OFFICE OF ENVIRONMENT, SAFETY, AND HEALTH (NA-ESH) INTERIM SAFETY GUIDANCE FOR ELECTRIC VEHICLES AND ELECTRIC VEHICLE SUPPLY EQUIPMENT

EV-ISG-01

I. INTRODUCTION

This Interim Safety Guidance (ISG) is applicable to all National Nuclear Security Administration (NNSA) Sites for use in site design and implementation of electric vehicles (EV)[1] and Electric Vehicle Supply Equipment (EVSE). It sets technical expectations for implementation until Department of Energy (DOE)/NNSA requirements are developed and/or the DOE/NNSA safety standards are updated.

The ISG aligns with DOE Order 450.2, *Integrated Safety Management* principles and practices, addresses the use of various codes and standards, and provides acceptable methods and practices for ensuring the safe operation of EVs and EVSE across the Nuclear Security Enterprise (NSE). Except in those cases in which a management and operating partner (M&O), working through a Field Office, has previously established acceptable methods for addressing the unique safety hazards associated with deploying EVs and EVSE, the Field Office and the Office of Environment, Safety, and Health (NA-ESH) will use the codes, standards, and methods described in this ISG. While this interim guidance is not retroactive, existing EVSE installations should be reviewed for applicability, and immediate safety and health concerns should be addressed through site-specific procedures.

This interim guidance was developed and vetted by a team of DOE/NNSA Subject Matter Experts including explosives safety, fire protection, nuclear safety, transportation safety, electrical, environmental, and worker safety and health. As EV and EVSE safety standards evolve, NA-ESH will continue to interact with stakeholders to refine and update this guidance. The goal of the ISG is to support the electrification of the fleet within the NSE, as directed by DOE/NNSA Leadership, while balancing safety requirements at each site. While electric vehicles provide advantages, they also carry some risks that require additional guidance to address fire, electrical, and explosives hazards.

II. PURPOSE

In accordance with Executive Order (EO) 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability,* the DOE/NNSA is transitioning its fleet to zero-emission vehicles (ZEV). The EO calls for 100% ZEV acquisitions for light-duty vehicles (e.g., sedans, station wagons, SUVs, minivans, and light duty trucks) by 2027 and 100% for medium- and heavy-duty vehicles by 2035. To support this transition, DOE/NNSA is also expected to install EVSE ("charging stations") to support the transition to a ZEV fleet.

[1] The ISG uses the terms electric vehicle (EV) and Zero Emission Vehicle (ZEV) interchangeably.

To meet this policy and consistent with the Deputy Secretary's memorandum, *Accelerating the Department of Energy's Transition to Zero-Emission Vehicles* of December 14, 2023, the presumption is that all newly acquired DOE/NNSA vehicles, especially light-duty vehicles, will be ZEVs. It is understood that the transition to ZEVs and charging stations will be driven by availability, mission functional requirements for ZEVs, and appropriations.

III. CONTEXT

NNSA Field Offices and M&O partners have raised safety concerns with deploying ZEVs and EVSE to include concerns associated with explosive safety, fire protection, nuclear safety, transportation safety, electrical safety, environmental, and worker safety and health. In addition, NA-ESH has found that deployment of ZEVs and EVSE across the NSE is inconsistent due in part to the evolving nature of codes and requirements, including safety requirements.

The principle for developing this ISG is to address the unique safety concerns posed by ZEVs and EVSE and to facilitate a coherent, consistent approach across the NSE. With the addition of lithium batteries and other technologies onto NNSA sites, the unique hazards of ZEVs and EVSE should be considered, analyzed, and adequately controlled as part of their deployment.

As ZEV and EVSE deployment increases and the regulations, codes, standards, and safety practices continue to evolve, NA-ESH will stay apprised of the latest direction and continue to ensure the adequate protection of operators, facilities, and personnel across the Enterprise.

IV. TECHNICAL BACKGROUND

Overall, when compared to Internal Combustion Engine (ICE) vehicles, ZEVs are generally as safe as ICE vehicles and have some similar hazards. However, ZEVs and EVSE have the potential to present unique safety concerns, including the following:

- Ignition concerns associated with EVs and thermal runaway when connected to EVSEs due to battery management system failures or accidents;
- Toxic off-gassing from battery components;
- Stranded energy after disconnecting or disabling the batteries;
- Longer duration fires and associated structural impacts due to prolonged heat exposure;
- Reignition of electrical vehicle fires after extinguishment;
- Electrical safety of personnel during maintenance of high voltage EV equipment;
- Explosive safety concerns, including Hazards of Electromagnetic Radiation to Ordnance (HERO); and
- Increased weight in parking structures.

Note: Attachment 1, *Glossary* provides applicable definitions.

The guidance below was developed using various sources, including General Services Administration Facilities Standards for Public Buildings Service (P100) [2], the International Building Code, and National Fire Protection Association (NFPA) standards for EVSE. The guidance reflects a graded approach for NNSA based on NNSA mission requirements.

V. GENERAL GUIDANCE AND EXPECTATIONS

1. EVSE should not be installed in areas within the boundary of nuclear facilities without first completing an Unreviewed Safety Question (USQ) Screen per the site-specific process.
2. EVs should be limited to outdoor use only (including open parking garages) at this time, pending further guidance and research from voluntary consensus code organizations (i.e., International Code Council [ICC], NFPA), unless a Fire Hazards Analysis confirms that an EV fire can be mitigated using automatic suppression or extinguishment (including the installation of a Class 1 standpipe system), or operation of the EV inside an enclosed parking garage does not affect the safety of the personnel and the structure.
3. Charging cords associated with EVSE should not interfere with pedestrian traffic or present tripping hazards.
4. EVSE should be protected against vehicle impact by vehicle barriers in accordance with the requirements in the IBC. Curbs, bollards, wheel stops, and/or equipment setbacks should be used to prevent vehicles from damaging EVSE.

VI. ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) GUIDANCE AND EXPECTATIONS

A. FIRE PROTECTION GUIDANCE AND EXPECTATIONS

1. EVSE Locations
   a. EVSEs should not be installed within 10-ft of buildings having combustible exteriors or less than a 1-hr rated fire-resistive assembly.
   b. EVSEs should not be installed within 3-ft of buildings that have a minimum of a 1-hr rated fire-resistive assembly.
   c. EVSEs should not be located within 20-ft in all directions from the following:
      i. Fuel dispensing facilities, including gas pumps
      ii. Underground or aboveground storage tanks for ignitable liquids
      iii. Storage of combustible or flammable liquids or gases
   d. EVSEs should maintain a free space that does not have any vegetation (e.g., plants, trees, branches, shrubs, etc.) and combustible and flammable materials within a minimum of 10 feet in each direction.

2. EVSE Implementation and Operating Considerations

[2] U.S. General Services Administration, P100 FACILITIES STANDARDS FOR THE PUBLIC BUILDING SERVICE, May 2024, pages 315-321. P100 establishes mandatory design standards and performance criteria for GSA-owned buildings.

a. EVSE should be listed by a Nationally Recognized Testing Laboratory (NRTL) or approved by the site's Fire Protection Authority Having Jurisdiction (AHJ).

b. EVSEs should be secured to the ground per the manufacturer's instructions and have guard posts installed to prevent collisions and damage.

c. EVSEs should have Emergency Instructions posted that include the following information:
   i. 911 or Emergency Number in Case of Fire
   ii. Report Location
   iii. Emergency Shutoff Location

d. An emergency disconnect should be located in an easily identifiable and accessible location between 20-ft and 100-ft of the EVSE or bank of EVSEs with the disconnect mounted no lower than 42 inches from the ground and no higher than 48 inches from the ground.

e. Unless the hazard is otherwise fully addressed by a different site-adopted code or standard, energy storage systems (ESS) must meet the requirements of NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*. All stationary ESS, including mobile energy storage system equipment that utilize lithium-ion batteries are required to be listed in accordance with UL 9540, *Standard for Safety of Energy Storage Systems and Equipment*.
   i. ESS that are not listed in accordance with UL 9540 should be documented and verified as meeting the provisions of NFPA 855 using a documented equivalency per the site's Fire Protection Program requirements.
   ii. The requirements contained in NFPA 855 applies to all lithium-ion battery energy storage systems (BESS) greater than 20 kWh.
   iii. If a mobile BESS will be charged and stored for longer than 30 days at a specific site location, it is no longer considered temporary and should be treated as a permanent outdoor ESS installation in accordance with the requirements in NFPA 855.

Note: Numerous other requirements are listed in P100 as follows: (1) Section 8.5.1 EV Charging that should be implemented as applicable; (2) Section 8.5.3, Privately Owned Vehicle Requirements; (3) Section 8.5.4 EVSE Infrastructure; (4) Section 8.5.5 EVSE Charging Requirements should be considered in ZEV deployment; (5) § 8.5.6 EVSE Fire Protection-should be considered particularly in connection with a GSA building.

B. ELECTRICAL SAFETY GUIDANCE AND EXPECTATIONS

1. All EVSEs should adhere to design, application, and maintenance requirements of NFPA 70, 70E, and 70B.
2. All EVSEs should be Level 2 or Level 3 charge capable.
   a. Recommend that some vehicles be Direct Current Fast Charging (DCFC) capable for rapid response.
   b. Recommend that all vehicles be programmable to charge at specific times of the day.

3. All EVSEs should adhere to the requirements of 49 CFR 571.305 and UL 2594, *Electric Vehicle Supply Equipment.*
4. Direct Current EVSEs should meet the requirements of UL 2202, *DC Charging Equipment for Electric Vehicles.*
5. EVSE equipment with vehicle-to-grid capability should be listed in accordance with UL 1741 *Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources, Supplements A and B*.

VII. ELECTRIC VEHICLE (EV) GUIDANCE AND EXPECTATIONS

A. TRANSPORTATION SAFETY

1. ZEVs should not be used to handle, move, or transport Class 1, Division 1.1-1.6 explosives. Other hazardous materials should be evaluated on a case-by-case basis by the Authority Having Jurisdiction.

B. EXPLOSIVES SAFETY

1. EVs (privately or government owned) shall not be parked or charged within 100 feet of an explosives facility or storage location. EVCSs shall not be sited within 100 feet of an explosives facility or storage location. The minimum 100 ft [30.5 m] separation may be reduced to 50 ft [15.2 m] provided the explosives locations are of non-combustible construction (e.g., concrete, masonry, and metal structures). These distances may be reduced in accordance with the results of a fire hazards analysis or V4.E5.25 of the Defense Explosive Safety Regulation (DESR) 6055.09, Edition 1 Change 1, February 23, 2024. Note: The minimum separation distance for EVs and EVCS does not apply to facilities that are limited to Hazard Division (HD) Storage Compatibility Group (SCG) 1.4S items only.
2. Until additional data is obtained, EVs should not be used in proximity of electro-explosive devices (EEDs) or in explosives areas where EEDs may be in use unless a Hazards of Electromagnetic Radiation to Ordnance (HERO) survey is conducted to determine if EVs present a risk to such devices.

VIII. EMERGENCY RESPONSE GUIDANCE AND EXPECTATIONS

A. Site emergency response organizations should already address ICE vehicle fires and should modify procedures to include the additional hazards associated with EV fires including but not limited to building exposures, suppression, extinguishment, and containment.

B. Site emergency response organizations should evaluate the use and implementation of suppression strategies and operating procedures as necessary, including implementation of guidance of best practices from Emergency Management Special Interest Group (EMISIG) Field and First Responder Subcommittee (FFRSC), NFPA, United States Fire Administration (USFA), or other entities.

C. EVs that have experienced fires or thermal runaway events should be stored a minimum of 50 ft away from any other combustible, hazardous, or flammable material for a minimum of 90 days to ensure that reignition does not occur.

Note: Attachment 2 provides additional Emergency Response Guidance.

IX. FUTURE REQUIREMENTS

Future requirements in various standards, such as NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages,* may differ in applicability and scope, however, are being used NNSA enterprise-wide until further requirements are evaluated and incorporated in directives or standards. Interim guidance was developed from various sources, including an NFPA Tentative Interim Agreement that was ultimately not approved during the standards development process. Additional requirements may be implemented, such as in DOE-STD-1212, which would negate the requirements for interim guidance. This ISG will be updated and re-released and/or cancelled as those requirements are added to future standards.

X. REFERENCES

1. National Fire Protection Association (NFPA) 30A Draft Tentative Interim Agreement

2. DOE-STD-1212-2019, Chg. 1, *Explosives Safety*

3. DOE-STD-1066-2023, *Fire Protection*

4. NFPA 70, *National Electric Code*

5. 49 CFR 571.305, *Electric-powered vehicles*

6. General Services Administration P100, *Facility Standards for the Public Building Service*

7. S-2 Memorandum, *Accelerating the Department of Energy's Transition to Zero-Emission Vehicles*

8. American National Standards Institute (ANSI) *Roadmap of Standards and Codes for Electric Vehicles at Scale*, June 2023

9. *Electrical vehicle chargers and fire safety | Marsh*. (n.d.). https://www.marh.com/ca/en/services/risk-consulting/insights/electrical-vehicle-chargers-fire-safety.html

10. Jones, W. D. (2023, December 8). Extinguishing the EV battery fire hype. IEEE Spectrum. https://spectrum.ieee.org/lithium-ion-battery-fires

11. Staff, Z. (n.d.). Electric Vehicles are Safe - ZETA. https://www.zeta2030.org/insights/electric-vehicles-are-safe

12. Federal Motor Vehicle Safety Standards; FMVSS No. 305a Electric-Powered Vehicles: Electric Powertrain Integrity Global Technical Regulation No. 20, Incorporation by Reference, 49 C.F.R Part 571 (2024). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571

13. National Electric Vehicle Infrastructure Standards and Requirements, 23 C.F.R Part 680 (2023). https://www.federalregister.gov/documents/2023/02/28/2023-03500/national-electric-vehicle-infrastructure-standards-and-requirements

14. What if an EV fire occurs inside a tunnel? (2024, January 26). https://www.nfpa.org/en/News-Blogs-and-Articles/Blogs/2024/01/26/Electric-Vehicle-Considerations-for-Tunnel-Fire-Protection

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ATTACHMENT 1
GLOSSARY

Electric Vehicle (EV) - An automotive-type vehicle for on-road use, such as passenger automobiles, buses, trucks, vans, neighborhood electric vehicles, electric motorcycles, and the like, primarily powered by an electric motor that draws current from a rechargeable storage battery, fuel cell, photovoltaic array, or other source of electric current. Plug-in hybrid electric vehicles (PHEV) are electric vehicles having a second source of motive power. [NFPA 70, 2023] Note: Off-road, self-propelled electric mobile machines, such as industrial trucks, hoists, forklifts, transports, golf carts, airline ground support equipment, tractors, and boats that do not incorporate lithium-ion or similar battery chemistries are not considered electric vehicles. Although not specifically addressed, lithium-battery powered forklifts and other material-handling equipment (MHE) should also be evaluated and follow similar guidance.]

Electric Vehicle Supply Equipment (EVSE) - Electrical hardware used to supply electric energy to a plug-in electric vehicle, including solar charging stations and storage devices. Note: The terms EVSE and Electric Vehicle Charging Station (EVCS) may be used interchangeably.

Hazards of Electromagnetic Radiation to Ordnance (HERO) - Munitions containing electrically initiated devices (EIDs) (e.g., exploding foil initiators, laser initiators, burn wires, fusible links, hot bridge wires, carbon bridges, and conductive compositions) and electro-explosive devices should be designed or protected such that electromagnetic radiation (EMR) does not cause an inadvertent initiation, degradation, or disablement. Direct radio frequency (RF)-induced actuation of the EID or electrical coupling to and triggering of the associated firing circuits can occur, especially in a tactical radiated electromagnetic environment (EME). The potential exists for the battery systems of EVs and maybe even charging stations to present an electromagnetic radiation hazard to NSE explosive operations.

Off-gassing - The gases that are released from EV batteries are highly flammable and toxic. The type of gas released depends on the battery chemistry involved but typically includes gases such as carbon monoxide, carbon dioxide, hydrogen, methane, ethane, and other hydrocarbons.

If the gas is able to reach its lower explosive limit before finding an ignition source, then there is the potential for an explosion. The big difference between electric vehicles and combustion engine vehicles when it comes to off-gassing is that electric vehicles can produce flammable gases without a flame, whereas combustion engine vehicles need to be burning to produce similar gases. To complicate this even more, since road tunnels often lack the natural ventilation that open roads offer, smoke management becomes an even more critical aspect of tunnel fire protection.

Reignition - Once a battery cell goes through thermal runaway and is ignited, it usually is destroyed and is unable to reignite. The risk of reignition comes into play when the neighboring cells were damaged by the fire but did not release their electrical potential energy. Those cells are at risk of going into thermal runaway at a later time.

Australian based organization EV FireSafe found through its research that 13 percent of electric vehicles it studied reignited following initial suppression, with one of the fires reigniting 68 days after the initial incident. This reignition is a serious concern, not only for emergency responders and salvage workers, but also for the tow truck drivers who typically help transport a burned vehicle after an incident. It also makes storing burned electric vehicles more challenging since a separation distance is recommended between the EV and other combustibles so that a reignition fire doesn't spread.

Stranded Energy - Standard energy is the term used for when a battery has no safe way of discharging its stored energy. This commonly occurs after an EV fire has been extinguished and the battery terminals have been damaged. This is a shock hazard to those working with the damaged battery pack since it still contains an unknown amount of electrical energy.

Thermal Runaway - Thermal runaway is the uncontrollable self-heating of a battery cell. It begins when the heat generated within a battery exceeds the amount of heat that can be dissipated to its surroundings. The initial overheated cell then releases flammable and toxic gases and can reach a high enough heat to ignite those gases. This phenomenon can cascade to adjacent cells and progress through the EV battery, thus the term "runaway." Battery cells can enter thermal runaway for a number of reasons, such as damage through a collision.

ATTACHMENT 2
EV AND EVSE EMERGENCY RESPONSE GUIDANCE

Emergency Response – Safety Risks

1. Fires in electric vehicles powered by lithium-ion batteries pose two main dangers to emergency responders. First is the risk of electric shock from exposure to high-voltage connections in a damaged battery. Second is the risk that damaged cells in the battery will experience uncontrolled increases in temperature and pressure, known as *thermal runaway*, which can lead to venting and combustion of toxic gases, cell rupture and release of projectiles, and battery reignition/fire. The risks of electric shock and battery reignition/fire arise from the energy that remains in a damaged battery—known as *stranded energy*.

2. **Electric Shock**. The human body is an electrical conductor; if it contacts an energized source of electricity, current will flow through it. The body's resistance—its ability to reduce an electric current—varies from person to person and according to whether the skin is wet or dry, among other things. *The maximum voltages considered safe for humans are 50- or 60-volts DC and 30 volts AC.23 The high-voltage system of a BEV operates well above those thresholds (at 300 to 400 volts or more)*, creating a safety risk when the high-voltage battery is damaged in a crash and safety features such as protective covers and circuit fuses are defeated. If a crash damages the electrical isolation system, a person who touches the vehicle (or an exposed connector) can become part of the high-voltage circuit and suffer serious injury or death.

3. **Thermal Runaway**. The originating cause of thermal runaway is generally short-circuiting inside a battery cell and a resulting increase in the cell's internal temperature. A short circuit in a lithium-ion battery cell can result from defects introduced during manufacturing, such as contamination, or from damage to the cell caused by crushing or puncturing—precisely the kind of damage produced by high-impact, high-severity car crashes. An external fire might also heat a battery cell enough to initiate thermal runaway.

   A recent study (Stephens and others 2017) identified four primary hazards of thermal runaway: (1) venting of toxic and flammable vapors from the electrolytic solvent, through pressure-relief devices or holes in the battery casing; (2) combustion of vapors ejected from the flammable electrolyte solvent; (3) localized overpressure; and (4) rupture of the cell casing and release of projectiles if pressure-relief devices are absent or fail. *Secondary hazards identified in the study were release of toxic and corrosive chemicals, ignition and burning of combustible parts of the vehicle, asphyxiation of vehicle occupants from toxic gases vented by the battery, and electric shock to occupants, first responders, or maintenance personnel from exposure to high-voltage conductors if electrical insulation and isolators melt or burn*. Flammable gases (hydrogen, ethylene, ethane, and propane) released from a damaged battery constitute the most significant fire threat, according to the study.

4. **Stranded Energy**. If a high-voltage battery is damaged, energy remains inside any undamaged battery modules and cells, with no path to discharge it. That stranded energy

can cause a high-voltage battery to reignite multiple times after firefighters extinguish an electric vehicle fire. Emergency responders have no way of measuring how much energy remains in a damaged battery, and no way of draining that energy, other than such time-consuming methods as allowing a battery fire to burn itself out. Engineers or other specialists can use the battery management system to check for remaining voltage if the system is operational, and some batteries have built-in discharge ports, also for use by specialists. However, the high-voltage battery system can be damaged in a crash, preventing access to the battery management system or to the discharge ports. ***One of the first steps in responding to an electric-vehicle fire is to cut the supply cable to the 12-volt battery—which will depower the battery management system.***

Emergency Response Guidance and Considerations

1. **High-Voltage Disconnects**: Emergency responders face a risk of electric shock from the energy stored in damaged high-voltage lithium-ion batteries. To protect against electric shock, safety standards require isolating an electric vehicle's high-voltage battery system from the chassis, giving minimal values for isolation resistance. The methods of disconnecting high-voltage circuits vary by vehicle manufacturer—federal standards (FMVSS 305) do not mandate a uniform method. Although the disconnects will isolate a high-voltage lithium battery, they will not remove energy from the battery itself.

   SAE J2990, addresses the hazards faced by first and second responders to crashes and other incidents involving electric vehicles, first responders should be familiar with and trained in the ZEV manufacturers methods of disconnecting the vehicles' high-voltage systems. The following methods are listed: (1) automatic shutdown; (2) switching the ignition switch to OFF (to disconnect the high-voltage system from the high-voltage sources and discharge the system to ≤ 60 volts DC or 30 volts AC within 10 minutes); (3) cut or disconnect battery cables to discharge the 12-volt system and cut or disconnect the 12-volt output cable. SAE J2990 states that using a manual disconnect (such as pulling a plug) should not be the primary method for first responders to disable a vehicle's high-voltage circuits. That is because (1) the variety of designs makes locating and activating manual disconnects inefficient, (2) first responders do not always have the required PPE, and (3) the manual disconnect mechanism might be inaccessible.

   Manufacturers' emergency response guides provide sufficient vehicle-specific information for disconnecting an electric vehicle's high-voltage system when the high-voltage disconnects are accessible and undamaged. Further, crash damage and resulting fires may prevent first responders from accessing the high voltage disconnects in electric vehicles.

2. **Fire Suppression:** The NFPA emergency field guide states that large, sustained volumes of water are required to extinguish a high-voltage battery fire: "it could require over 2,600 gallons, depending on the size and location of the battery." The guidance also highlights the difficulty of applying extinguishing agents directly onto burning cells because of the batteries' protective cases. It further states that applying a large volume of water might cool the battery enough to prevent the fire from propagating to adjacent

cells. A high-voltage lithium-ion battery is designed to resist water, but water is critical for cooling overheated cells to stop thermal runaway and further combustion.

In the four National Transportation Safety Board (NTSB) investigations, the total amount of water used to suppress the high-voltage lithium-ion battery fires ranged from 300 gallons in Fort Lauderdale and West Hollywood to 1,000 gallons in Mountain View and to over 20,000 gallons in Lake Forest. In the Fort Lauderdale incident, the battery fire was intense, but a rupture in the battery case between the front seats allowed water into the case, which helped extinguish the fire. In the West Hollywood battery fire, which did not result from a crash, the flames were extinguished quickly, but firefighters had to apply water for a further 30 minutes to stop the battery from smoking. In the Mountain View case, the flames were also extinguished quickly, but more water had to be applied when the battery fire reignited. In the Lake Forest case, firefighters applied large quantities of water, but they could not extinguish the fire until they elevated the vehicle and applied water directly to the battery on the underside.

Manufacturers generally do not give vehicle-specific information for fighting a high-voltage lithium-ion battery fire, such as where and how to apply water in order to extinguish and cool the battery. In the Lake Forest fire, firefighters searched online for assistance, but they did not apply enough water directly onto the battery case in the beginning to cool the high-voltage battery, which ended up requiring 2 hours and 20,000 gallons of water to extinguish. In the West Hollywood fire, firefighters contacted the manufacturer directly once the flames had died down because they could not determine where to apply water to stop the vehicle from smoking. While searching for a way to apply water to the battery, firefighters used a metal pry bar to remove body panels from the vehicle, a procedure that posed a risk of electric shock and that guidance documents warn against.

The NTSB investigations concluded that the instructions in most manufacturers' emergency response guides for fighting high-voltage lithium-ion battery fires lack necessary, vehicle-specific details on suppressing the fires. However, it was noted that if manufacturers include inlet ports through which water can be applied directly to the lithium-ion batteries in its electric vehicles, battery fires can be extinguished quickly.

3. **Thermal Runaway and Battery Reignition:** Damaged high-voltage lithium-ion batteries pose a risk to emergency responders because of the potential for thermal runaway, which can cause a battery to ignite, or reignite. The risk of thermal runaway in electric vehicles powered by high-voltage lithium-ion batteries became evident in 2011, when a Chevrolet Volt caught fire 3 weeks after a crash test. SAE J2990 recommends using a thermal camera or infrared temperature probe to inspect a damaged battery. Emergency responders are also counseled to use their senses when inspecting a damaged electric vehicle—to listen for noises from the battery (gurgling, bubbling, crackling, hissing, or popping), which can indicate that overheated cells are venting or that the high-voltage system is arcing; and to notice whether a burnt odor is coming from the battery, which is evidence of fire or heat damage.

SAE J2990 warns that if a high-voltage lithium-ion battery is involved in a fire, "there is a possibility that it could reignite after extinguishment." The NFPA's emergency field guide also warns that a fire in a high-voltage lithium-ion battery could reignite and recommends that emergency responders use thermal imaging to monitor the battery. The guide states that reignition is accompanied by a "whooshing" or "popping" sound, followed by off-gassing of white smoke or electrical arcs or sparks that reignite, with visible flames or fire. The guidance states that reignition can occur within several hours to a day or more after the fire is extinguished. The NFPA advises firefighters to continue applying water (even after they can no longer see a flame) to sufficiently cool the battery pack—it could take an hour or more—so as to reduce the risk of reignition.

4. **Stranded Energy**: The manufacturers' emergency response guides contain sufficient information for first responders to disconnect an electric vehicle's high-voltage system, provided the disconnects are accessible and are undamaged. However, even if an electric vehicle's high-voltage system is disconnected, energy will remain trapped in a damaged high-voltage lithium-ion battery. The stranded energy poses a risk of electric shock to emergency responders and creates the potential for thermal runaway that can result in reignition and fire.

   Battery reignition can be caused by thermal or mechanical means. Mechanical reignition results when parts of a battery or other conductive debris cause a short circuit in cells that contain stranded energy. For example, if a damaged electric vehicle is shifted, twisting of the wreckage can create new electrical connections that can then release energy and cause reignition. This phenomenon was observed after a ZEV fire, the battery reignited twice—once while the wreckage was being loaded onto a tow truck, and again when a chain passed over the battery after the vehicle had been loaded onto the truck.

   Reignitions are evidence that stranded energy remains in undamaged parts of the high-voltage batteries post-crash. Observations post-crash in one case revealed that the voltage in battery modules 1 through 5 ranged from 69.9 to 167.3 volts DC, well above the safe limits for human exposure (50 to 60 volts DC).

   Firefighters have no method of determining whether stranded energy is present in a damaged high-voltage lithium-ion battery or of removing energy from the battery pack (generally, methods of deenergizing a battery is not within an emergency responder's scope and typically take an impractically long-time). Engineers or other specialists can use the battery management system to check for remaining voltage if the system is operational, and some batteries have built-in discharge ports. However, *NTSB investigations found the high-voltage battery system were damaged from the crash, preventing access to the battery management system or to the discharge ports. In addition, the status of a damaged battery is unknown and according to the NTSB must be treated as a high-voltage safety risk.*

   The NFPA's recent training video addressing high-voltage battery systems and stranded energy highlights the challenges to emergency responders (The video can be viewed on the NFPA's training and certification website). The NFPA warns responders that they should always assume that the high-voltage system is energized. According to the NFPA, first responders therefore must assume that stranded energy is present in a damaged electric vehicle, and they require vehicle-specific information on how to manage—and minimize—the associated risks for battery reignition and fire. According to the NFPA, secondary responders, including tow operators and storage facility operators, must also assess and mitigate the risks associated with high-voltage lithium-ion batteries.

Training

Specialized training is required for first responders to prevent and/or minimize the risks posed from extinguishing ZEV fires.