RESEARCH BRIEF

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Approaches to mitigate electric vehicle fire risks in enclosed spaces

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Background

On May 17, 2023, the International Zero Emission Vehicle Alliance (IZEVA) held a deep-dive session on electric vehicle (EV) fire safety in enclosed spaces. Such sessions provide a platform to facilitate deep knowledge sharing on one specific and timely topic. Each year, IZEVA members submit topic ideas which are then voted on by the other members. This is a summary of the May session.

Introduction

With more than 14 million light-duty EVs sold in 2023, including 9.9 million battery electric vehicles (BEVs) and 4.2 million plug-in hybrid vehicles (PHEVs), the global transition to EVs is progressing.[1] Nonetheless, consumers may have questions or concerns about EV technology. For example, recently, there have been questions about the possibility of EV lithium-ion batteries catching fire, particularly in enclosed spaces such as garages.

Compared to fires involving traditional internal combustion engine (ICE) vehicles, EV fires present different risks. Specifically, EV fires could be associated with specific risks like leakage of toxic chemicals from electrolytes, fire residue formation, or explosion hazards. These risks may be of greater concern in parking garages due to the high plastic content and larger sizes of modern vehicles (which may park closer together).[2] Firefighters also face new challenges when combating EV fires, including reignition risks, difficulty accessing batteries, or the need for additional personnel to remove an EV from a parking garage.

Governments across the globe have started deploying measures to mitigate EV fire risks and ensure they do not hinder the EV transition. These measures spread across different domains, including research, policies, regulations, and firefighter response procedures.

1 EV-Volumes. (2024). EV Data Center. http://www.ev-volumes.com/datacenter/.

2 Haavard Boehmer, Michael Klassen, M., and Stephen Olenick, *Modern Vehicle Hazards in Parking Structures and Vehicle Carriers* (Quincy, Massachusetts: Fire Protection Research Foundation, 2020), https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Building-and-life-safety/RFModernVehicleHazards-in-ParkingGarages.pdf.

Causes and frequency of EV fires

As with ICE vehicles, EVs can catch fire for different reasons, such as manufacturing defects, battery damage from collisions, short circuits caused by submersion in floodwaters, use of faulty chargers, or intentional acts like arson. However, the causes of most reported EV fires are unknown due to inadequate reporting or ongoing investigations.[3] EV FireSafe, a privately funded company supported by the Australian government, monitors global EV fires. According to their data as of September 2023, the distribution of EV fire causes is as follows: unknown, 48.25%; collisions, 23%; original equipment manufacturer (OEM) faults, 11%; submersion, 6%; external fire, 4%; arson, 3%; repair/workshop-related, 2%; repair, 2%; overheating, 2%; manufacturing defect, 0.5%; and human error, 0.25%.[4]

Existing data and literature indicate that EV fires are rare but could become more frequent as the EV stock grows and ages. According to an EV FireSafe study, from 2010 to June 2023, there were 488 light duty EV fires globally, of which 393 (78%) were verified EV lithium-ion battery fires.[5] The study points out that as the EV market continues to grow, the number of EV fires is expected to increase. This is illustrated in Figure 1, where the x-axis shows the number of fires and the y-axis the year they occurred. The larger numbers of fires in 2020 and 2021 are primarily attributable to the Chevrolet Bolt and Hyundai Kona, which were recalled due to a battery defect that occurred during manufacturing.

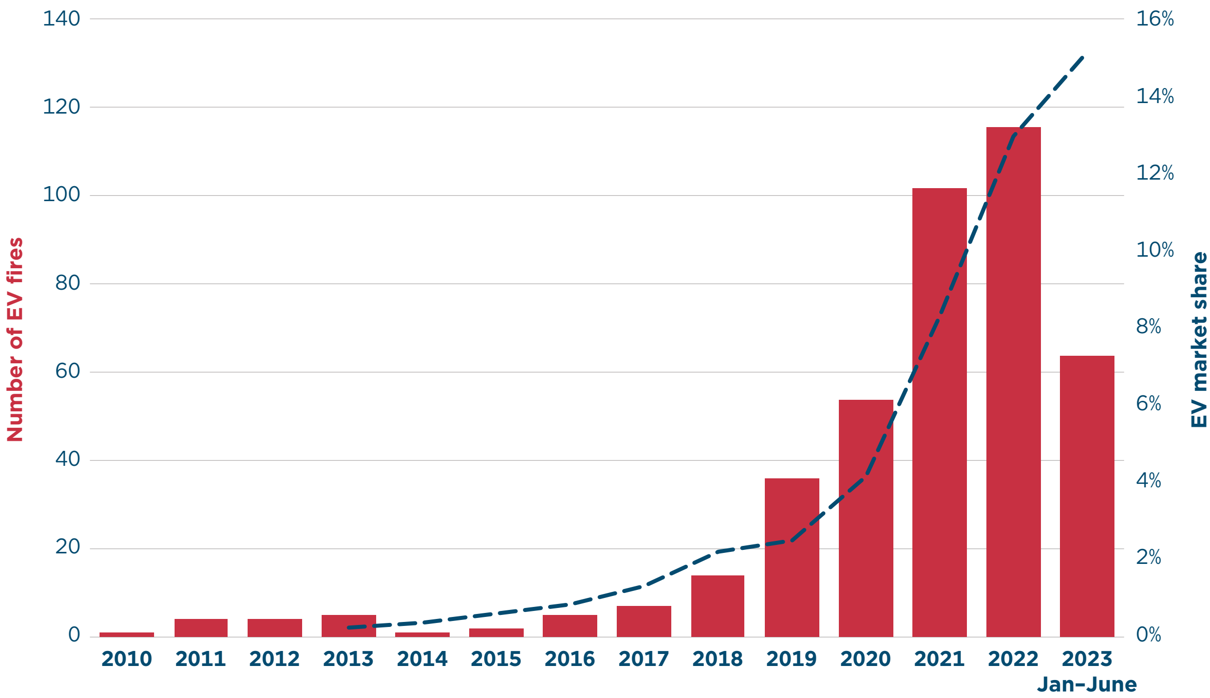

Figure 1. Number of light-duty EV fires by year and EV global market share (source: EV FireSafe).

3 "Compilation of Fires in Electric Vehicles and Electric Means of Transport in 2018–2022," Swedish Civil Contingencies Agency, 2023, https://www.msb.se/sv/publikationer/sammanstallning-av-brander-i-eltransportmedel-2018-2019/; "How Common Are EV Fires," EV Fire Safe, 2023, https://www.evfiresafe.com/post/how-common-are-ev-fires; Sun, Peiyi, Roeland Bisschop, Huichang Niu, and Xinyan Huang, "Correction to: A Review of Battery Fires in Electric Vehicles," *Fire Technology*, February 2020. https://doi.org/10.1007/s10694-020-00958-2.

4 Data shared by EV FireSafe.

5 "What Is an EV Battery Fire?," EV Fire Safe, 2023, https://www.evfiresafe.com/electric-vehicle-fires.

Few studies have investigated how EV fires compare to ICE vehicle fires. Tesla (2019) reported that from 2012–2021, one of its vehicles caught fire every 210 million miles (338 million km) traveled. [6] By comparison, data from the National Fire Protection Association (NFPA) and the U.S. Department of Transportation indicates one vehicle fire for every 19 million miles (31 million km) traveled in the United States (across all powertrains).[7] Linja-aho (2020) found that in Finland, the annual incidence of fires per 10,000 EVs ranges from 0–1.1 for hybrid electric vehicles (HEVs) and PHEVs, and from 0–5.2 for BEVs. This compares to 4.7 fires per 10,000 passenger vehicles across all powertrains, suggesting that HEVs and PHEVs experience significantly fewer incidents compared to the average for all passenger vehicles, while BEVs exhibit a similar order of magnitude (i.e.,4.7 fires per 10,000 passenger cars).[8] In Norway, data collected from 3 Norwegian insurance companies indicate that EVs represented less than 5% of total passenger vehicle fires from 2006–2016.[9] Finally, in Sweden, the Civil Contingencies Agency found that from 2018–2022, a total of 81 BEVs and PHEVs caught fire, compared to 656 ICE vehicles.[10]

Though limited, these data show that EV fires are less common than ICE vehicle fires. However, it is important to stipulate that the ICE vehicle fleet is larger and older than the EV fleet; and studies have shown that the risk of catching fire in ICE vehicles tends to increase as vehicles age.[11] It will, therefore, be important to monitor whether a similar trend emerges for EVs, which were only introduced in the early 2010s.

Research initiatives to better understand the risks of EV fires

The relative novelty of EV fires suggests that more needs to be learned regarding their causes and their risks to human life and material goods. Within this context, several jurisdictions have launched research initiatives that could inform EV fire risk mitigation strategies.

Australia: Fire and Rescue NSW (FRNSW) is the official state government agency responsible for fire, rescue, and hazardous material services in New South Wales. In 2022, FRNSW launched the Safety of Alternative and Renewable Energy Technologies (SARET) research program, a 2-year initiative to shed light on the risks associated with lithium-ion battery fires.[12] SARET is organized into four research streams:

1. Fire service response to lithium battery fires: To evaluate the efficiency of new products to extinguish lithium-ion battery fires relative to water use. Additionally, the research aims to develop guidance on the effectiveness of current personal protective equipment and clothing in safeguarding firefighters from exposures to gases, vapors, liquid electrolytes, chemical residue, and electrical energy found.

6 "Tesla Vehicle Safety Report," Tesla, 2019, https://www.tesla.com/VehicleSafetyReport.

7 "Impact Report 2020," *Tesla,* 2020, https://www.tesla.com/ns_videos/2020-tesla-impact-report.pdf.

8 Vesa Linja-aho, "Hybrid and Electric Vehicle Fires in Finland 2015-2019," SESKO, December 15, 2020, https://www.ri.se/sites/default/files/2020-12/five-linja-aho-version-3.pdf.

9 Roeland Bisschop, Ola Willstrand, Francine Amon, and Max Rosengren, *Fire Safety of Lithium-Ion Batteries in Road Vehicles* (Borås, Sweden: RISE Research Institutes of Sweden, 2019), https://www.researchgate.net/publication/336640117_Fire_Safety_of_Lithium-Ion_Batteries_in_Road_Vehicles.

10 Swedish Civil Contingencies Agency, "Compilation of fires in electric vehicles and electric means of transport in 2018–2022," 2023, https://www.msb.se/sv/publikationer/sammanstallning-av-brander-i-eltransportmedel-2018-2019/.

11 National Highway Traffic Safety Administration, "Motor Vehicle Fires in Traffic Crashes and the Effects of the Fuel System Integrity Standard," (November 1990), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/807675; Michael Spearpoint, "Analysis of Vehicle Fire Statistics in New Zealand Parking Buildings," Fire Technology 43, no. 2 (June 1, 2007): 93–106. https://doi.org/10.1007/s10694-006-0004-2.

12 Fire and Rescue NSW, *Safety of Alternative and Renewable Energy Technologies (SARET) Research*, accessed July 26, 2023, https://www.fire.nsw.gov.au/page.php?id=9395.

2. End-of-life lithium battery hazard management: To provide information on hazard management practices regarding battery recycling, handling, storage, and transportation of damaged, fire-affected lithium-ion batteries. The information aims to minimize the risks of exposure to secondary ignitions for first and second responders.

3. EV fires in structures: To examine the specific difficulties posed by EV fires in parking garages and car parks. The study aims to quantify the distinctions between BEVs and ICE vehicles regarding fire severity and propagation, building performance, detection and suppression requirements, air handling, and ventilation, among other elements.

4. Fire propagation in energy storage systems: To understand the fire propagation behaviors exhibited by battery energy storage systems and inform the development of guidelines for the separation, detection, and protection requirements for new installations, from residential to commercial and grid-scale applications.

Austria: In 2021, the Graz University of Technology led a large-scale research initiative to understand the risks associated with EV fires on tunnel roads.[13] The study aimed to answer several questions, including what happens when a battery catches fire in a tunnel, how hot it gets, what gases are produced, and what risks are involved for people. Researchers ignited several modules of an EV battery, three electric cars and vans, and two diesel-powered cars and vans to test different methods for fighting EV battery fires. The study found that:

- Tunnel road infrastructure can withstand the fire load and heat generated by an EV battery.
- EV fires in tunnels burn marginally hotter than those involving ICE vehicles: EV fire heat release was measured at 6–7MW, compared to 5MW for ICE vehicles.
- Fires produce high levels of gases and heavy metals which collect on the upper side of the tunnels; they, therefore, do not affect people on the ground. This is due to the advanced ventilation systems integrated into tunnel roads, which typically do not exist in parking garages (where risk will be more significant and more research needs to be conducted).
- Finally, of the extinguishing methods tested, firefighting with water proved more effective if the water could reach the inside of the battery. Extinguishing lances proved particularly effective; however, firefighters need to be specifically trained to use this equipment.

Canada: The National Research Council Canada (NRC), in collaboration with Transport Canada, has researched lithium-ion battery thermal runaways and their fire risks. Large-scale tests have been conducted in airports, where, in many instances, a fire occurred. The research led to the development of a test methodology, which, as of 2023, the International Organization for Standardization (ISO) lists as a standard thermal runaway test methodology.[14] Discussions are also taking place under the UN Global Technical Regulation platform (UN GTR) where a standard could be proposed for a rapid heating test methodology informed by NRC work.[15]

13 "Großversuch: E-Autos sind bei Bränden in Tunneln keine erhöhte Gefahr," *Innovation & Technologie*, (October 13, 2021). https://infothek.bmk.gv.at/grossversuch-e-autos-bei-braenden-in-tunneln-keine-erhoehte-gefahr/.

14 International Organization for Standardization, *ISO 6469-1:2019/Amd 1:2022.* Accessed August 1, 2023, https://www.iso.org/standard/73574.html.

15 Information shared during the EV fire deep-dive session and through email; For more on the rapid heating test methodology proposed by NRC, see *Thermal Runaway Initiation Methodology (TRIM): A Leading-Edge Technology Solution to Improve the Safety of Battery Systems*, National Research Council of Canada (2020), https://nrc-publications.canada.ca/eng/view/ft/?id=c32c4684-53e8-422e-9cf5-2845bbe92f33.

While EV fire safety research and testing are needed, NRC identifies funding as a major barrier to these efforts (e.g., high equipment costs, including the purchase of EVs). Furthermore, because EV fires can develop in many ways, the systems deployed at testing sites might not always be well adapted. Such concerns about funding and practicality have led to hesitation among other agencies in Canada to engage more proactively in research efforts.[16]

United States: NFPA is a U.S based international non-profit organization that aims to prevent fatalities, injuries, and property and economic damage caused by fire, electrical, and associated risks. In 2010, NFPA conducted research to evaluate emergency responders' experience and readiness to address EV fires. Their finding that most firefighters were not trained on EV fires motivated the creation of the "U.S. Emergency Responder Safety Training for Advanced Electric Drive Vehicles" training and education program supported by a grant from the U.S. Department of Energy.[17]

The U.S. National Highway Traffic Safety Administration (NHTSA) is also active in this space and has launched the Battery Safety Initiative for Electric Vehicles to collect data and coordinate research and activities efforts among relevant stakeholders. Part of its data collection efforts includes examining field incidents. NHTSA is also investigating battery manufacturing defects and their relation to fire incidents.[18]

While these initial research efforts provide helpful data, more research is needed to build the body of knowledge required to inform EV fire risk mitigation strategies. Securing investments to conduct such research will, therefore, be important.

Regulation, policy, and standard approaches

Recognizing the increasing risk of EV fires as the EV market continues to grow, several governments are developing or implementing policies, standards, and regulatory measures to address EV fire risks more effectively.

Austria: In June 2023, the Austrian government revised its building legislation (now referred to as OIB Richtlinie 2.2), which introduced restrictions on EV charging stations in parking garages for the first time; it mandates charging stations be protected from collision hazards and prohibited them in garages only accessible by elevator (due to increased access difficulties). Furthermore, the legislation stipulates that charging stations with power greater than 22kW could only be installed in single-story garages of less than 250 m^2 or with sprinkler systems and automatic emergency shutdown devices. Alternatively, they could be installed in parking garages with automatic fire system alarms and emergency shutdown devices and need to be placed near garage entrances so firefighters can easily remove EVs.

The legislation also restricts charging stations with integrated energy storage systems. They can only be installed in small garages (less 250 m^2) with a storage unit of less than 100 kWh which has passed a fire propagation test. Finally, a fire protection plan (e.g., mapping charging station locations and emergency charging station shutdown devices) is required to be developed for

16 Information shared during the EV fire deep-dive session.

17 "Alternative Fuel Vehicle Training," National Fire Protection Association, 2023, https://www.nfpa.org/for-professionals/training-for-me/alternative-fuel-vehicles-training/.

18 "Battery Safety Initiative," National Highway Traffic Safety Administration, 2023, https://www.nhtsa.gov/battery-safety-initiative.

garages of more than 250 m^2. The fire protection plan serves as a strategy tool that informs firefighters' interventions in case of an EV fire.[19]

China: In 2020, the government of China announced "Electric Vehicles Traction Battery Safety Requirements," which went into effect in January 2021. These requirements are meant to optimize the safety of battery cells and modules by requiring stricter requirements on thermal diffusion, mechanical shock, external short-circuit, overheating, and overcharging, among other elements. Standards require that the battery system not catch fire or explode within 5 minutes after a battery cell undergoes thermal runaway, leaving sufficient time for EV passengers to leave the vehicle.[20]

Netherlands: Under the National Charging Infrastructure Agenda, a taskforce was created to bring together governments, fire specialists, and relevant organizations to address EV fire safety. The taskforce's role is to investigate, advise policymakers, and inform stakeholders about EV safety.[21] In 2021, the Institute of Fire Safety collaborated with firefighter brigade agencies to identify measures for increased fire safety in indoor EV charger-enabled parking garages. Those measures represent general guidance to be adapted to specific circumstances (e.g., garage construction materials, layout, etc.). They are classified under four categories:[22]

1. *Architectural:* Various measures can be implemented to protect buildings from multiple forms of fire development, including long-term fires, reignition incidents, and flare fires. One approach could involve enhancing the protection of building structures near parking areas equipped with chargers. To decrease the likelihood of fires, charging stations can be equipped with collision protection or placed in areas where collisions are unlikely.

2. *Installation:* Precautionary measures implemented during installation can minimize the hazards associated with EV charging and the potential emission of toxic combustion byproducts. For instance, a facility could be designed to shut down a charging station's power supply through a single action by facility personnel or firefighters. Measures also call for a focus on design elements (like the placement of EV parking spaces and charging stations in relation to ventilation openings and escape routes) to mitigate the risk of toxic combustion products. Additionally, displacement ventilation and effective smoke and heat removal systems can help firefighting in buildings. Finally, exhaust ducts should be positioned strategically to minimize potential environmental disturbances caused by the escape of combustion byproducts from indoor parking areas.

3. *Organizational:* These include instructions about the use of parking and charging facilities (including their maintenance), instructions to drivers about how to handle fires, and educating drivers about how to address error messages from the battery management system (BMS).

4. *Fire suppression:* These measures aim to facilitate firefighter intervention logistics in case EV fires occur in garages. They include, but are not limited to, the use of an emergency notification system to alert firefighters, the use of smoke removal devices, and/or facilitating accessibility for firefighter intervention (e.g., having EV parking only at street level or the installation of

19 Österreichishes Institut für Bautechnik, *OIB-Richtlinie 2.2 Brandschutz bei Garagen, überdachten Stellplätzen und Parkdecks*, accessed July 26, 2023, https://www.oib.or.at/de/oib-richtlinien/richtlinien/2023/oib-richtlinie-22.

20 The State Council, the People's Republic of China, "三项电动汽车强制性国家标准正式发布_服务信息_中国政府网 [Three Manadatroy National Standards for Electric Vehicles Officially Released]," May 14, 2020, accessed July 26, 2023, https://www.gov.cn/fuwu/2020-05/14/content_5511415.htm.

21 Information shared by email by a government representative.

22 "Parkeergarages," Nederlands Instituut Publieke Veiligheid, accessed July 26, 2023, https://nipv.nl/wp-content/uploads/2023/09/20210715-NIPV-Fire-safety-of-indoor-car-parks-accommodating-electrically-powered-vehicles.pdf https://nipv.nl/parkeergarages/.

sprinkler and smoke removal devices in garages). Measures also focus on how to safely remove EVs from a premises after a fire, for example, by cooling them in a water tank.

Starting in 2024, the government is expected to introduce several legislative measures.[23] One example is a requirement for a system capable of simultaneously switching off all charging stations in parking garages. Moreover, clear information about the switch-off system and the location of the charging stations in the parking garage must be documented to inform firefighter interventions. Another measure will require charging stations be “Mode 3” or “Mode 4”[24] (these stations are better protected against malfunctions that could lead to fires as they allow a switch-off of the charging station building-related installation). Furthermore, it will be mandatory to indicate charging station modes and locations at parking garage entrances. Finally, sprinkler systems will have to be installed in new parking garages under buildings where people sleep (e.g., residential buildings, childcare facilities, hospitals).

New Zealand: Government efforts have focused on research to compare EV and ICE vehicle fires and inform the development fire mitigation measures. The government is also working with emergency services to formalize operational protocols to manage on-road EV fires. While the scope of this work is broad, its overall objectives are to define the scope and scale of the risk of EVs in New Zealand’s transport system; identify the EV fire challenges different stakeholders face; and define and implement solutions to mitigate EV fire risks.

United Kingdom: In 2023, the government published interim fire safety guidance for EVs and charging stations, subject to be updated as more research and data on EV fires becomes available. The guidance lists measures that operators of new and existing garages could consider to either eliminate, reduce, isolate, or control EV fires. Examples include the removal of defective charging stations (eliminating measure); increasing the distance between parked cars to limit fire propagation (reducing measure); equipping garages with automatic fire detection alarm systems to alert occupants and notify firefighters when a fire occurs (isolating measure); and the installation of switch-off devices to cut off electricity to charging stations during a fire (control measure).[25]

United States: In 2018, the NHTSA led the development of Global Technological Regulations (GTR) for EV safety. It presented guidelines and requirements for conducting EV battery fire safety tests. NHTSA is now working on phase 2 of the GTR standards which focuses on safety issues related to battery thermal runaways, water immersion, and vibration resistance, among other topics.[26]

Also relevant are the NFPA National Electric Codes 70 and 88A (NFPA 70 and 88A) which establish safety standards for EVs in parking garages. The standards help ensure that the electrical capacity in buildings can accommodate the additional load from EV charging. They also require that charging stations in parking garages be listed and have an switch-off system to disconnect them from the power grid.[27]

23 “Nieuwe bouwregels opladen elektrische voertuigen (EV’s) in parkeergarages,” vb&t, March 18, 2022, https://www.vbtbrandveiligheidenmilieu.nl/nieuwe-bouwregels-opladen-elektrische-voertuigen-evs-in-parkeergarages/.

24 For more on charging modes, see: “Charging Modes,” Deltrix Charging Solutions, 2019, https://deltrixchargers.com/about-emobility/charging-modes/.

25 “Covered Car Parks – Fire Safety Guidance for Electric Vehicles,” United Kingdom Office of Zero Emission Vehicles, July 2023, https://www.gov.uk/government/publications/covered-car-parks-fire-safety-guidance-for-electric-vehicles.

26 “Battery Safety Initiative,” National Highway Traffic Safety Administration.

27 “EVs and Parking Structures,: National Fire Protection Association, 2023, https://www.nfpa.org/News-and-Research/Publications-and-media/Blogs-Landing-Page/NFPA-Today/Blog-Posts/2022/11/28/EVs-and-Parking-Structures.

These standards are evolving over time to enhance safety in parking garages. For example, 2023 revisions to NFPA Code 88A require the installation of sprinklers in all garages. Similarly, the 2022 revision of NFPA 13 standards recommended upgrading parking structures from Ordinary Hazard Group 1 to Group 2. This means increasing the density of water discharge for sprinkler systems from 0.15 to 0.2 gallons per minute per square foot (a 33% increase).

Conclusions

The literature reviewed and discussion among IZEVA jurisdictions during the May 17, 2023, deep-dive session leads to three conclusions on EV fire safety:

1. **EV fires are rare but may become more frequent.** The literature concludes that up to 2023, EV fires have been less frequent than ICE vehicle fires. An ongoing study supported by the Australian government found that from 2010 to June 2023, there were 488 EV fires globally. However, EV fires are expected to become more frequent as the number of EVs on the roads increases. Accordingly, governments should consider enacting measures to help mitigate EV fire risks.

2. **More EV fire research is needed, but it might be impeded by financial constraints.** Several governments and affiliated agencies have researched the risks associated with EV fires. These efforts have shed light on specific risks related to EV fires and informed safety measures that could be considered in parking garages (e.g., charging station shutdown devices, sprinkler installation, adequate ventilation, etc.). Yet there is more to learn about EV fires, including how fires can start in different circumstances and the best approaches for emergency responders. In certain jurisdictions, however, the funding level needed to support consistent EV fire research has been an obstacle.

3. **From 2020 to mid-2023, several governments have introduced policies and regulations on EV fire safety that could serve as models in other EV markets.** In 2021, the Netherlands published comprehensive guidance on EV fire safety in parking garages. These will be complemented by legislative measures that will enter into force in 2024, requiring, for example, that all chargers in new residential building parking garages be equipped with sprinkler systems. China presents a unique case where a manufactural requirement entered into force in 2021, assuring that EV drivers have sufficient time to exit their vehicle when the battery experiences thermal runaway. Moreover, in June 2023, Austria revealed its revised building legislation, which includes provisions for EV fire safety in garages for the first time. The legislation prevents the installation of charging stations in parking garages that are only accessible by elevator and requires that chargers be protected against collisions. It also places restrictions on energy storage system in parking garages.

The International Zero-Emission Vehicle Alliance is a network of leading national and sub-national governments demonstrating their deep commitment to accelerating the transition to zero-emission vehicles within their markets and globally. Its members include Austria, Baden-Württemberg, British Columbia, California, Canada, Chile, Connecticut, Costa Rica, Germany, Maryland, Massachusetts, the Netherlands, New Jersey, New York, New Zealand, Norway, Oregon, Québec, Rhode Island, Switzerland, the United Kingdom, Vermont, and Washington. The members collaborate through discussion of challenges, lessons learned, and opportunities; hosting events with governments and the private sector; and commissioning research on the most pressing issues in the ZEV transition.

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