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Emergency Management Strategies for Electric Vehicles

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Analysis revealed a statistically significant increase in long-duration vehicle fires between 2016 and 2019 and between 2022 and 2024, with fires exceeding 4 hours increasing by 42%. This shift is consistent with growing electric vehicle adoption and the extended cooling requirements documented for lithium-ion battery fires. Although Virginia has mandated electric vehicle safety training for firefighters, comparable requirements do not exist for transportation agency personnel or towing operators who play critical roles in incident management.

The study recommends that the Virginia Department of Transportation develop protocols for protecting critical infrastructure during electric vehicle fires, encourage additional electric vehicle training and requirements for police- and county-maintained towing rotations, implement systematic tracking of electric vehicle incidents in operations centers, and evaluate emerging suppression technologies for strategic deployment.

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FINAL REPORT

EMERGENCY MANAGEMENT STRATEGIES FOR ELECTRIC VEHICLES

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ABSTRACT

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INTRODUCTION

The Virginia Department of Transportation (VDOT) manages and operates more than 128,000 lane-miles of roadways in the Commonwealth (VDOT, 2023). Traffic incidents on these roadways require a coordinated multi-agency response to ensure safety and minimize disruption to traffic flow. In recent years, the increasing adoption of electric vehicles (EVs) has introduced new challenges to incident management that differ significantly from conventional vehicle incidents.

EVs—including battery EVs (BEVs), plug-in hybrid EVs, and hybrid EVs—use lithium-ion battery technology that presents unique hazards during fire incidents. These hazards include thermal runaway events, extended fire suppression durations, toxic gas emissions, and the potential for battery reignition hours or even days after initial extinguishment (National Transportation Safety Board [NTSB], 2020). Although EVs offer environmental and economic benefits through reduced emissions and lower operating costs, their distinct fire characteristics require specialized response protocols and coordination strategies.

Virginia has experienced significant growth in EV registrations, with more than 134,000 registered EVs as of 2024, of which 102,000 are BEVs and 32,000 are plug-in hybrid EVs (Atlas Public Policy, 2024). Current traffic incident management practices in Virginia were developed primarily for conventional vehicle incidents. Fire suppression protocols, towing procedures, storage requirements, and multi-agency coordination frameworks assume incident characteristics typical of internal combustion engine vehicles. However, NTSB found that EV fires required water volumes ranging from 300 gallons to more than 20,000 gallons in investigated incidents, with some manufacturer guidance specifying approximately 3,000 gallons for cooling high-voltage lithium-ion batteries (NTSB, 2020). These volumes significantly exceed the 500–1,000-gallon capacity of a typical fire apparatus. EV fires may burn for 6 to 10 hours, rather than 30 minutes to 2 hours for conventional vehicles, and present ongoing risks through stranded energy in undamaged battery cells.

In response to these emerging challenges, the Virginia General Assembly passed House Bill 2451 in 2023, mandating that all professional and volunteer firefighters complete EV fire training by December 2025 (Lawrence, 2023). Although this legislation addresses fire service preparedness, the broader implications for roadway operations, traffic management, and multi-agency coordination during extended EV incidents remain unaddressed. Transportation agencies, towing operators, and storage facilities require guidance on managing the unique operational, safety, and environmental challenges associated with EV incidents.

The Virginia Transportation Research Council (VTRC) System Operations Research Advisory Committee rated this problem as a high need.

PURPOSE AND SCOPE

This study was initiated to assess the prevalence and characteristics of EV fires, review current emergency response practices, and identify methods for VDOT to support effective incident management. The research builds on national investigations by NTSB, guidance from the National Fire Protection Association (NFPA), and emerging practices from jurisdictions with higher EV adoption rates. By examining incident data, interviewing responders, and evaluating current protocols, this study aimed to provide actionable recommendations for enhancing VDOT's capability to manage EV incidents safely and efficiently.

The objectives of this project were to:

1. Assess the prevalence and severity of EV fires in Virginia and nationwide.
2. Review current and emerging practices in EV fire suppression and incident management, including incident recovery.
3. Identify methods for VDOT to support EV fire suppression and incident management.

This study focused on passenger EVs operating on public roadways in Virginia. The scope was limited to EVs using lithium-ion batteries because these battery types are most prone to thermal runaway. The researcher paid special attention to commercially available BEVs given their larger batteries and greater potential for prolonged fires. The study investigated fire suppression strategies only to the extent that VDOT may be able to provide support and did not make determinations regarding the effectiveness of any particular strategy in extinguishing EV fires beyond what exists in the literature.

METHODOLOGY

To accomplish the study objectives, the following tasks were performed:

1. Conducting a literature review.
2. Analyzing EV fire incident data.
3. Reviewing current emergency response guidelines.
4. Interviewing incident responders.
5. Identifying best practices and gaps.

Literature Review

The researcher conducted a review of relevant scientific literature, industry publications, and government reports. This literature review examined current statistics on EV adoption and EV-related incidents, technical aspects of lithium-ion battery thermal runaway, existing and emerging EV fire suppression techniques, emergency response protocols for EV-related incidents, and case studies of significant EV fire incidents.

Analysis of Electric Vehicle Fire Incident Data

This task involved collecting and analyzing data on vehicle fire incidents in Virginia and multiple other states to assess whether fire characteristics have changed over time in ways consistent with increased EV adoption. The analysis employed incident management records and crash data from multiple sources.

Incident Duration Analysis

Vehicle fire incident data were obtained from the Regional Integrated Transportation Information System (RITIS), which aggregates real-time traffic incident data from state departments of transportation (DOTs) across the United States. RITIS data were selected because they include incident clearance times, a critical metric for assessing fire severity and the operational complexity of incident response. Unlike crash reports, which typically document only the occurrence of a fire, incident management records capture the full duration from detection to clearance, providing insight into how long emergency responders must work to control and extinguish vehicle fires.

The study period covered January 1, 2016, through December 31, 2024. Data from 2020 and 2021 were excluded from the analysis because of significant disruptions in travel patterns due to the COVID-19 pandemic, following established practice in transportation research. Therefore, the analysis compared two periods: 2016 through 2019 (pre-pandemic) and 2022 through 2024 (post-pandemic).

Data were pulled from RITIS for all available state DOTs using the standard crash type as "Vehicle Fire." The initial dataset included Arizona, California, District of Columbia, Florida, Georgia, Illinois, Louisiana, Maryland, Minnesota, New Jersey, New York, North Carolina, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, and Wisconsin because they were the only states in RITIS. These states varied considerably in the completeness and consistency of their incident reporting.

Data Cleaning

The raw dataset contained 214,918 records. Several cleaning steps were applied to ensure data quality. First, duplicate records were removed based on incident identification numbers. Second, many of the returned records were not classified as vehicle fires regardless of the filter. These records were excluded, reducing the dataset to 178,354 records. Third, incidents with negative durations (data entry errors) were removed, leaving 178,289 records. Finally, incidents lasting longer than 10 hours were excluded because extremely long durations typically resulted from operators failing to close incidents in the system rather than actual incident characteristics. After this final filter, the dataset contained 172,110 vehicle fire incidents.

Visual inspection of the data revealed several dates with missing records, likely due to system outages or data transfer issues: February 21, 2017; May 2, 2017; September 4, 2018; May 17, 2019; July 6, 2021; and August 30, 2021. These gaps were noted but did not substantially affect the overall sample size.

Duration as a Proxy for Electric Vehicle Fires

The RITIS dataset does not include vehicle make, model, or propulsion type because transportation management center operators typically observe incidents via closed-circuit television and are focused on operational response rather than vehicle characteristics. Therefore, direct identification of EV fires was not possible from this dataset.

However, lithium-ion battery fires in EVs are known to burn significantly longer than conventional vehicle fires because of the difficulty extinguishing thermal runaway events in battery cells. Previous research and incident reports suggest that EV fires often require 2 to 4 hours or more to fully extinguish and clear from the roadway (NTSB, 2020). Therefore, incident duration was used as a proxy measure for potential EV involvement, with the hypothesis that an increase in long-duration vehicle fires over time would be consistent with increased EV adoption.

To test this hypothesis, cumulative distribution functions were constructed for fire durations in the 2016–2019 period and the 2022–2024 period. A two-sample Kolmogorov-Smirnov test was performed to determine whether the distributions differed significantly between the two periods.

Virginia Crash Data Analysis

As a supplementary analysis, police crash records from Virginia were examined to assess the feasibility of directly identifying EV fires in state crash databases. Data were obtained from SmarterRoads.org for the 2016–2024 period, covering more than 1 million crash records.

Because vehicle propulsion is not identified directly in the database, an attempt was made to determine whether a vehicle was an EV from the make, model, and year, but inconsistencies in vehicle model encoding prevented successful matches in many cases. Because all Tesla vehicles are electric, crashes involving Tesla vehicles were identified by filtering records by vehicle make. The total number of crashes involving at least one Tesla was tallied, as was the number of those crashes that involved a fire. This analysis included all years from 2016 to 2024 without excluding the years from 2020 to 2021 because the goal was simply to assess data availability rather than establish trends.

The purpose of this analysis was to determine whether state crash records contained sufficient information to directly measure EV fire rates. If successful, this approach could provide a more direct measure than the duration-based proxy used with RITIS data.

Review of Current Emergency Response Guidelines

This task reviewed existing emergency response guidelines and protocols for EV incident management through systematic examination of three categories of guidance: manufacturer-provided emergency response guides, national guidelines and standards, and state and local protocols.

Manufacturer guides were accessed through the National Highway Traffic Safety Administration (NHTSA) Emergency Response Guide repository (NHTSA, 2025), which became the official federal repository in July 2025 after transitioning from NFPA (2025a). The review consisted of examining common elements across guides, including vehicle identification features, high-voltage system layouts, suppression recommendations, and post-incident handling procedures.

National guidelines were reviewed from authoritative sources, including NFPA's Alternative Fuel Vehicles Safety Training program (NFPA, 2025b), SAE International standard J2990 for towing and storage protocols (SAE International, 2019), NTSB's special investigation reports on lithium-ion battery fires (NTSB, 2020), and NHTSA's interim guidance for EVs (NHTSA, 2012). These documents provided consensus standards for emergency response, although most focused primarily on fire service operations.

State and local protocols were examined to identify implementation practices and innovations. Sources included Virginia's legislative and training requirements, county-level towing contracts, regional planning commission guidelines, and other state DOT investigations. VDOT's current protocols were reviewed through the Traffic Incident Management Strategic Plan and relevant Instructional and Informational Memoranda to assess existing capabilities and identify gaps in EV-specific guidance.

The analysis focused on implications for roadway incident management rather than fire suppression tactics. Particular attention was paid to incident duration expectations, multi-agency coordination requirements, transport and storage challenges, and the specific roles of transportation agencies during extended EV incidents. Gaps were identified by comparing manufacturer recommendations and national standards with actual implementation practices at the state and local levels.

Interviews with Incident Responders

Representatives from VDOT incident management, fire departments, law enforcement, and towing companies in Virginia were contacted to determine current best practices for managing EV fire incidents. Interviewees were identified from existing VDOT incident management partnerships. Towing companies were selected based on Towing Recovery Incentive Program (TRIP) participation, with the highest volume operator from each VDOT district contacted. Fire departments were selected based on operation along high-volume interstate corridors. One out-of-state contact from Florida DOT was also interviewed to understand approaches in a state with higher EV adoption rates.

Twelve interviews were conducted via telephone between July and September 2025. The interviews were unstructured and covered experiences with EV fires, current practices, training received, and the state of EV incident response capabilities.

Identify Best Practices and Gaps

This task synthesized findings from previous tasks to identify effective strategies for incident management during EV fires and to highlight gaps in coverage. The analysis drew from literature review findings, interview responses, and the review of current emergency response guidelines to characterize both emerging best practices and significant gaps in preparedness, infrastructure, and coordination.

RESULTS AND DISCUSSION

Literature Review

The literature review covered peer-reviewed research, government reports, and industry publications related to EV fires, lithium-ion battery thermal runaway, fire suppression methods, and emergency response protocols. This review provides context for the unique challenges posed by EV incidents and establishes the foundation for analyzing current practices and developing recommendations for VDOT.

Electric Vehicle Technology

Modern EV battery systems consist of hierarchical components. Individual battery cells serve as the fundamental building block, with voltages of approximately 4 volts per cell (Bisschop et al., 2019). These cells are connected in series or parallel configurations to form battery modules, which typically operate below 60 volts to facilitate safer handling and shipping. Multiple modules are then integrated into complete battery packs, which include structural components, thermal management systems, wiring, and control electronics (Stephens et al., 2017; Sun et al., 2020). Current EV battery packs in passenger vehicles range from approximately 10 to 100 kilowatt-hours in capacity, with BEVs typically using larger packs than plug-in hybrid EVs (Sun et al., 2020). These packs operate at high voltages ranging from 400 to 800 volts or higher for electric-only vehicles (Liu et al., 2023), significantly exceeding the 36-volt threshold considered safe for direct human contact.

Battery placement in vehicles follows several common configurations to maximize both safety and interior space. The most prevalent approach positions the battery pack within the reinforced area in the center of the chassis, between the wheelbase (Bisschop et al., 2019). This location provides protection from crash forces by surrounding the battery with structural members. Three main configurations utilize this safe zone: (1) the “floor” solution distributes the battery pack across the entire area beneath the passenger compartment; (2) the “T” configuration arranges batteries in a T-shape using available space along the vehicle centerline; and (3) the "rear" solution concentrates the battery pack near or behind the rear axle (Bisschop et al., 2019).

Battery packs are housed within protective enclosures designed to shield the cells from physical damage and environmental exposure during normal operation (Bisschop et al., 2019). These enclosures typically incorporate reinforced structures, with some manufacturers using high-strength steel housing and shock-absorbing materials to protect battery cells during crash events (Bisschop et al., 2019). However, although these protective measures enhance safety during normal operation, they can complicate fire suppression efforts by restricting direct access to burning cells inside the enclosure (Brzezinska and Bryant, 2022).

Lithium-Ion Battery Fires and Thermal Runaway

The primary safety concern with lithium-ion batteries involves thermal runaway, a self-sustaining exothermic reaction that can lead to fire or explosion. Thermal runaway occurs when a battery cell reaches a temperature at which internal chemical reactions become uncontrollable, generating heat faster than it can be dissipated (Stephens et al., 2017). This process typically results in rapid temperature increases exceeding 18°F per minute, accompanied by the release of flammable gases, smoke, and potentially projectiles (Un and Aydın, 2021).

Several conditions can trigger thermal runaway, categorized into four main types: mechanical, electrical, thermal, and internal short circuits (Stephens et al., 2017; Un and Aydın, 2021). Mechanical abuse from vehicle crashes can damage the separator between electrodes, causing electrical shorting through the electrolyte and producing localized heating (Un and Aydın, 2021).

Electrical abuse includes overcharging or overdischarging beyond manufacturer specifications, which can lead to lithium plating and dendrite formation that pierce the separator (Stephens et al., 2017; Un and Aydın, 2021). Thermal abuse from external heat sources initiates decomposition when temperatures reach 190–250°F for the solid electrolyte interphase layer and above 390°F for the electrolyte (Un and Aydın, 2021). Manufacturing defects and battery aging through repeated charge-discharge cycles can also create vulnerabilities (Stephens et al., 2017).

Once initiated in a single cell, thermal runaway can propagate to adjacent cells through heat transfer, creating a cascading failure throughout the battery pack (Stephens et al., 2017; Un and Aydın, 2021). This cell-to-cell propagation is a major challenge in managing EV battery fires. The cathode materials within lithium-ion batteries release both heat and oxygen during decomposition at high temperatures, meaning that fires can continue burning even when external oxygen is limited or when the battery is submerged in water (Brzezinska and Bryant, 2022).

Characteristics of Electric Vehicle Fires

EV fires differ from conventional vehicle fires in several important ways. Although both types of vehicles contain similar amounts of combustible plastic components (220–440 pounds), the power source represents the key difference (Sun et al., 2020). Lithium-ion battery fires can burn at temperatures exceeding 1,800°F and may persist for hours or even days. The fires often produce intense, directional jet flames as pressurized gases vent from failing cells (Sun et al., 2020).

The heat release rate from EV battery fires varies depending on the battery size and state of charge. Studies have reported maximum heat release rates ranging from 2.8 megawatts for smaller 16-kilowatt-hour battery packs to more than 6 megawatts for larger battery packs at full charge (Yamazaki et al., 2014). Both internal combustion engine vehicles and EVs contain flammable plastic components with heat of combustion values (38.4 megajoules per kilogram for polyethylene, 27 megajoules per kilogram for polystyrene) comparable with gasoline (47 megajoules per kilogram), meaning plastic materials contribute significantly to total heat release in both vehicle types (Sun et al., 2020).

One of the most concerning characteristics of lithium-ion battery fires is their propensity for reignition. Damaged batteries can reignite hours or even days after the initial fire appears to be extinguished (NTSB, 2020). This reignition occurs because undamaged cells within the battery pack retain stored energy, termed "stranded energy," which can subsequently trigger thermal runaway in previously unaffected cells. NTSB (2020) investigated several Tesla vehicle crashes and found that batteries reignited at least 15 times in total across three high-severity crashes. In one case involving a Tesla Model X, the battery reignited at least six times after firefighters extinguished the initial fire. In another case, a Tesla Model S battery reignited three times, including twice during vehicle recovery operations, once while being loaded onto a tow truck and again when a chain passed over the battery (NTSB, 2020).

Battery reignition can occur through thermal or mechanical means (NTSB, 2020). Thermal reignition happens when the battery is not sufficiently cooled and thermal runaway resumes. Mechanical reignition results when parts of a battery or other conductive debris cause a short circuit in cells that contain stranded energy. For example, shifting a damaged vehicle can twist the wreckage and create new electrical connections that release energy and cause reignition. Manufacturer guidance and NFPA recommendations indicate that reignition can occur within several hours to a day or more after the initial fire is extinguished (NTSB, 2020).

The presence of stranded energy poses ongoing risks even after an EV's high-voltage system has been disconnected. NTSB (2020) found that even if high-voltage disconnects are activated, energy remains trapped in damaged high-voltage lithium-ion batteries, creating both electric shock risks for responders and the potential for thermal runaway that can result in reignition and fire. Existing methods to deenergize batteries take hours or days to remove stranded energy from undamaged batteries, and these methods may not be feasible when crash forces damage the batteries.

The toxic emissions from burning lithium-ion batteries present additional hazards. When battery temperatures exceed approximately 300°F, the risk for thermal runaway is significant. Once initiated, either the cell or its safety valve will burst and release toxic gases (Sun et al., 2020). As thermal runaway propagates through multiple cells, more smoke and toxic gases are generated. These emissions include hydrogen fluoride (HF), hydrogen cyanide, carbon monoxide, and phosphorous oxyfluoride, which may be more toxic than HF (Sun et al., 2020). Inhalation of these gases can result in dizziness, headache, loss of consciousness, or death.

Research by Ribière et al. (2012) found that burning a 95-gram pouch lithium-ion battery produced maximum emissions of 1.77 grams of carbon monoxide, 195 milligrams of nitric oxide, 220 milligrams of sulfur dioxide, 25 milligrams of hydrogen chloride, and 757 milligrams of HF. These gas emissions differ among EV manufacturers and battery types, with battery chemistry and size playing significant roles in potential emissions. Testing conducted by Lecocq et al. (2012) found that the total amount of HF released by EVs was roughly double that measured for internal combustion EV fires. The risk from these emissions depends heavily on the incident scenario. In outdoor environments, HF will likely rise and quickly dissipate, whereas in enclosed spaces such as tunnels or parking structures, toxic gas accumulation may be problematic if gases are not evacuated.

Fire Suppression Methods

Researchers of EV fire suppression have examined various extinguishing agents and application methods. Water remains the most effective suppressant for lithium-ion battery fires, primarily due to its superior cooling capacity (Bisschop et al., 2019; Brzezinska and Bryant, 2022). However, the quantity of water required far exceeds that needed for conventional vehicle fires. Full-scale fire tests have documented water requirements ranging from 660 to 1600 gallons for battery pack fires (Brzezinska and Bryant, 2022), with some real-world incidents requiring more. NTSB (2020) investigated several Tesla vehicle fires and found that manufacturer guidance specified approximately 3,000 gallons of water to cool high-voltage lithium-ion batteries. These volumes may exceed the capacity of a typical fire apparatus, which carries approximately 500 to 1,000 gallons.

The recommended water application rate for effective cooling is approximately 50 gallons per minute (Brzezinska and Bryant, 2022), although sustained application for extended periods is often necessary to prevent reignition. The cooling effect of water is critical because it is the only suppression method that can reduce battery temperatures sufficiently to prevent continued thermal runaway propagation (Brzezinska and Bryant, 2022). NFPA advises firefighters to continue applying water even after visible flames are extinguished, which could take an hour or more, to sufficiently cool the battery pack and reduce the risk of reignition (NTSB, 2020).

Testing by Sturk et al. (2014) evaluated multiple fire suppression agents on lithium-ion battery cells, including water, salt water, various foam types, dry chemical powder, carbon dioxide, Novec 1230, nitrogen, and Halotron II. All tested agents were able to extinguish flames from burning battery cells. However, fire suppression agents with the highest specific heat capacity and mass proved most effective at cooling the batteries. Consequently, gaseous agents were not advanced to testing on larger battery systems because of their inferior cooling performance.

A significant challenge in EV fire suppression is accessing the burning cells. Battery packs are typically enclosed within protective housings that restrict water penetration (Bisschop et al., 2019; Brzezinska and Bryant, 2022). The battery pack's compact design and high degree of protection make access to the seat of the fire difficult. Some research has covered techniques for creating access points to allow direct water application to battery cells. Sturk et al. (2014) tested a cutting extinguisher capable of cutting through multiple layers of sheet metal and then introducing cooling water or foam to the interior of the battery pack. The high-pressure water inserted into the battery was able to penetrate lithium-ion cells and channel cooling water through the battery pack. Test results showed that battery fires stopped reigniting, and the generation of gases was reduced in magnitude when the cutting extinguisher was deployed, with the battery housing temperature reaching only 200°F with no sign of increasing.

The effectiveness of external water application alone is limited because it primarily cools the exterior of the battery enclosure rather than the burning cells inside (Sun et al., 2020). Despite potential negative effects, such as short circuits or toxic runoff water, water appears to be the most effective extinguishing method for gaining control of lithium-ion battery fires (Brzezinska and Bryant, 2022; Sun et al., 2020).

Gaps in Current Knowledge

Although the literature provides substantial information on the mechanisms of lithium-ion battery fires and general firefighting approaches, several gaps remain. Limited data exist on the actual frequency and severity of EV fires relative to the growing population of EVs on roadways. Many fire incidents are not specifically coded as EV-related in incident reporting systems, making comprehensive analysis difficult.

The role of transportation agencies in supporting an emergency response to EV incidents is not well defined in existing literature. Most research focuses on firefighting techniques and first responder training rather than the broader context of incident management. Questions remain regarding optimal strategies for traffic management during extended EV fire suppression operations, coordination between multiple agencies, provision of specialized equipment or resources, and protocols for vehicle removal and storage.

NTSB (2020) identified that existing standards address damage sustained by high-voltage lithium-ion battery systems in survivable crashes, as defined by federal crash standards, but these standards do not address high-speed, high-severity crashes resulting in damage to high-voltage lithium-ion batteries and the associated stranded energy. NTSB (2020) recommended that NHTSA convene a coalition of stakeholders to continue research on ways to mitigate or deenergize the stranded energy in high-voltage lithium-ion batteries and to reduce the hazards associated with thermal runaway resulting from high-speed, high-severity crashes. Existing deenergizing devices take hours or days to remove the stranded energy from undamaged high-voltage lithium-ion batteries, and these devices may not function when crash forces or thermal runaway events damage the batteries.

The rapid evolution of EV technology means that current knowledge may not fully apply to future vehicle designs. Emerging battery chemistries, thermal management systems, and fire suppression technologies integrated into vehicles may alter the risk profile and response requirements for EV incidents. Continued research and information sharing will be necessary to keep pace with technological developments and ensure that emergency response protocols remain effective.

Analyze Electric Vehicle Fire Incident Data

Incident Duration Analysis

The cleaned RITIS dataset contained 172,110 vehicle fire incidents across 19 states and the District of Columbia for the analysis period. After excluding 2020 and 2021, the dataset included 85,564 incidents from 2016 to 2019 and 55,242 incidents from 2022 to 2024. Table 1 shows the distribution of incidents by state and year.

Table 1. Filtered Vehicle Fire Counts in the Regional Integrated Transportation Information System by State and by Year

State	Year					
	2017	2018	2019	2022	2023	2024
Arizona	0	0	1	0	0	687
California	15,666	14,985	14,372	13,645	13,447	13,075
District of Columbia	15	18	10	13	22	16
Florida	1,128	657	1,333	1,786	1,929	2,062
Georgia	440	620	675	741	746	750
Illinois	0	0	11	16	97	120
Louisiana	0	0	0	156	162	137
Maryland	583	605	633	716	695	707
Minnesota	0	0	0	0	0	359
New Jersey	327	158	468	203	428	486
New York	459	457	5	0	358	646
North Carolina	113	27	55	19	0	1
Oregon	128	220	243	425	366	415
Pennsylvania	172	2	0	0	0	0
South Carolina	28	33	22	0	1	0
Tennessee	0	0	1	555	602	596
Texas	0	43	6	0	0	0
Virginia	908	918	892	967	1,034	1,056
Wisconsin	75	52	0	0	0	0
Total	**20,042**	**18,795**	**18,727**	**19,242**	**19,887**	**21,113**

State participation and reporting consistency varied considerably. California reported the highest volume of vehicle fires, accounting for approximately 70% of all incidents in the dataset. Florida, Georgia, Virginia, and Maryland also maintained consistent reporting throughout the study period. Several states showed sporadic reporting patterns, with some years having zero or near-zero incident counts, suggesting incomplete data capture or inconsistent classification practices. Because the analysis compared proportional durations rather than total counts, these differences were not considered to affect the results, although any bias in reporting longer- versus shorter-duration fires could affect the results.

Figure 1 shows the cumulative distribution functions for fire durations in the two periods. The 2022–2024 period exhibited a noticeable shift toward longer incident durations compared with 2016 through 2019. At 60 minutes (1 hour), 68.9% of fires in the 2016–2019 period had cleared compared with 63.1% in the 2022–2024 timeframe. This difference became more pronounced at longer durations.

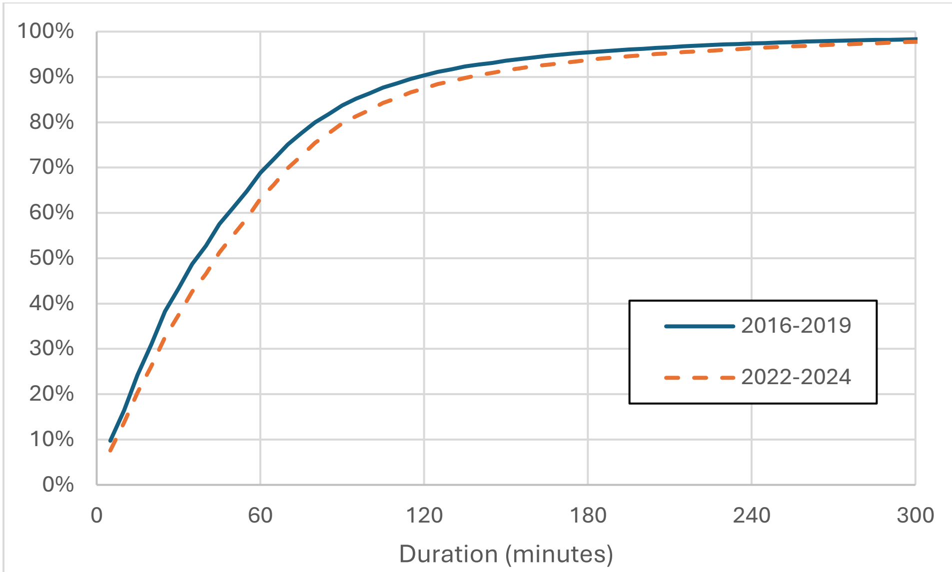

Figure 1. Cumulative Density Function of Vehicle Fire Incident Durations from 18 States and the District of Columbia

At 120 minutes (2 hours), 90.3% of fires had cleared in the 2016–2019 period compared with 87.4% in the 2022–2024 period. This result indicates that 9.7% of fires in the earlier period lasted longer than 2 hours compared with 12.6% in the later period, a relative increase of 30%. Similar increases were seen at 3 hours (37%) and 4 hours (42%).

A two-sample Kolmogorov-Smirnov test confirmed that the distribution of fire durations differed significantly between the two periods ($D = 0.063$, $p < 0.001$). This statistical result indicates that the shift toward longer fire durations in the more recent period is not attributable to random variation but instead represents a fundamental change in the distribution of incident characteristics.

To address potential concerns that inconsistent reporting across states might influence the observed trends, a sensitivity analysis was conducted using only the five states that demonstrated the most consistent reporting throughout the study period: California, Florida, Georgia, Virginia, and Maryland. As Table 1 shows, these states maintained relatively stable incident counts across all years examined, and several other states showed sporadic patterns with zero or near-zero counts in some years.

When analysis was limited to these five states, the dataset contained 54,415 incidents from 2016 to 2019 and 53,356 incidents from 2022 to 2024. The cumulative distribution functions for this subset showed patterns consistent with the full dataset. At 120 minutes (2 hours), 90.6% of fires had cleared in the 2016–2019 period compared with 88.7% in the 2022–2024 period, indicating that 9.4% and 11.3% of fires exceeded this threshold, respectively—a relative increase of 20%. At 180 minutes (3 hours), fires exceeding this threshold increased from 4.4% to 5.4% (a 23% relative increase) and at 240 minutes (4 hours), from 2.5% to 3.0% (a 20% relative increase).

A two-sample Kolmogorov-Smirnov test on the five-state subset confirmed statistical significance ($D = 0.052$, $p < 0.001$). Although the effect size was smaller than in the full dataset ($D = 0.052$ versus $D = 0.063$), the pattern remained statistically significant. This outcome demonstrates that the shift toward longer fire durations persists even when analysis is limited to states with the highest data quality, strengthening confidence that the observed trend represents genuine changes in incident characteristics rather than reporting anomalies.

Virginia Crash Data Analysis

The Virginia crash dataset from 2016 to 2024 contained more than 1 million crash records. Of these crashes, 2,966 involved at least one Tesla vehicle. Among crashes involving Tesla vehicles, only one crash was recorded involving a fire. The total number of crashes with fires recorded across all vehicle types was 1,210.

These results indicate that although crash databases can identify vehicle make and fire occurrence, the frequency of fires, particularly EV fires, is too low to permit meaningful statistical analysis of fire rates by vehicle type. With only a single fire among nearly 3,000 Tesla crashes, confidence intervals would be extremely wide and comparisons with conventional vehicles would lack statistical power. This finding reinforced the rationale for using incident duration as a proxy measure in the RITIS analysis, in which the much larger sample size of vehicle fires (more than 140,000 incidents) enabled the detection of distributional changes over time.

Review Current Emergency Response Guidelines

The review of current emergency response guidelines reveals a foundation of safety information that serves fire services well but leaves gaps for roadway incident management operations.

Manufacturer Emergency Response Guides

Emergency response guides for EVs have undergone significant changes in recent years. Prior to July 2025, NFPA maintained a collection of emergency response guides from manufacturers. However, in July 2025, NHTSA (2025) assumed responsibility for hosting these guides, providing a centralized federal repository for first responders. This transition aligns with new federal regulations under Federal Motor Vehicle Safety Standard 305a, which require manufacturers to submit standardized emergency response information to NHTSA before the first sale or lease of covered EV models (Federal Register, 2024). The new regulations establish requirements for manufacturers to provide vehicle-specific information, including high-voltage system details, battery specifications, disconnect procedures, and post-incident handling recommendations in a standardized format (Federal Register, 2024).

Despite variations in format, manufacturer emergency response guides typically contain several common elements. Vehicle identification information helps responders quickly determine whether a vehicle is electric, hybrid, or plug-in hybrid. This section usually includes visual identifiers, such as badging, unique design features, vehicle identification number location and format, and the presence of charging ports. For EVs, identification can be challenging because many models closely resemble their internal combustion engine counterparts, and some manufacturers use minimal badging to distinguish electric variants (NTSB, 2020).

High-voltage disconnect procedures form a critical component of every guide. These procedures detail how to safely de-energize the vehicle's high-voltage system, typically by cutting a "first responder loop" or similar disconnect mechanism. The guides provide specific locations for these disconnect points, which vary by manufacturer and model. Most guides emphasize that even after following disconnect procedures, responders should always assume that high-voltage components remain energized because damaged systems may not respond predictably to standard disconnect methods (SAE International, 2019).

Battery location and specification information includes diagrams showing the physical location of the high-voltage battery pack, typically under the vehicle floor between the axles. The guides specify battery voltage (commonly 400–800 volts), capacity in kilowatt-hours, and battery chemistry (predominantly lithium-ion) (NTSB, 2020). Some guides provide module-level information showing how individual battery modules are arranged within the pack, although the level of detail varies across manufacturers.

Towing and storage recommendations address post-incident vehicle handling. Nearly all guides recommend flatbed towing to prevent voltage generation from turning wheels. SAE J2990 specifies that if wheels must be turned during recovery operations, speed should be kept below 5 miles per hour (SAE International, 2019). Storage recommendations consistently emphasize the need for isolation, with most guides recommending a 50-foot separation from structures and other vehicles on all sides, or alternatively, physical barriers constructed of earth, steel, or concrete (NTSB, 2020; SAE International, 2019).

National Guidelines and Standards

National Fire Protection Association Guidance

NFPA has developed several resources to support emergency response to EV incidents. The U.S. Emergency Responder Safety Training for Advanced Electric Drive Vehicles launched in 2010, training more than 30,000 emergency responders in 48 states (Klock, 2013). In 2023, NFPA has since expanded this effort through its Alternative Fuel Vehicles Safety Training program (NFPA, 2025b). The training covers vehicle identification, hazard recognition, fire suppression tactics, and post-incident considerations. NFPA offers both online and in-person training modules, allowing fire departments to select formats appropriate to their resources and training schedules.

NFPA's guidance continues to evolve as new research and incident experience become available. A notable recent example occurred in January 2025, when NFPA issued guidance cautioning against the use of fire blankets for EV fires (U.S. Fire Administration, 2025). Fire blankets, which some manufacturers and organizations had promoted as a tool to contain EV fires and reduce water usage, were found to present risks in certain scenarios. The NFPA notice highlighted that blankets might trap heat and gases, potentially exacerbating thermal runaway conditions rather than suppressing them. This shift demonstrates the dynamic nature of best practices in EV emergency response.

Although NFPA guidance focuses primarily on fire service operations, many principles apply to multi-agency response. The emphasis on scene safety, hazard communication, and extended incident timelines has implications for all responders, including transportation agencies managing traffic during these incidents.

SAE J2990 Recommended Practice

SAE J2990, "Hybrid and EV First and Second Responder Recommended Practice," provides standardized guidance for emergency responders, towing operators, and vehicle storage facilities (SAE International, 2019). The document addresses the full incident lifecycle, from initial response through vehicle storage and final disposition.

Towing protocols represent a key contribution of SAE J2990. The standard recommends flatbed towing for all damaged EVs to avoid generating voltage through wheel rotation. When wheels must be turned during vehicle recovery, such as when a vehicle is off the road or positioned in a way that prevents direct loading onto a flatbed, the standard specifies that speed should not exceed 5 miles per hour. After loading, the vehicle's structural integrity should be monitored. If the vehicle shifts or rolls while on the tow truck, inspection procedures should be repeated (SAE International, 2019).

Storage requirements in SAE J2990 address the unique risks of EV batteries. The standard presents two acceptable barrier methods: separating the vehicle from combustibles and structures by at least 50 feet on all sides, or creating a barrier of earth, steel, concrete, or solid masonry around the vehicle. The standard acknowledges that many tow yards lack sufficient space to maintain 50-foot clearances, making physical barriers the more practical option for many facilities. The standard recommends that storage areas be well ventilated to prevent gas accumulation and that vehicles be monitored with thermal imaging cameras when available (SAE International, 2019).

Hazard communication recommendations in SAE J2990 emphasize the need for clear information flow between manufacturers, emergency responders, and downstream handlers. The standard notes that a 24-hour manufacturer hotline, although useful, should not be the primary method of communication for time-sensitive emergencies. Instead, the standard recommends that emergency response guides be available digitally at all times and that information be accessible to third parties that may aggregate and repackage it for easier field use (SAE International, 2019).

Post-incident inspection procedures outlined in SAE J2990 provide a systematic approach to assessing vehicle condition. The inspection includes checking for battery damage indicators such as deformation of the battery case; electrolyte leakage, which may present as a sweet smell similar to ether; carbon traces indicating loss of high-voltage isolation; evidence of arcing; and thermal damage. The standard recommends that towing operators notify storage facilities of potential hazards and that vehicles be inspected again after transport and periodically during storage (SAE International, 2019).

National Transportation Safety Board Recommendations

NTSB's 2020 special investigation report, *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles,* analyzed four EV battery fires that occurred during a 1-year period (NTSB, 2020). The investigation identified several safety concerns and made recommendations to improve emergency response.

Stranded energy emerged as a critical safety issue. Even when parts of a battery pack are severely damaged, intact cells may retain substantial voltage. In the incidents investigated by NTSB, stranded energy contributed to battery reignition hours and even days after initial fires were suppressed. In one case, a battery reignited 5 days after the crash, highlighting the persistent nature of this hazard. NTSB found that first responders often lack tools to measure stranded energy because most electrical testing equipment is designed for alternating current rather than the direct current in EV batteries.

Extended observation periods are necessary but create operational challenges. NTSB documented cases in which batteries reignited during transport, requiring tow truck operators to stop and firefighters to respond again. In one incident, a tow truck operator suffered minor burns while attempting to lower a reigniting vehicle from the flatbed. The need for extended observation conflicts with the operational imperative to clear roadways quickly, presenting difficult decisions for incident commanders and transportation officials.

Storage facility challenges received significant attention in the NTSB report. The 50-foot separation distance recommended by manufacturers and standards organizations often proves infeasible at tow and storage yards. In multiple incidents investigated by NTSB, yard operators attempted to provide separation but lacked sufficient space to achieve 50-foot clearances on all sides. One facility managed only 40 feet on two sides, 20 feet on a third side, and 10 feet from a concrete wall on the fourth side. This spatial constraint puts other vehicles, buildings, and personnel at risk if stored batteries reignite.

Multi-agency coordination requirements became apparent in the incidents reviewed. The NTSB noted that successful outcomes required coordination between fire departments, law enforcement, highway patrol, towing services, and, in some cases, manufacturer representatives. In one incident on a California highway, the fire department coordinated with the highway patrol to keep the highway closed while awaiting manufacturer engineers. The manufacturer sent battery specialists who spent hours attempting to stabilize the vehicle on scene before determining it needed to be removed. A fire engine escorted the tow truck for more than an hour to the storage facility. Such extended, complex operations require incident management structures that clearly define roles and maintain coordination during many hours.

National Highway Traffic Safety Administration Interim Guidance

In 2012, NHTSA issued interim guidance for electric and hybrid EVs equipped with high-voltage batteries (NHTSA, 2012). Developed with assistance from NFPA, the U.S. Department of Energy, and other stakeholders, the guidance targets three audiences: vehicle owners and the general public, emergency responders, and towing operators and storage facilities.

The guidance emphasizes general safety principles rather than vehicle-specific procedures. For all crashes involving electric or hybrid vehicles, the guidance recommends that responders assume high-voltage batteries are energized and treat exposed components as energized. The guidance advises responders to use personal protective equipment appropriate for electrical hazards and to avoid contact with high-voltage components, which are typically orange in color.

For fires involving lithium-ion batteries, NHTSA's guidance notes that large, sustained volumes of water will be required for extinguishment. If the threat to life or property is not immediate, the guidance suggests considering defensive tactics and allowing the fire to burn while protecting exposures. This recommendation aligns with manufacturer guidance but presents challenges in many roadway scenarios in which allowing prolonged burning may not be acceptable due to traffic impacts, smoke hazards, or proximity to structures.

The guidance addresses post-incident vehicle handling, recommending that damaged vehicles not be stored inside structures or within 50 feet of structures or other vehicles. The guidance advises that passenger and cargo compartments should remain ventilated to prevent gas accumulation and that authorized service centers or manufacturer representatives should be notified as soon as possible for guidance on additional safety measures.

Although NHTSA's interim guidance provides useful general principles, it offers limited specificity on the role of transportation agencies in incident management. The guidance does not address traffic control, roadway closure duration, or coordination between fire services and highway authorities. This gap reflects the document's primary focus on first responders and vehicle handlers rather than transportation operations.

State, Regional, and Local Protocols

Virginia

Virginia has taken proactive steps to address EV fire safety through legislative action. House Bill 2451, passed in 2023, requires all professional and volunteer firefighters in Virginia to complete EV fire training by December 1, 2025 (Lawrence, 2023). The Virginia Department of Fire Programs developed the EV training program, which is available in both online and in-person formats to accommodate different department needs and resources (Lawrence, 2023).

The mandated training program covers EV identification, battery fire characteristics, suppression tactics, and safety considerations for responders. Training materials address thermal runaway processes, the potential for battery reignition, toxic gas hazards, and proper use of personal protective equipment. The program includes information on the large water volumes required for EV fire suppression, with specific guidance on techniques for applying water to battery packs located under vehicle floors.

Virginia's current approach focuses primarily on fire suppression and firefighter safety. The training program, although comprehensive for its intended audience, does not specifically address traffic incident management coordination or the role of transportation agencies in EV incidents.

Chesterfield County

Chesterfield County, Virginia, has implemented a comprehensive system for managing EV towing and storage through its police towing contracts. The county contracts with 19 towing companies, of which 5 have agreed to handle EV incidents. The county requires towing contractors that wish to handle electric and hybrid vehicles to establish accounts with the Energy Security Agency (ESA), a private organization that provides technical assessment and guidance for damaged EVs.

Under Chesterfield's system, when a towing contractor responds to an incident involving an electric or hybrid vehicle, they must contact ESA before or immediately on arrival. ESA provides remote assessment based on photographs and information about the incident. The assessment results in a color-coded placard system that communicates risk level and required actions.

Green placards indicate minimal risk. In this case, the vehicle showed no significant battery damage during ESA assessment. Storage can proceed at regular rates with normal spacing requirements. Towing contractors receive an additional surcharge of $250 for disabled vehicles or $250 for crashed vehicles to account for the assessment process and required use of dollies or skates when towing EVs. According to Chesterfield County's towing program coordinator, approximately 90% of ESA evaluations result in "green tag" status.

Yellow placards indicate moderate risk and require a 2-day isolation period. In this situation, the ESA assessment identified potential battery concerns that warrant monitoring. Vehicles must be stored with appropriate spacing or barriers, and contractors can charge up to $250 per day during the isolation period (for a maximum of 2 days). After the isolation period expires, regular storage rates apply. The surcharge structure is $250 for disabled vehicles and $500 for crashed vehicles.

Red placards indicate high risk and require a 30-day isolation period. Significant battery damage was identified during assessment in these cases. Storage requires the same separation or barrier requirements as yellow placards, with the same $250 per day rate applicable for up to 30 days. The surcharge is $250 for disabled vehicles and $500 for crashed vehicles.

The system includes important safeguards. Contractors must release vehicles to owners even during isolation periods because the isolation period represents a recommended monitoring timeframe rather than mandatory impoundment. Contractors are encouraged to use liability release forms when releasing vehicles before the isolation period expires. All assessments, photographs, and placard information must be retained for audit purposes.

Chesterfield County's approach addresses several challenges identified in other jurisdictions. The ESA assessment provides expert evaluation that towing contractors may lack the training to perform independently. The placard system creates clear, visual communication of risk level that travels with the vehicle. The tiered pricing structure acknowledges the additional costs, liability, and storage requirements for EVs while preventing price gouging. The system also provides documentation that benefits all parties, as contractors have records justifying their actions, insurance companies have assessment data, and public safety officials have monitoring information.

Philadelphia Region

The Delaware Valley Regional Planning Commission (DVRPC), which serves the Greater Philadelphia region, including parts of Pennsylvania and New Jersey, developed comprehensive best practices for EV emergency operations (DVRPC, 2024). Published in May 2024, the DVRPC guide represents collaboration between fire services, law enforcement, emergency medical services, hazmat teams, towing operators, and transportation agencies.

DVRPC's best practices emphasize coordinated multi-agency response from initial dispatch through final vehicle disposition. The guidance recommends that dispatch centers determine vehicle type during 911 call intake. If an EV fire is confirmed or suspected, dispatch should notify fire services, police, Emergency Medical Services (EMS), hazmat representatives, towing services, the roadway authority (state DOT or toll authority), and the communications center. This comprehensive notification ensures that all stakeholders are aware of the incident early and can coordinate a response.

The DVRPC guide includes detailed protocols for each responder type. For fire services, the guidance covers apparatus positioning, water supply considerations, battery fire tactics, and post-suppression monitoring. For law enforcement, the guidance addresses scene security, traffic control, and coordination with the roadway authority for extended closures. For EMS, the guidance covers smoke exposure treatment and awareness of hydrofluoric acid risks from battery fires (DVRPC, 2024).

Towing protocols in the DVRPC guide address both immediate and long-term considerations. The guidance recommends that towing operators engage with ESA or similar assessment services before moving damaged EVs. Equipment specifications include requirements for flatbed tow trucks with steel decks and gross vehicle weight ratings appropriate for heavy EVs. The guide notes that most EVs exceed the capacity of standard dollies, reinforcing the need for flatbed equipment (DVRPC, 2024).

The DVRPC guide candidly addresses liability and cost issues that other guidance documents often overlook. The guide notes that towing operators face the greatest liability with the least protection and support. Risks include hazardous exposure to employees, potential total loss of equipment if a vehicle reignites during transport, property damage at storage facilities, and environmental cleanup costs for contaminated firefighting water. The guide recommends that regulatory agencies and municipalities adjust towing rates to account for EV-specific risks, training, and equipment requirements. It also suggests that towing operators who choose not to handle EVs should not be penalized, given the substantial risks involved (DVRPC, 2024).

Current VDOT Protocols

Existing Traffic Incident Management Framework

VDOT has developed a mature traffic incident management program with strong partnerships and established procedures. The VDOT Traffic Incident Management Strategic Plan, most recently revised in July 2025, outlines a comprehensive approach to managing roadway incidents through multi-agency coordination.

VDOT incident management coordinators serve as the primary interface between transportation operations and emergency responders. Incident management coordinators operate in each district and maintain relationships with fire departments, law enforcement, EMS, towing operators, and other stakeholders. They participate in local and regional traffic incident management meetings that bring together responders from multiple agencies and jurisdictions. These meetings provide forums for discussing operational challenges, reviewing incident responses, and developing coordinated approaches to common problems.

The Safety Service Patrol program provides roving assistance on high-volume corridors. Safety Service Patrol vehicles help with minor incidents, provide traffic control, and can request additional resources when needed. The program reduces incident duration for many events and improves safety for stranded motorists. Safety Service Patrol operators complete training on incident response, traffic control, and coordination with other agencies.

VDOT has established numerous Instructional and Informational Memoranda that guide traffic incident response. IIM-TOD-24-02.1 (VDOT, 2025) establishes the Traffic Incident Process, providing a structured workflow for incident detection, notification, assessment, scene management, and clearance. IIM-TOD-19-01.3 (VDOT, 2024a) covers Incident Photograph and Video Streaming Guidance, establishing procedures for documenting incident conditions to support situational awareness at Traffic Operations Centers (TOCs). IIM-TOD-20-02.3 (VDOT, 2024b) addresses Two-Way Radio Communications, ensuring effective coordination during incidents.

VDOT has both a Towing Recovery Incentive Program and a program for contract, staged wreckers for heavy-duty towing. These programs ensure that appropriate equipment and expertise are available for vehicle removal, particularly for large commercial vehicles that require specialized recovery capabilities. Towing contractors must meet established requirements for equipment, insurance, and response times.

TOCs serve as coordination hubs during incidents. TOC operators monitor traffic conditions, coordinate with field personnel, manage traveler information systems, and activate resources as needed. For significant incidents, TOCs can implement detour plans, activate changeable message signs, and coordinate with adjacent jurisdictions when incidents affect regional traffic patterns.

VDOT's protocols for EV incidents remain limited, with no specific guidance in existing Instructional and Informational Memoranda for handling EV fires differently from conventional vehicle fires.

Limited Electric Vehicle-Specific Guidance

Despite VDOT's strong general traffic incident management framework, protocols specific to EV fires remain underdeveloped. Current Instructional and Informational Memoranda do not distinguish between EV fires and conventional vehicle fires. The Traffic Incident Process applies the same assessment and response procedures regardless of vehicle type or power source.

This gap means that VDOT personnel may not be aware of the unique characteristics of EV fires when they respond to incidents. The extended duration potential, reignition risk, and need for specialized assessment are not reflected in current protocols. Without specific guidance, field personnel may not recognize when an incident requires different coordination or duration planning than a conventional vehicle fire.

VDOT's current towing contracts do not include provisions specific to EVs. Unlike Chesterfield County's system, VDOT contracts do not require towing operators to have capabilities for EV assessment, specialized storage, or extended monitoring. Pricing structures do not account for the additional costs and risks that EVs present to towing operators. This gap may result in towing contractors being unprepared for EV incidents or unwilling to accept such tows because of liability concerns.

Storage facility requirements in VDOT's towing programs do not address the 50-foot separation recommended for damaged EVs. VDOT has not established relationships with assessment services like ESA, leaving gaps in how damaged EVs are evaluated and monitored after removal from roadways. Without these systems, reignition events at storage facilities may occur without adequate preparation or monitoring.

Training for VDOT personnel on EV hazards remains limited. Although Virginia's mandate requires firefighters to complete EV safety training, no equivalent requirement exists for VDOT field staff, incident management coordinators, or TOC operators. These personnel may encounter EV fires but lack specific knowledge about the hazards, required response duration, or coordination needs. The absence of training means VDOT personnel may not know when to request additional resources or what information to provide to TOCs for traffic management planning.

Coordination protocols with fire departments during extended EV incidents are not established. Current procedures assume that once fire services arrive and assume scene command, VDOT's primary role is traffic control and clearance support. However, EV fires may require hours of cooling and observation, creating scenarios in which fire services maintain scene control for extended periods while VDOT manages traffic impacts. Clear protocols for this extended coordination do not currently exist.

Summary

The review of current emergency response guidelines reveals both operational challenges and emerging solutions as EV incidents become more common on Virginia roadways.

The primary operational consideration is incident duration. Although conventional vehicle fires typically clear within 30 minutes to 2 hours, manufacturer guides and NTSB documentation indicate EV battery fires may require 6 to 10 hours of cooling and observation. This extended timeframe affects traffic management strategies, resource deployment, and public communication. Current incident classification systems do not distinguish between conventional and electric vehicles, limiting the ability to anticipate these extended durations or track incident patterns over time.

Promising practices are emerging across jurisdictions to address these challenges. Third-party assessment services, such as ESA, provide specialized expertise through color-coded risk placarding. Chesterfield County and other jurisdictions have incorporated these assessment systems into their towing contracts, creating standardized risk communication and documentation. Fire departments are adopting context-dependent strategies, applying continuous suppression near critical infrastructure while using defensive tactics in rural areas without immediate threats. Transport and storage protocols have evolved to address reignition risks, with consensus around flatbed-only transport and alternatives like concrete barrier storage. DVRPC's comprehensive checklist demonstrates how these modifications can be systematized.

Virginia's mandatory firefighter training establishes important baseline knowledge, and VDOT's Traffic Incident Management framework provides strong multi-agency partnerships for coordination. As EV adoption continues, these emerging practices of systematic assessment, flexible response strategies, and modified handling protocols can be integrated into existing incident management structures. The innovations documented here represent practical adaptations that build on current capabilities rather than requiring wholesale system changes.

Interviews with Incident Responders

Representatives from fire departments, law enforcement, towing operators, and VDOT incident management in Virginia were contacted via telephone to determine current best practices for EV fire incidents. Interviewees were identified from existing VDOT incident management partnerships, including TRIP participants and emergency services agencies operating along high-volume corridors.

Interviews were unstructured and covered experiences with EV fires, current practices, training received, and the state of EV incident response capabilities. Interviewees were asked about best practices identified in Tasks 1 and 3 to determine familiarity with emerging techniques and perceived feasibility for Virginia operations. One out-of-state contact (Florida DOT) was also interviewed to understand approaches in a state with higher EV adoption rates.

A total of 12 interviews were conducted between July and September 2025. Interviewees represented fire departments in Chesterfield County, Loudoun County, and Virginia Beach; law enforcement from the Virginia State Police; towing operators from five VDOT districts (Bristol, Fredericksburg, Richmond, Salem, and Staunton); VDOT incident management coordinators; and tunnel operations managers. One interview was conducted with Florida DOT's Traffic Incident Management Program Manager.

Fire Department Practices

Fire departments have varying approaches to EV fires, depending on location and available resources. Chesterfield County Fire and EMS reported their policy is to initiate fire attack with water and search for victims, but if the initial attack is unsuccessful, they assess whether it is safe to allow the fire to burn. Their most recent EV fire lasted approximately 6 hours. The department expressed concern about thermal runaway characteristics and noted that under critical infrastructure, such as overpasses, they continue active suppression regardless of duration.

Loudoun County Department of Fire and Rescue has adopted different strategies for urban versus rural settings. In rural areas, they generally allow fires to burn to minimize toxic runoff, whereas in urban areas, they apply water. The department recently participated in a research project funded by UL (previously Underwriters Laboratories) testing EV fire blankets, which revealed explosion risks when gases accumulate under blankets. Based on this research, they have moved away from blanket use. Loudoun County is exploring high-pressure piercing nozzles such as PyroLance or Cold Cut Cobra systems that can penetrate battery casings with minimal water use. Several local departments, including Culpeper County and Brandy Station, have mounted these systems on brush trucks. The PyroLance approach can extinguish fires in 10 to 30 minutes using significantly less water than traditional methods, although questions remain about electrical conductivity through water lines.

Fire departments universally expressed that the most valuable support VDOT can provide is rapid traffic diversion and control. Several departments mentioned that fire blankets were previously considered helpful, but recent research has raised safety concerns, and the cited $2,500- to $2,800-per-unit cost, combined with single-use limitations, makes them impractical.

Law Enforcement and Incident Management

A Virginia State Police Sergeant from the Northern Neck area reported seeing a slow increase in EV incidents, particularly with electric buses. He noted that sand has been more effective than water in some cases. However, the Virginia State Police has not issued updated policies specific to EV fires from headquarters.

VDOT incident management coordinators reported concerns about moving EVs using standard push-pull-tug procedures. Several sources indicated that rotating the wheels can generate power back into the battery pack, potentially causing vehicle movement or increasing fire risk. This phenomenon was compared with how toy cars with regenerative mechanisms work. One VDOT coordinator suggested that, in extreme circumstances, front-end loaders or similar heavy equipment could be used to move EVs away from critical infrastructure in extenuating circumstances if responders agree and deem it safe.

Florida DOT's Traffic Incident Management Program Manager reported that thermal runaway events have not been common enough to justify major program changes. Florida has a Rapid Incident Scene Clearance program that would be activated for EV fires. Some towing companies in Florida's District 3 have created concrete bunker storage facilities and proactively reach out to traffic incident management teams when they become aware of EV incidents. Florida DOT provides incentives for quick clearance (up to $6,500) but separates this cost from cleanup costs, which are billed to the responsible party.

Towing Industry Practices

Towing operators across VDOT districts reported significant variability in capabilities and preparedness. No statewide regulations currently exist for towing company training or equipment requirements specific to EV incidents. Some companies have invested heavily in specialized equipment and training, whereas others lack a basic understanding of EV systems. One operator described using rotators—specialized truck-mounted cranes—to lift damaged EVs into dumpster-style containers mounted on flatbed trailers, minimizing damage that could occur from reignition during transport. Other operators reported minimal training and storage facilities for damaged EVs. This variability contrasts with more structured approaches in other states, such as Florida's Rapid Incident Scene Clearance program, which establishes qualification requirements and standardized protocols for participating operators.

Interviews with towing operators revealed that adoption of the ESA evaluation system has been uneven across Virginia. Although some operators regularly use ESA, many others remain unaware of such services or view them as optional. Operators who regularly use ESA reported that the system provides valuable liability protection through documented risk assessment and clear guidance on storage requirements.

Storage infrastructure is a statewide challenge. Several operators have constructed dedicated containment facilities, including concrete bunkers and barrier systems, to meet the 50-foot separation requirements. Others are exploring alternative solutions such as roll-off containers filled with dirt to create temporary isolation areas. However, many operators lack appropriate storage facilities entirely, creating uncertainty about where to transport EVs requiring extended isolation periods, which ESA may recommend for up to 40 days based on damage assessments.

Transport protocols vary but show emerging consensus around certain practices. Most operators use flatbed trailers exclusively to avoid wheel rotation that could generate electricity in damaged systems. Many companies carry wheel skates on all trucks for this purpose. Temperature monitoring emerged as a standard practice, with operators waiting for fire department verification that battery temperatures have dropped below threshold levels (typically around 300°F) before transport. Several operators reported that when transporting vehicles at risk of thermal runaway, they choose routes that avoid tunnels and bridges even when it adds significant time and distance, although these decisions are made individually rather than through formal policy. Some operators dedicate older or less valuable trucks to EV transport because of reignition risks, and others request fire department escorts during transport. One operator described protocols of lifting vehicles using rollbacks to spray water underneath, although acknowledging limited effectiveness given battery pack waterproofing.

Wastewater disposal from suppression efforts presents an unresolved environmental challenge. Operators reported that no entity currently accepts responsibility for contaminated water from EV fire suppression that may contain toxic materials from battery components. Some companies have attempted mitigation strategies, including using absorbent materials like baking soda, but disposal pathways remain unclear. The lack of standardized storage facilities across Virginia was cited as a significant gap, with operators uncertain where to transport vehicles after recovery, particularly when extended isolation is recommended.

Tunnel Operations

Big Walker and East River Mountain Tunnels use TOM, LLC as contractors for incident management. Their Training Coordinator and Manager reported that tunnel operations have not yet experienced EV fires but have developed contingency plans. Their approach prioritizes protecting tunnel infrastructure first. They plan to use fire blankets to contain fires and monitor temperature using thermal cameras. Emergency response teams of five people are stationed at the tunnels. The tunnels do not have built-in fire suppression systems, so portable equipment would be used. They noted that towing companies in the area did not have isolation facilities a couple of years ago, although they were uncertain about the current status.

Water Quality and Environmental Concerns

Fire department representatives universally expressed concerns about runoff from EV fire suppression. The runoff is considered extremely toxic and can contaminate drinking water supplies. Paradoxically, allowing fires to burn completely may produce less environmental contamination than using large water volumes because complete combustion eliminates some toxins while creating air pollution instead of water pollution.

Multiple interviewees mentioned the Virginia Department of Environmental Quality’s role in managing this contamination, but specifics about cleanup protocols or disposal requirements were unclear. Jason Simmons of Hugh’s Transport Inc. towing in Buchanan, Virginia, noted that hazmat companies charge extremely high rates for lithium-ion battery disposal, providing an example of $1,300 for four AA lithium-ion batteries. These costs can create economic barriers to proper cleanup.

Identify Best Practices and Gaps

Synthesis of literature review findings, emergency response guideline review, and interview responses revealed several emerging best practices alongside significant gaps in current capabilities for managing EV fire incidents. This section characterizes effective strategies currently in use and areas requiring additional development.

Emerging Best Practices

Context-Dependent Fire Suppression Strategies

Interview responses and literature review findings revealed a growing recognition that fire suppression tactics should vary based on incident location and infrastructure criticality. Fire departments reported adopting different strategies depending on whether incidents occur near critical infrastructure or in rural areas without immediate threats.

Near critical infrastructure such as bridges, tunnels, and overpasses, fire departments consistently apply continuous water suppression despite the large volumes required. Chesterfield County Fire and EMS reported that their most recent EV fire near critical infrastructure required approximately 6 hours of active water application. This approach prioritizes infrastructure protection over operational efficiency, recognizing that structural damage from prolonged fire exposure could create far greater disruption than extended lane closures.

In rural areas or locations without immediate threats to life, property, or infrastructure, several fire departments reported allowing fires to burn, with defensive tactics focused on preventing spread. This “let it burn” approach aligns with NHTSA interim guidance developed in consultation with NFPA that suggests considering defensive tactics when no immediate threat exists. Loudoun County Department of Fire and Rescue reported implementing this strategy in rural settings to minimize toxic runoff contamination. Interview responses suggested that complete combustion may reduce total incident duration compared with water suppression, although this approach produces significant air quality impacts and remains controversial.

The literature review supported this context-dependent approach. Brzezinska and Bryant (2022) noted that water remains the most effective cooling agent but requires volumes that may not be practical or environmentally preferable in all scenarios. The choice between active suppression and defensive tactics is a risk management decision balancing infrastructure protection, environmental contamination, traffic impacts, and incident duration.

Third-Party Technical Assessment Systems

Chesterfield County’s implementation of the ESA evaluation system represented the most developed third-party assessment approach identified during interviews. Under this system, towing contractors contact ESA before or immediately on arriving at incidents involving electric or hybrid vehicles. ESA provides remote assessment based on photographs and incident information, then issues color-coded placards communicating risk level and required actions.

Chesterfield County's towing program coordinator reported that approximately 90% of ESA evaluations result in green tag status, suggesting that most damaged EVs do not present elevated fire risk. This finding indicates that systematic assessment can identify the subset of vehicles requiring special handling while allowing routine processing of most damaged EVs.

Florida DOT reported similar approaches emerging among towing contractors in their jurisdiction, with some companies in District 3 creating concrete bunker storage facilities and proactively coordinating with traffic incident management teams when they become aware of EV incidents. This pattern suggests that third-party assessment systems represent an emerging industry best practice rather than an isolated innovation.

Modified Towing Protocols

Interview responses revealed consensus around several towing protocol modifications specific to EVs. All interviewed towing operators reported using flatbed transport rather than dollies or traditional towing methods. This approach addresses concerns about wheel rotation generating electricity back into damaged battery packs, a phenomenon compared by one VDOT coordinator with regenerative mechanisms in toy cars.

Temperature monitoring before transport initiation emerged as a common practice among interviewed operators. Vehicle temperatures must be below a certain threshold for a minimum amount of time before permitting transport, with firefighters using infrared cameras to verify battery pack temperatures. Operators typically wait 30 to 45 minutes after fire department clearance before initiating transport to allow additional cooling. Some operators reported requesting fire department escorts during transport, although such requests depend on individual relationships between agencies and local resources.

The variable nature of towing operator capabilities represents both a best practice consideration and a gap. Although some operators have invested in specialized equipment and training, even using small cranes to lift vehicles into truck-mounted dumpsters for transport, capabilities vary significantly among towing companies. Interviewed towing companies report that some responding operators may have little to no training on EV procedures, and some tow yards may not have space or facilities to store damaged EVs at risk of reignition.

Storage Solutions Addressing Space Constraints

The 50-foot separation distance recommended by manufacturers and standards organizations exceeds the practical capabilities of many storage facilities, particularly in urban areas. Interview responses revealed two approaches to managing this constraint: physical barriers and dedicated isolation areas.

One towing company reported constructing two concrete bunkers specifically for EV storage. These structures provide physical containment that serves as an alternative to open-area separation distances. Chesterfield County's system allows towing operators to construct safety berms using concrete barriers on three sides with drainage below when permanent isolation areas are not available. This pragmatic approach acknowledges that perfect compliance with separation distance recommendations may be impossible while still providing meaningful risk reduction.

Storage facility modifications require significant capital investment. Interview responses indicated that operators who choose to handle EVs must balance this investment against the relatively low frequency of EV incidents requiring extended isolation. Chesterfield County uses a tiered pricing structure, with surcharges of $250 for disabled EVs or $500 for crashed EVs, plus up to $250 per day during isolation periods. This structure provides economic justification for these investments while preventing price gouging.

Transport Routing and Escort Protocols

Several jurisdictions have developed transport protocols that acknowledge the persistent reignition risk of damaged EV batteries during towing operations. These protocols balance operational efficiency with infrastructure protection and public safety.

Fire department escorts during transport emerged as a practice among some towing operators interviewed, although implementation depends on individual relationships between agencies rather than formal protocols. Some tow operators reported requesting fire department escorts when transporting vehicles that experienced thermal runaway, recognizing that reignition during transport creates immediate hazards for the tow operator and surrounding traffic, but the practice was not universal. The escort vehicle can provide immediate suppression capability if reignition occurs, reducing response time from minutes to seconds.

Strategic routing to avoid critical infrastructure is another emerging practice, although formal implementation remains limited. The risk of battery reignition in confined spaces such as tunnels or on major bridges creates scenarios with catastrophic potential, such as limited escape routes, concentrated smoke exposure, and restricted emergency access. A battery reignition in the Hampton Roads Bridge-Tunnel or the Chesapeake Bay Bridge-Tunnel, for example, could trap hundreds of vehicles and create mass casualty potential from toxic smoke exposure. Similarly, reignition on high-volume bridges could necessitate the complete closure of critical transportation links.

Some operators interviewed reported informal practices of avoiding tunnels and taking longer surface routes when transporting vehicles with known battery damage. However, individual operators make these decisions ad hoc rather than through systematic risk assessment. The absence of formal routing protocols means that damaged EVs may transit through critical infrastructure based solely on the shortest path to storage facilities.

DVRPC’s (2024) best practices guide represents the most developed framework identified, recommending comprehensive notification of all stakeholders when an EV fire is confirmed or suspected. This early notification allows transportation authorities to provide routing guidance before transport begins. However, the guide stops short of mandating specific routing restrictions or escort requirements.

Implementation challenges include resource constraints and coordination complexity. Fire departments may lack available units for extended escort duties, particularly during transport to distant storage facilities. Longer alternative routes increase transport costs and time, creating economic disincentives without contractual provisions for compensation. The determination of which vehicles require special handling remains subjective without systematic assessment protocols like the ESA's color-coded system.

Chesterfield County's tiered risk assessment provides a potential framework for determining escort and routing requirements. Green-tagged vehicles with minimal risk could follow normal transport procedures. Yellow-tagged vehicles requiring isolation might warrant routing restrictions to avoid critical infrastructure. Red-tagged vehicles with high reignition risk could require both fire escorts and mandatory alternative routing. This risk-based approach allocates limited resources to the highest risk scenarios while avoiding unnecessary restrictions for the approximately 90% of damaged EVs that pose minimal risk.

For VDOT, formalized transport protocols could be integrated into towing contracts and Instructional and Informational Memoranda. Requirements might include mandatory notification to the TOC when transporting vehicles involved in thermal runaway events, consultation with TOC for routing guidance that avoids tunnels and major bridges when feasible alternatives exist, and coordination with fire departments for escort availability based on risk assessment. These protocols would require modification of existing contracts to address additional time and mileage costs for alternative routing, similar to how Chesterfield County's pricing structure acknowledges the additional costs of EV incidents.

High-Pressure Piercing Nozzle Systems

Interview responses and recent deployments indicate the growing adoption of high-pressure piercing nozzle systems, specifically PyroLance and Cold Cut Cobra technologies, for rapid suppression of EV battery fires. These systems represent a significant departure from conventional water application methods by directly accessing battery cells through penetration of protective casings.

PyroLance technology operates at ultra-high pressure (1,200–1,500 pounds per square inch), creating water droplets that can extinguish 90 to 95% of fires via indirect attack. The system uses a combination of high-pressure water and granite abrasive material to pierce through steel, concrete, or other materials at "phenomenal rates," creating a pea-sized hole through which atomized water can be delivered directly to the fire source (Industrial Fire World, 2014). The system operates at a 10-gallons-per-minute flow rate and can be deployed up to 1,000 feet from the ultra-high-pressure pump using a three-fourths-inch high-pressure hose (Industrial Fire World, 2014).

Cold Cut Cobra is a similar product used predominately in Europe. In a 2023 study, the Swedish Civil Contingencies Agency testing demonstrated that the Cobra system could prevent thermal runaway propagation within 10 minutes using only 60 gallons of water compared with the more than 2,900 gallons that some manufacturers recommend for conventional suppression methods (CTIF, 2023b).

Real-world deployments provide validation of effectiveness. Prague fire services successfully used Cobra on an EV fire in an underground parking garage in May 2024, with firefighters using the cutting extinguisher to break through the battery casing for direct cooling (CTIF, 2023a). In May 2025, Portland Fire and Rescue in Oregon became the first U.S. fire department to deploy this technology. The department has reported that the system addresses critical safety concerns by containing toxins inside the battery compartment rather than allowing them to disperse as smoke or contaminated runoff (Portland Fire and Rescue, 2025).

However, significant barriers to adoption remain. Cost is significant, with systems ranging from $10,000 to $80,000 depending on configuration. The specialized nature of the equipment means that departments must justify investment for relatively low-frequency EV fire incidents. Training requirements add additional costs because operators need instruction in proper piercing techniques, battery anatomy identification, and thermal imaging integration to locate optimal penetration points.

Operational limitations include the need for precise knowledge of battery pack geometry and construction. As Battalion Chief Jasen Dodson from Loudoun County noted in interviews, manufacturer emergency response guides often lack critical information such as battery vent port locations, making optimal lance positioning challenging. The systems also require specific support equipment, including thermal imaging cameras for identifying hot spots, personal protective equipment for operators working in proximity to thermal runaway events, and adequate water supply despite reduced volume requirements.

Integration challenges with existing fire service operations present additional considerations. The Cobra operator requires protection from jet flames exiting the battery pack during suppression, necessitating the use of coordinated multi-person crews. Communication between the Cobra operator, thermal imaging camera operator, and incident commander is essential for effective deployment (Bäckmark, 2023). Questions remain about electrical conductivity through water lines when penetrating high-voltage systems, although manufacturers assert safety with proper procedures.

The deployment model emerging from early adopters suggests that regional or shared equipment strategies may be the most practical. Such specialized vehicles could be strategically positioned along high-EV-traffic corridors or shared among multiple jurisdictions.

Gaps

Data and Tracking Systems

Current VDOT incident management systems cannot identify or track EV fires, preventing agencies from understanding the scope and characteristics of these incidents. TOCs record all vehicle fires identically, whether they involve a 30-minute conventional vehicle fire or a 10-hour EV battery incident. Without tracking EV incidents, VDOT cannot measure the scale of the problem, assess whether policy changes reduce incident duration, or calculate the costs and benefits of equipment investments. The system cannot identify high-risk corridors where specialized resources should be staged or provide accurate reporting to federal agencies that are increasingly focused on EV safety. As one TOC operator noted during interviews, they often know they are dealing with an EV fire from radio traffic but have no way to document it in their systems.

Towing Readiness and Infrastructure

Interviews with towing operators revealed highly variable preparedness for EV incidents across Virginia, with capabilities ranging from comprehensive programs to a complete lack of awareness. No statewide regulations exist for towing company training or equipment requirements specific to EVs. Some operators have invested in concrete bunkers, specialized training, and ESA partnerships, whereas others remain unaware of basic battery hazards or reignition risks.

Some tow yards are unable to accommodate the 50-foot separation distance recommended by NTSB (2020), especially in urban areas. SAE International (2019) has recommended alternatives such as concrete barriers, roll-off containers, or purpose-built bunkers but implementation remains inconsistent. Operators report that damaged EVs requiring extended isolation periods of up to 40 days can overwhelm available storage capacity.

Specialized Suppression Equipment Availability

High-pressure piercing nozzle systems and other specialized suppression technologies show promise for reducing EV fire suppression time from 6 to 10 hours to 10 to 30 minutes, although questions remain about their effectiveness in all scenarios. These tools remain largely unavailable to Virginia fire departments because of acquisition costs ranging from $15,000 to $80,000 per unit, placing them beyond reach for many departments, particularly smaller rural agencies.

CONCLUSIONS

- *Vehicle fire incident durations have increased in ways consistent with growing EV adoption.* Analysis of 172,110 vehicle fire incidents from 2016 to 2024 revealed a significant shift toward longer incident durations in the post-pandemic period. The percentage of fires exceeding 4 hours increased by 42% between 2016 and 2019 and between 2022and 2024. A sensitivity analysis limited to the five states with the most consistent reporting confirmed this trend with a 20% increase in fires exceeding 4 hours. Although the dataset does not directly identify vehicle propulsion type, this pattern aligns with the timeline of increased EV adoption and the extended cooling requirements characteristic of lithium-ion battery thermal runaway. The shift suggests that EV fires may be contributing to longer roadway closure durations, although direct confirmation requires improved incident tracking systems.

- *VDOT's traffic incident management protocols do not address EV-specific challenges.* Current Instructional and Informational Memoranda apply identical procedures to all vehicle fires, regardless of propulsion type. Extended duration potential, reignition risk during transport and storage, and the need for specialized post-incident assessment are not reflected in existing protocols. Field personnel lack guidance on when EV incidents require coordination approaches or duration planning that differ from those used for conventional vehicle fires.

- *Virginia lacks statewide standards for towing operators handling EV incidents.* Interview responses revealed highly variable capabilities across towing companies, with some operators well equipped and trained, but others lacking a basic understanding of EV systems. Virginia has no regulations for towing company training or equipment requirements specific to EVs, contrasting with more structured approaches in other states. VDOT's TRIP and towing rotation lists do not include EV-specific provisions.

- *Third-party assessment systems provide practical solutions for evaluating damaged EVs.* Towing companies reported positive experiences with the ESA evaluation system, which provides clear guidance for transporting and stowing EVs. Most vehicles are classified as low risk, allowing towing companies to allocate more resources to higher risk vehicles.

- *Current incident reporting systems cannot track EV fire trends or evaluate protocol effectiveness.* TOC records do not identify vehicle propulsion type, preventing analysis of how EV incidents differ from conventional vehicle fires in terms of duration, resource requirements, or operational impacts. Without systematic data collection, VDOT cannot assess whether response protocols are adequate or identify corridors where EV incidents may require enhanced capabilities.

- *Emerging fire suppression technologies show promise but may be out of budget for individual fire departments.* High-pressure piercing nozzle systems can reduce suppression time from hours to 10 to 30 minutes while using significantly less water than conventional methods. However, acquisition costs may be prohibitive for individual departments, particularly smaller rural departments. Strategic regional deployment could provide advanced capabilities where EV traffic is highest while distributing costs across jurisdictions most likely to benefit.

- *Storage facility constraints represent a significant infrastructure challenge.* The 50-foot separation distance recommended for damaged EVs exceeds the practical capabilities of most storage facilities, particularly in urban areas. Although some operators have constructed concrete bunkers or barrier systems as alternatives, most of towing facilities lack appropriate containment infrastructure. Towing contract pricing structures do not account for the additional costs and liability associated with extended isolation storage periods.

RECOMMENDATIONS

1. *VDOT should establish emergency protocols for protecting critical infrastructure during EV fire incidents.* When EVs burn near or on bridges, tunnels, and overpasses, the extended heat exposure from long-duration battery fires can cause structural damage. VDOT should develop protocols that include:

- Pre-authorized use of heavy equipment (e.g., front-end loaders and excavators) by VDOT personnel or contractors to relocate burning EVs away from critical structures when an immediate threat exists.
- Tentative thresholds for infrastructure risk based on vehicle temperature and distance from critical structures.

This recommendation focuses on the practical emergency response capability while establishing clear decision criteria for when to act. The thresholds would help field personnel and incident commanders make consistent decisions about when infrastructure protection measures are warranted.

2. *VDOT's Traffic Operations Division should encourage the use of training standards and best practices for towing operators handling EV incidents within VDOT's programs and in other towing programs.* Virginia currently has no statewide regulations for towing company training or equipment requirements specific to EVs. VDOT should promote best practices that address EV-specific training, enrollment with third-party assessment services, flatbed transport capabilities, and access to appropriate storage facilities.

3. *VDOT's Traffic Operation Division should implement systematic tracking of EV fires in TOC incident records.* Current incident reporting systems do not identify vehicle propulsion type, preventing analysis of EV fire trends and evaluation of response protocol effectiveness. TOC operators should be trained to attempt identification of vehicle type (conventional, hybrid EV, plug-in hybrid EV, or BEV) during extended-duration vehicle fires, ideally capturing make, model, and year when feasible. This information should be recorded in incident management systems to support future analysis and protocol refinement. Training materials for TOC operators should include visual identification guidance and interview protocols for gathering vehicle information from responders at the scene.

4. *VDOT's Traffic Operation Division should evaluate emerging fire suppression technologies and consider strategic equipment investments to support regional fire service capabilities.* High-pressure piercing nozzle systems show promise for dramatically reducing suppression time (to 10–30 minutes) and water volume requirements compared with conventional methods. However, acquisition costs may be prohibitive for individual fire departments. VDOT could purchase a limited number of these systems for strategic placement at high-volume locations with protocols for rapid delivery to incident scenes or loan agreements with regional fire departments. This approach would provide advanced capabilities where EV traffic is highest while distributing costs across the jurisdictions most likely to benefit. Equipment evaluation should also consider thermal imaging cameras for monitoring battery temperatures during transport and storage.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, VDOT's Traffic Operations Division, with the support of VTRC and VDOT's Structure and Bridge Division, will develop infrastructure protection protocols within 24 months of the date of publication of this report. VTRC will assist in establishing temperature and distance thresholds based on structural engineering analysis and fire science research. VTRC will prioritize this recommendation for implementation funding, subject to availability, given its direct connection to this report's findings.

Regarding Recommendation 2, VDOT's Assistant Division Administrator for Traffic Operations and Incident Management will develop and share EV safety best practices and training materials with TRIP participants, Virginia State Police, and counties within 36 months of the date of publication of this report. VDOT will recommend annual training for TRIP participants. VDOT may request that Virginia State Police and counties operating towing rotation lists to provide annual training on EV fire incidents and consider implementing capability standards for towing companies regarding EV fires. VDOT will promote the use of third-party assessment services, flatbed transport protocols, and appropriate storage facilities through outreach and information sharing rather than mandatory requirements. VTRC will prioritize this recommendation for implementation funding, subject to availability, given its direct connection to this report's findings.

Regarding Recommendation 3, VDOT's Assistant Division Administrator for Traffic Operations and Incident Management will request that additional EV fire incident reporting fields be added to the Advanced Traffic Management System within 24 months of the April 2026 transition from the current VaTraffic system. The additional field will be a subfield of the existing "vehicle on fire" field and will specify when an EV is one of the burning vehicles. VTRC will prioritize this recommendation for implementation funding, subject to availability, given its direct connection to this report's findings.

Regarding Recommendation 4, VDOT's Assistant Division Administrator for Traffic Operations and Incident Management, with the support of VTRC, will evaluate suppression technologies within 24 months of the date of publication of this report. The evaluation will be based on guidance from NFPA and in consultation with local fire departments. If technologies are deemed suitable for deployment, VDOT's Traffic Operations Division may investigate deployment options.

Benefits

The benefit of implementing Recommendation 1 is the protection of critical infrastructure from costly damage during EV fire incidents. Structural damage to bridges or tunnels from extended heat exposure could result in months of repairs and millions in costs, far exceeding the expense of emergency relocation. Clear thresholds for action will enable rapid decision-making during incidents, reducing uncertainty about when infrastructure protection measures are warranted. Pre-authorized protocols eliminate delays in obtaining permissions during active emergencies when minutes matter for preventing structural damage.

The benefits of implementing Recommendation 2 are enhanced towing industry preparedness and reduced incident clearance times. Trained and equipped towing operators will handle EV incidents more safely, reducing risks of reignition during transport and storage. The third-party assessment system will provide documented risk evaluation that benefits insurance claims processing and liability determination. Standardized requirements across VDOT's towing programs will ensure consistent capabilities statewide, eliminating current variability in which some operators are well prepared and others lack basic EV awareness.

The benefit of implementing Recommendation 3 is data-driven decision-making for future protocol refinement. Systematic tracking will identify trends in EV incident frequency, duration, and resource requirements. These data will support budget planning for equipment and training needs, validate the effectiveness of implemented protocols, and provide metrics for federal reporting requirements. TOCs will be able to identify corridors with elevated EV incident risk and adjust response resources accordingly.

The benefit of implementing Recommendation 4 is reduced incident duration and water usage during EV fire suppression. High-pressure piercing systems can reduce suppression time by 80 to 95% compared with conventional methods, minimizing roadway closure duration and traffic impacts. As one example, a 4-hour, two-lane closure on an interstate freeway during the morning peak period in the Northern Virginia District has an average cost of $522,847 in delay and increased secondary crash risk (Lan et al., 2021). An identical closure of only 1 hour has an average cost of $130,712, for a cost savings of $392,135 per comparable incident.

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