby causing a more rapid fire growth and reducing the available time to escape and to intervene respectively. Subsequent investigations also focus on the performance of passive fire protection solutions such as fire protection panels and mortar, the implementation of large EV fire scenarios in a road tunnel risk assessment framework, development of strategies for firefighters and transfer of results to similar infrastructures such as bridges and underpasses. By reducing the large uncertainties associated with large EV fires in tunnels, the eTruckDACH project represents a significant contribution to sustainably ensure safe road tunnels.

REFERENCES

[1] European Commission, European Alternative Fuels Observatory, 2026; https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/vehicles-and-fleet [accessed: 28.03.2026]

[2] Schöberl, J., Ank, M., Schreiber, M., Wassiliadis, N. & Lienkamp, M. (2024) Thermal runaway propagation in automotive lithium-ion batteries with NMC-811 and LFP cathodes: Safety requirements and impact on system integration. eTransportation, 19, p. 100305. doi: 10.1016/j.etran.2023.100305.

[3] Fößleitner, P. (2024) Challenges of alternative fuel vehicles and their impact on safety in road tunnels. PhD Thesis. Graz: University of Technology Graz. doi: 10.3217/mk26s-s1544.

[4] Audi AG (2018), *Audi e-tron drivetrain and battery system (technical illustration)*. Available at: https://www.audi-mediacenter.com (Accessed: 29 March 2026).

[5] MAN Truck and Bus SE; Der neue MAN eTGX: Der eTruck für die Langstrecke; Website, 2026; https://www.man.eu/at/de/lkw/alle-modelle/der-man-tgx/der-man-etgx/uebersicht.html [accessed: 29.03.2026]

[6] Designwerk Technologies AG; HIGH CAB - Der E-LKW für weite Strecken, Website, 2026; https://www.designwerk.com/elektro-lkw-high-cab/ [accessed: 29.03.2026]

[7] Daimler Truck AG, eActros600 - ProCabin , Website, 2026; https://www.mercedes-benz-trucks.com/at/de/trucks/eactros.html#layer-eactros-600-procabin [accessed: 29.03.2026]

[8] Voigt, S., Pahl, M., Lienenlüke, S., Berger, A. and Bräuer, A. S. (2023) ‘An empirical model for lithium-ion battery fires for CFD applications’, *Fire Safety Journal*, 135, p. 103725. doi: 10.1016/j.firesaf.2022.103725.

[9] Ingason, H., Li, Y.Z. and Lönnermark, A. (2015) Tunnel Fire Dynamics. Cham: Springer. doi:10.1007/978-1-4939-2199-7.

[10] Sturm, P. Fößleitner, P., Fruhwirt, D., Galler, R., Wenighofer, R., Heindl, S.F., Krausbar, S., Heger, O.; Fire tests with lithium-ion battery electric vehicles in road tunnels, Fire Saf. J., 134 (2022), Article 103695, 10.1016/j.firesaf.2022.103695

[11] Haack, A. (1998) Fire protection in traffic tunnels: General aspects and results of the EUREKA project. Tunnelling and Underground Space Technology, 13(4), pp. 377–381. doi: 10.1016/S0886-7798(98)00080-7

[12] Hynynen, J., Willstrand, O., Blomqvist, P. and Andersson, P. (2022), Analysis of combustion gases from large-scale electric vehicle fire tests, Fire Safety Journal, 131, 103597. https://doi.org/10.1016/j.firesaf.2022.103597

[13] Goupil, V., Gaya, C., Boisard, A. and Robert, E. (2022), Effect of the heating rate on the degassing and combustion of cylindrical Li-Ion cells, Journal of Power Sources, 523, 231030. https://doi.org/10.1016/j.jpowsour.2022.231030

[14] Sturm, P.-J., Fößleitner, P., Fruhwirt, D., Heindl, S.F., Kohl, B., Heger, O., Galler, R., Wenighofer, R. and Krausbar, S. (2021), BRAFA – Brandauswirkungen von Fahrzeugen mit alternativen Antriebssystemen: Ergebnisbericht. Graz: Technische Universität Graz, Institut für Verbrennungskraftmaschinen und Thermodynamik. https://doi.org/10.3217/8vj91-gc832

[15] Mellert, L.D., Welte, U., Tuchschmid, M., Held, M., Hermann, M., Kompatscher, M., Tesson, M. and Nachef, L. (2020), Risk minimisation of electric vehicle fires in underground traffic infrastructures. Final report AGT Project 2018/006. Zurich: Swiss Association of Road and Transport Experts (VSS)

[16] ASTRA & BTVE Working Group (2022) Guideline for the recovery, transportation, storage and disposal of vehicles with electric drive [PDF]. Bern: Bundesamt für Strassen (ASTRA). Available at: https://www.astra.admin.ch/dam/astra/de/dokumente/abteilung_strassenverkehrallgemein/btve-leitfaden-efahrzeuge-entsorgung.pdf.download.pdf/leitfaden-bergung-transport-verwahrung-entsorgung.pdf [Accessed: 29.03.2026].