

Electric Drive Vehicle Systems: Suggested Changes to Large Truck and Motorcoach Regulations and Inspection Procedures



U.S. Department of Transportation
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FOREWORD

This report provides recommendations for changes to the Federal Motor Carrier Safety Regulations (FMCSRs), North American Standard (NAS) inspection procedures, and out-of-service (OOS) criteria that are needed to accommodate and facilitate the use of commercial vehicles with high-voltage electric drive systems. Such vehicles include battery-electric vehicles, vehicles with hybrid-electric drive systems, and vehicles with hydrogen fuel cell engines. In addition to providing specific recommendations for changes, this report summarizes the process used to arrive at the recommendations.

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16. Abstract This report provides recommendations for changes to the Federal Motor Carrier Safety Regulations (FMCSRs), North American Standard (NAS) inspection procedures, and Out-of-Service (OOS) criteria that are needed to accommodate and facilitate the use of commercial vehicles with high-voltage electric drive systems. Such vehicles include battery-electric vehicles, vehicles with hybrid-electric drive systems (including plug-in hybrids), and vehicles with hydrogen fuel cell engines. In addition to providing specific recommendations for changes, this report summarizes the process used to arrive at the recommendations, which included a literature review and gap analysis, industry site visits and consultations, and a formal peer review process. Because most of the commercial vehicles now in service have only low-voltage electrical systems (12/24 volts direct current [VDC]), the current FMCSRs, NAS inspection procedures, and OOS criteria do not address the unique safety aspects of high-voltage systems (less than 60 VDC or greater than 30 volts alternating current [VAC]) when present on a vehicle. The purpose of this project was to identify necessary changes to the current FMCSRs and inspection procedures, if any, to address the unique safety requirements associated with high-voltage vehicle systems, and to improve the overall safety of commercial vehicle operations by ensuring that commercial vehicles with high-voltage drive systems meet appropriate safety criteria while operating on public roads.			
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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yards	0.836	square meters	m ²
ac	Acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
Volume (volumes greater than 1,000L shall be shown in m³)				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
Temperature (exact degrees)				
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
Force and Pressure or Stress				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
Approximate Conversions from SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
Ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
Volume				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
Temperature (exact degrees)				
°C	Celsius	1.8c+32	Fahrenheit	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

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LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

Acronym	Definition
AC	alternating current
ANSI	American National Standards Institute
ASE	Automotive Service Excellence
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BEV	battery-electric vehicle
CCR	California Code of Regulations
CCR-NY	Codes, Rules, and Regulations of the State of New York
CFR	Code of Federal Regulations
CVSA	Commercial Vehicle Safety Alliance
DC	direct current
USDOT	U.S. Department of Transportation
EMI	electromagnetic interference
FCV	fuel cell vehicle
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulations
FMVSS	Federal Motor Vehicle Safety Standards
HEV	hybrid-electric vehicle
FTA	Federal Transit Authority
HM	hazardous materials
IC	internal combustion
IEC	International Electromechanical Commission
ISO	International Standards Organization
km/h	kilometers per hour

Acronym	Definition
mi/h	miles per hour
NAS	North American Standard
NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration
OEM	original equipment manufacturer
OOS	out of service
PHEV	plug-in hybrid-electric vehicle
RESS	rechargeable energy storage system
RMS	root mean squared
SAE	Society of Automotive Engineers
UL	Underwriters Laboratories
UNECE	United Nations Economic Commission for Europe
VAC	volts, alternating current
VDC	volts, direct current
Symbol	Definition
Ω	ohm

EXECUTIVE SUMMARY

PURPOSE

This report provides recommendations for changes to the Federal Motor Carrier Safety Regulations (FMCSRs), North American Standard (NAS) inspection procedures, and out-of-service (OOS) criteria that are needed to accommodate and facilitate the use of commercial vehicles with high-voltage electric drive systems. Such vehicles include battery-electric vehicles, vehicles with hybrid-electric drive systems (including plug-in hybrids), and vehicles with hydrogen fuel cell engines.

Most commercial vehicles have only low-voltage electrical systems (12/24 volts direct current [VDC]), and the current FMCSRs, NAS inspection procedures, and OOS criteria do not address the unique safety aspects of high voltages (greater than 60 VDC or greater than 30 volts alternating current [VAC]) when present on a vehicle. The purpose of this project was to identify necessary changes to the current FMCSRs and inspection procedures, if any, to address the unique safety requirements associated with high-voltage vehicle systems and to improve the overall safety of commercial vehicle operations by ensuring that commercial vehicles with high-voltage drive systems meet appropriate safety criteria while operating on public roads.

PROCESS

This project began with a review of current FMCSRs that are applicable to the electrical drive systems in commercial vehicles. The review focused on the aspects of the identified FMCSRs that would potentially be different for high-voltage systems as compared to low-voltage systems.

Following the review, the researcher conducted a literature review of codes, standards, and best practices related to high-voltage electrical systems on medium- and heavy-duty vehicles. The reviewed documents include codes, standards, and best practices developed by U.S. and international standards organizations, and safety regulations related to high-voltage vehicle electrical systems adopted by the U.S. Federal Government, Canada, the European Union, and the State of New York.

Using the review of current regulations and the literature review for reference, the researcher identified gaps in the current regulations, NAS inspection procedures, and vehicle OOS criteria that leave the unique safety concerns of high-voltage vehicle electrical systems unaddressed. Based on this gap analysis, the researcher developed a preliminary list of recommendations for changes to FMCSRs, NAS inspection procedures, and OOS criteria to address the identified gaps.

The researcher then conducted a series of industry site visits/consultations to gather feedback on the preliminary recommendations from a representative sample of organizations that would be most affected by any proposed changes to the FMCSRs. These organizations included companies involved in the design, manufacture, and use of medium- and heavy-duty commercial vehicles with high-voltage electrical systems, as well as other State and Federal Government agencies. The site visits included vehicle original equipment manufacturers (OEMs) that produce battery-electric and hybrid-electric commercial vehicles; suppliers and integrators of high-voltage

electrical system components; and fleets that operate battery-electric and hybrid-electric commercial vehicles.

STUDY FINDINGS

The gap analysis conducted for this project identified a number of areas where current FMCSRs and NAS inspection procedures do not fully address the unique safety issues of high-voltage electrical systems installed on commercial vehicles. In order to strengthen the regulations and to ensure that battery-electric, hybrid-electric, plug-in hybrid electric, and fuel cell commercial vehicles will be maintained and operated in a manner that provides the highest level of public safety according to the best practices that now prevail, this report makes a number of recommendations for changes, including the following:

- FMCSA should specify minimum labeling requirements for in-use commercial vehicles with high-voltage electrical systems.
- FMCSA should specify minimum requirements for inclusion of onboard safety systems on in-use commercial vehicles with high-voltage electrical systems.
- FMCSA should specify minimum standards for in-use condition of high-voltage components and systems on commercial vehicles.
- FMCSA should modify current accident reporting requirements to require additional information about reportable accidents involving commercial vehicles with high-voltage electrical systems.
- FMCSA should specifically include the rechargeable energy storage system (RESS) (battery pack) and other high-voltage components in the list of vehicle components/systems to be checked during daily driver inspections of commercial vehicles with high-voltage electrical systems.
- FMCSA should work with the Commercial Vehicle Safety Alliance (CVSA) to modify the NAS inspection procedures in order to clarify what items an inspector should look for when inspecting a commercial vehicle with a high-voltage electrical system.
- FMCSA should provide recommendations to CVSA regarding additional OOS criteria for in-use commercial vehicles with high-voltage electrical systems.

As with current FMCSRs, the proposed changes would apply to all in-use commercial vehicles subject to FMCSRs (i.e., those used in interstate commerce) whether manufactured with high-voltage electrical systems by OEMs or converted to electric drive operation by the vehicle owner or a third party. Note that a commercial vehicle does not necessarily have to cross State lines to be in interstate commerce; if the passengers or carrier cargo cross a State line, the commercial vehicle is involved in interstate commerce. Individual States have the option of adopting the FMCSRs. In this case, an individual State would apply the applicable FMCSRs to all commercial vehicles operating in the State, including vehicles used exclusively in intrastate commerce.

All of the recommendations contained within this report are consistent with industry standards and best practices for high-voltage vehicle electrical systems. In particular, they generally follow

the recommendations of Society of Automotive Engineers (SAE) J2910, “Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety.”¹ The final recommendations were also informed by feedback received during industry site visits, and they reflect comments received from peer reviewers.

¹SAE International, “Standard J2910: Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety,” http://standards.sae.org/j2910_201404/.

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1. INTRODUCTION

This report provides recommendations for changes to the Federal Motor Carrier Safety Regulations (FMCSRs), North American Standard (NAS) inspection procedures, and out-of-service (OOS) criteria that are needed to accommodate and facilitate the use of commercial vehicles with high-voltage electric drive systems. Such vehicles include battery-electric vehicles, vehicles with hybrid-electric drive systems, and vehicles with hydrogen fuel cell engines. In addition to providing specific recommendations for changes, this report summarizes the process used to arrive at the recommendations.

1.1 PURPOSE

This report is the final deliverable of a project designed to implement necessary changes to the FMCSRs, NAS inspection procedures, and vehicle OOS criteria in order to accommodate and facilitate the use of commercial vehicles with high-voltage electric drive systems. This project supports the Federal Motor Carrier Safety Administration (FMCSA) mission to promote safe commercial vehicle operations through education, regulation, enforcement, and innovative research and technology, and to reduce truck and bus crashes and resulting injuries and fatalities.

Most commercial vehicles today have only low-voltage electrical systems that provide either 12-volt direct current (VDC) or 24 VDC to power vehicle auxiliary loads for engine starting, lighting, vehicle control systems, and passenger compartment climate control. Commercial vehicles that use electricity to provide, fully or partially, motive power typically use “high-voltage” systems^{2,3,4}, with nominal voltage between 300 and 600 VAC, to provide this power. These vehicles typically also include a high-voltage rechargeable energy storage system (RESS)—i.e., battery pack—which operates at a nominal voltage of 300 VDC or more.⁵

The presence of these levels of electrical potential on a vehicle introduces the potential for bodily injury or death from shock if energized components are contacted directly. Hazardous voltage levels are defined in Underwriters Laboratories (UL) 2231, “Outline of Investigation for Personnel Protection Systems for High Voltage Supply Circuits.”⁶ According to this definition,

²Different entities use different definitions for “high voltage.” The National Electrical Code (NEC) defines any voltage greater than 600 volts to be high voltage, whereas the Society of Automotive Engineers (SAE) generally considers any voltage greater than 60 VDC or 30 VAC to be “high” or “hazardous” voltage because of the potential for bodily injury due to shock from direct contact.

³SAE and the International Standards Organization (ISO), as well as the National Highway Traffic Safety Administration (NHTSA), have generally adopted the more generic term RESS when developing standards, best practices, and regulations. This document follows that convention.

⁴Chemical storage batteries only accept and deliver direct current (DC), while generators produce alternating current (AC). While electric motors can be designed to operate on either AC or DC power, in order to incorporate both onboard power generation (generator) and onboard storage (battery), both AC and DC voltages will be present on a vehicle, and power electronics are required to convert from one to the other.

⁵While most electric and hybrid-electric vehicles use electrochemical battery cells for energy storage, the more generic term “RESS” is meant to encompass other methods of storing electrical energy, including electrostatic capacitors. It is not meant to encompass methods of storing energy mechanically, such as rotating flywheels or hydraulic or pneumatic pressure accumulators.

⁶UL 2231-1, “Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General Requirements,” <http://ulstandardsinfontet.ul.com/scopes/scopes.asp?fn=2231-1.html>.

voltage levels greater than 30 VAC or 60 VDC can harm humans through electric shock, and systems should be designed to protect against direct contact.

Vehicles with high-voltage electric drive systems include:

- Battery-electric Vehicles (BEVs). BEVs do not include an internal combustion engine, and they derive all or most of their motive power from electricity centrally produced off-board. These vehicles include electric drive motors powered by relatively large battery packs, which are recharged periodically by plugging into the grid. These vehicles may also derive some of their motive power from energy generated onboard by the drive motor during vehicle braking.
- Hybrid Electric Vehicles (HEVs). HEVs include an internal combustion (IC) engine, one or more electric motor/generators, and a battery pack.⁷ Different configurations are possible, but in general an HEV commercial vehicle draws power from the battery to supplement the IC engine (via an electric drive motor) when vehicle power needs are high. During vehicle braking, the motor generates electricity, which is stored in the battery pack for later use. HEVs derive all their net energy from the onboard IC engine and do not connect to the power grid.
- Plug-in Hybrid Electric Vehicles (PHEVs). PHEVs are similar to HEVs, but they include a larger battery pack and the ability to plug into the grid periodically. These vehicles are designed to utilize grid-produced electricity to supply some of their net motive power needs, with the rest supplied by the internal combustion engine.
- Fuel Cell Vehicles (FCVs). FCVs include an electric drive motor and a hydrogen fuel cell engine. A hydrogen fuel cell engine produces electricity directly through low-temperature chemical oxidation of hydrogen in galvanic cells. FCVs may also include a battery pack to supplement the fuel cell engine when motive power needs are high, and to store energy generated by the drive motor during braking.

Current FMCSRs, NAS inspection procedures, and OOS criteria do not address the unique safety aspects of high or hazardous voltage when present on a vehicle. The purpose of this project is to identify necessary changes to the current FMCSRs and inspection procedures, if any, to address the unique safety requirements associated with high-voltage vehicle systems and to improve the overall safety of commercial vehicle operations by ensuring that commercial vehicles with high-voltage drive systems meet appropriate safety criteria while operating on public roads.

In 2011, there were approximately 10.2 million medium- and heavy-duty trucks registered in the United States.⁽¹⁾ Of those vehicles, approximately 900 were BEVs, 10,000 were HEVs, and 100 were FCVs.⁽²⁾ In 2011, vehicles with high-voltage electric drives comprised approximately 0.1 percent of the in-use medium- and heavy-duty vehicle fleet, and less than 1 percent of new vehicle sales. A recent market survey by a non-profit organization that works to promote advanced transportation technologies, estimates that sales of HEV and BEV trucks will be in the

⁷The scope of work for this project specifically did not include consideration of hybrid-hydraulic vehicles, which include an internal combustion engine, one or more hydraulic motor/generators, and one or more hydraulic pressure accumulators. While those vehicles pose their own unique safety challenges related to high-pressure mechanical energy storage, they do not typically include high-voltage electrical systems, which are the focus of this study.

range of 4,200 units per year over the next 5 years, and that by 2017 more than 30,000 electric drive commercial vehicles will be on the road.⁽³⁾

Of the medium- and heavy-duty electric drive vehicles in use in 2011, 56 percent were transit buses (mostly HEVs). The remainder includes a range of vocational truck types, including long- and short-haul tractor-trailers, refuse haulers, utility trucks, and pick-up-and-delivery trucks with van bodies.

1.2 PROCESS

This project began with a review of current FMCSRs that are applicable to commercial vehicles with high-voltage electric drive systems. The review focused on the aspects of the current FMCSRs that could be different for high-voltage systems as compared to low-voltage electrical systems. Both the text of the relevant FMCSRs and a summary of current NAS inspection procedures and OOS criteria are shown in Appendix A.

Following this review, the researcher conducted a literature review of codes, standards, and best practices related to medium- and heavy-duty vehicles with electric drive systems. The list of reference documents included in the literature review was developed by FMCSA and the researcher, based on prior industry experience, consultation with other Federal agencies, and an Internet search. The reference documents include:

- Codes, standards, and best practices developed by U.S. and international standards organizations (American National Standards Institute [ANSI], National Fire Protection Association [NFPA], ISO, SAE).
- U.S. Federal Motor Vehicle Safety Standards (FMVSSs) applicable to light-duty vehicles.
- Interim guidance documents from the U.S. Department of Transportation (USDOT) related to electric and hybrid-electric vehicles.
- Safety regulations related to electric drive vehicles adopted by the Codes, Rules, and Regulations of the State of New York (CCR-NY), Canada (Transport Canada), and the European Union (United Nations Economic Commission for Europe [UNECE]).

Citations for all documents included in the literature review are shown in Appendix B. A brief summary of the most important points gleaned from the literature review is provided in Section 3. A more comprehensive summary of the literature review was provided to FMCSA in a separate document as the first deliverable under this project.

Note that many of the documents reviewed for this project provide design standards primarily targeted OEMs and/or vehicle converters. FMCSA does not regulate vehicle manufacturers. FMVSSs, which provide minimum standards for new vehicles produced by vehicle manufacturers, are promulgated by NHTSA. FMCSA regulates commercial vehicle owner/operators (motor carriers); the FMCSRs, which FMCSA promulgates, provide minimum standards for in-use operation and maintenance of commercial vehicles.

FMCSA's presumption is that new vehicles will be originally manufactured in accordance with applicable industry standards and FMVSSs. (An exception is in the area of diesel fuel tanks. Although NHTSA did not promulgate an FMVSS for diesel fuel tanks, FMCSA has promulgated an FMCSR that applies to diesel fuel tanks. Manufacturers follow the FMCSR that applies to diesel fuel tanks.) However, during in-use operation and maintenance, original vehicle systems may be compromised or modified and fall out of compliance. FMCSRs and associated standard inspection procedures are intended to ensure that commercial vehicle owners and operators maintain their vehicles in appropriate condition throughout their life, such that they will continue to be safe to operate. As such, the codes, standards, and best practices applicable to OEMs are relevant to the development of appropriate FMCSRs and commercial vehicle inspection procedures.

Using the review of current regulations and the literature review as a reference, the researcher identified gaps in the current FMCSRs, NAS inspection procedures, and vehicle OOS criteria that leave the unique safety concerns of high-voltage electric drive systems unaddressed. Based on this gap analysis, the researcher developed a preliminary list of recommended changes to the FMCSRs and the NAS inspection procedures and OOS criteria to address the identified gaps.

The researcher then conducted a series of industry site visits/consultations to gather feedback on the preliminary recommendations from a representative sample of organizations that would be most affected by any proposed changes to FMCSRs. These organizations included companies involved in the design and manufacture of components used in high-voltage electric drive systems for medium- and heavy-duty vehicles, OEMs of BEV and HEV commercial vehicles, commercial fleet owner/operators of HEVs and BEVs, and a commercial vehicle enforcement agency. Fourteen meetings were conducted with 57 representatives of 18 different companies/organizations. A complete list of the individuals who participated in these meetings is provided in Appendix C.

At each meeting, the researcher presented background information on the project and a summary of the preliminary recommended changes to the FMCSRs, NAS inspection procedures, and OOS criteria to address commercial vehicles with high-voltage electric drive systems. The presentation used at these meetings is provided in Appendix D.

Meeting participants were encouraged to ask questions and provide feedback on the preliminary recommendations, both verbally and in writing, as a follow-up to the meeting. Written comments were received from one organization. Section 4 shows a summary of the feedback received during the consultations.

The comments and feedback received during the industry consultations were considered by the researcher when developing the final recommendations and this final report. This report was submitted to FMCSA for review and was then submitted for a formal peer review process. The complete peer review report is available upon request.

In parallel with the peer review, the draft report was also submitted to all organizations included in the site visits, as well as to other USDOT agencies, for review. Feedback received from the reviewing organizations and agencies was also evaluated by the researcher and FMCSA and incorporated into this final report as appropriate. Section 6 shows a summary of comments not accepted, including areas of disagreement among the different reviewers.

2. SUMMARY OF FMCSA REQUIREMENTS FOR VEHICLES WITH HIGH-VOLTAGE ELECTRICAL SYSTEMS

This section briefly summarizes the current safety regulations promulgated by FMCSA that are applicable to vehicles with high-voltage electric drive systems, as well as the NAS vehicle inspection procedures and OOS criteria that are published by the CVSA.

2.1 FEDERAL MOTOR CARRIER SAFETY REGULATIONS

The FMCSRs, which are contained in the Code of Federal Regulations (CFR), Title 49 (49 CFR), cover all aspects of commercial vehicle operations and maintenance. This section highlights only those regulations that are relevant to attributes of high-voltage electric drive systems—in particular, requirements related to wiring systems and battery installations, which are contained in 49 CFR Part 393, subpart E, as well as Inspection, Repair, and Maintenance requirements contained in 49 CFR Part 396, and minimum inspection standards and OOS criteria contained in 49 CFR Chapter III, Subchapter B, Appendix G. The full text of these regulations is shown in Appendix A.

2.1.1 Electrical System Requirements

The U.S. Code of Federal Regulations, 49 CFR 393.28, contains requirements for “wiring systems” on commercial vehicles. This section of the regulation says that “electrical wiring shall be installed and maintained to conform to SAE J1292, Automobile, Truck, Truck-Tractor, Trailer, and Motor Coach Wiring, October 1981.”⁸

SAE J1292 is now out of date; as of 2008 it was replaced by two separate, updated documents: SAE J2174 “Heavy Duty Wiring Systems for Trailers 2032 mm or More in Width,”⁹ and SAE J2202, “Heavy Duty Wiring Systems For On Highway Trucks.”¹⁰

Both the original SAE J1292 and the updated SAE J2202 include standards for material selection (e.g., conductors), wire size, color-coding, installation, use of overload protection devices, and circuit identification for wiring systems installed on commercial trucks. However, both SAE J1292 and SAE J2202 specify that they are only applicable to wiring systems designed for less than 50 volts and, as such, are not applicable to high-voltage wiring systems.

Federal regulation 49 CFR 393.30 contains requirements for “battery installation” on commercial vehicles.¹¹ It states: “Every storage battery on every vehicle, unless located in the engine compartment, shall be covered by a fixed part of the motor vehicle or protected by a removable cover or enclosure. Removable covers or enclosures shall be substantial and shall be securely latched or fastened. The storage battery compartment and adjacent metal parts which might

⁸SAE International, SAE J1292, “Automobile, Truck, Truck-Tractor, Trailer, and Motor Coach Wiring,” http://standards.sae.org/j1292_198110/.

⁹SAE International, SAE J2174, “Heavy-Duty Wiring Systems for Trailers 2032 mm or More in Width,” http://standards.sae.org/j2174_200904/.

¹⁰SAE International, SAE J2202, “Heavy-Duty Wiring Systems for On-Highway Trucks,” <http://standards.sae.org/wip/j2202/>.

¹¹U.S. Government Printing Office, 49 CFR 393.30, “Battery Installation,” <http://www.gpo.gov/fdsys/granule/CFR-2011-title49-vol5/CFR-2011-title49-vol5-sec393-30>.

corrode by reason of battery leakage shall be painted or coated with an acid-resisting paint or coating and shall have openings to provide ample battery ventilation and drainage. Wherever the cable to the starting motor passes through a metal compartment, the cable shall be protected against grounding by an acid and waterproof insulating bushing. Wherever a battery and a fuel tank are both placed under the driver's seat, they shall be partitioned from each other, and each compartment shall be provided with an independent cover, ventilation, and drainage."

There are no other requirements in 49 CFR 393 specific to any other electrical components or systems installed on commercial vehicles, and there are no requirements specific to high-voltage systems or components.

2.1.2 Inspection, Repair, and Maintenance Requirements

Federal regulation 49 CFR 396 requires that every motor carrier must "systematically inspect, repair, and maintain" all motor vehicles subject to its control, and that all parts and accessories shall be in "safe and proper operating condition at all times." It also specifies that "authorized personnel" may declare and mark OOS any motor vehicle which "by reason of its mechanical condition or loading would likely cause an accident or breakdown." 49 CFR 396 specifies that, at a minimum, every vehicle will be inspected once every 12 months.¹²

2.1.3 Inspection Standards and OOS Criteria

Federal regulation 49 CFR Chapter III, Subchapter B, Appendix G, specifies that "a vehicle does not pass an inspection if it has defects or deficiencies in one of the following categories of equipment:

- Brake systems.
- Coupling devices.
- Exhaust system.
- Fuel system.
- Lighting devices.
- Safe loading.
- Steering mechanism.
- Suspension.
- Frame.
- Tires.
- Wheels and rims.
- Windshield wipers."¹³

¹²U.S. Government Printing Office, 49 CFR 396, "Inspection, Repair, and Maintenance," <http://www.gpo.gov/fdsys/pkg/CFR-2011-title49-vol5/xml/CFR-2011-title49-vol5-part396.xml>.

¹³U.S. Government Printing Office, 49 CFR 396, "49 CFR Appendix G to Subchapter B of Chapter III - Minimum Periodic Inspection Standards," <http://www.gpo.gov/fdsys/granule/CFR-2011-title49-vol5/CFR-2011-title49-vol5-subtitleB-chapIII-subchapB-appG/content-detail.html>.

Appendix G distinguishes between the OOS criteria listed there for annual inspections and the OOS criteria maintained by CVSA—discussed in Section 2.2 below—which “are intended to be used in random roadside inspections.” While the two sets of criteria are very similar, Appendix G indicates that an annual inspection requires that “all items required to be inspected are in proper adjustment, are not defective, and function properly prior to the vehicle being placed in service.” By contrast, an inspector would place a vehicle OOS during a roadside inspection only if the vehicle’s condition was “imminently hazardous” as defined by CVSA OOS criteria. It also indicates that at the roadside, inspecting officials are given flexibility to decide whether to place the vehicle OOS at the inspection site, or whether it would be less hazardous to allow the vehicle to proceed to a repair facility less than 25 miles away.

Note that the list of critical systems, which if defective could put a vehicle OOS, does not include anything related to high-voltage energy storage devices or high-voltage systems or components.

2.2 NAS INSPECTION PROCEDURES AND OOS CRITERIA

The NAS inspection procedures and OOS criteria, developed by CVSA, are used by local and State officials to conduct roadside safety inspections of commercial vehicles. The following text from the CVSA Web site describes the organization:⁽⁴⁾

CVSA is an international not-for-profit organization comprised of local, state, provincial, territorial and federal motor carrier safety officials and industry representatives from the United States, Canada, and Mexico. Our mission is to promote commercial motor vehicle safety and security by providing leadership to enforcement, industry and policy makers. CVSA member jurisdictions are represented by various Departments of Transportation, Public Utility and Service Commissions, State Police, Highway Patrols and Ministries of Transport. In addition, CVSA has several hundred associate members who are committed to helping the Alliance achieve its goals: uniformity, compatibility and reciprocity of commercial vehicle inspections, and enforcement activities throughout North America by individuals dedicated to highway safety and security.

There are six levels of inspection, which focus on different aspects of commercial vehicle operations, as follows.⁽⁵⁾

- LEVEL I—NAS Inspection.
 - An inspection that includes examination of driver’s license, medical examiner’s certificate and waiver, if applicable, alcohol and drugs, driver’s record of duty status as required, hours of service, seat belt, vehicle inspection report, brake system, coupling devices, exhaust system, frame, fuel system, turn signals, brake lamps, tail lamps, head lamps, lamps on projecting loads, safe loading, steering mechanism, suspension, tires, van and open-top trailer bodies, wheels and rims, windshield wipers, emergency exits on buses and hazardous materials (HM) requirements, as applicable.

NOTE: The NAS Level I Inspection Procedure requires the inspector to go under the vehicle. The NAS Level I Passenger Vehicle Inspection Procedure includes the use of ramps to allow the inspector to go under the vehicle.⁽⁶⁾

- LEVEL II—Walk-around Driver/Vehicle Inspection.
 - An examination that includes each of the items specified under the North American Standard Inspection. At a minimum, Level II inspections must include examination of: driver’s license, medical examiner’s certificate and waiver, if applicable, alcohol and drugs, driver’s record of duty status as required, hours of service, seat belt, vehicle inspection report, brake system, coupling devices, exhaust system, frame, fuel system, turn signals, brake lamps, tail lamps, head lamps, lamps on projecting loads, safe loading, steering mechanism, suspension, tires, van and open-top trailer bodies, wheels and rims, windshield wipers, emergency exits on buses, and HM requirements, as applicable. It is contemplated, that the walk-around driver/vehicle inspection will include only those items that can be inspected without physically getting under the vehicle.
- LEVEL III—Driver-only Inspection.
 - A roadside examination of the driver’s license, medical certification and waiver, if applicable, driver’s record of duty status as required, hours of service, seat belt, vehicle inspection report, and HM requirements, as applicable.
- LEVEL IV—Special Inspections.
 - Inspections under this heading typically include a one-time examination of a particular item. These examinations are normally made in support of a study or to verify or refute a suspected trend.
- LEVEL V—Vehicle-only Inspection.
 - An inspection that includes each of the vehicle inspection items specified under the NAS Inspection (Level I), without a driver present, conducted at any location.
- LEVEL VI—Enhanced NAS Inspection for Radioactive Shipments.
 - An inspection for select radiological shipments, which includes inspection procedures, enhancements to the Level I inspection, radiological requirements, and the enhanced OOS criteria.

This project is only concerned with the vehicle inspection portions of Level I, II, and V inspections. Procedures related to driver records, special inspections, and radiological shipments are not addressed.

The defined procedure for vehicle inspections includes 37 steps, with the inspector proceeding around the vehicle in a prescribed manner and inspecting specific items at each step. The inspector is evaluating both condition and operability of specific vehicle systems, including headlamps, turn signals, windshield wipers, tires, fuel tanks, frame and body, brakes, and cargo securement.

There are 14 critical vehicle inspection items; a vehicle passes inspection if no defects are found in any of those 14 items. The inspector may place a vehicle OOS if the condition of one or more critical items “would be likely to cause an accident or breakdown.” OOS vehicles must be repaired to correct the defective condition before being placed back into service.

The current inspection procedure does not include an inspection of any high-voltage energy storage devices, high-voltage components, or high-voltage systems if present on a vehicle. The 14 safety critical inspection items do not include any high-voltage components or systems.

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3. SUMMARY OF LITERATURE REVIEW

This section briefly summarizes the requirements of the reviewed codes, standards, best practices, research and guidance documents, and regulations related to commercial vehicles with high-voltage electric drive systems.

The reviewed codes and standards were produced by U.S. and international standards organizations, including the NFPA 70; ISO 6469-1, -2, -3; ISO 16750; and SAE J1654, SAE J1673, SAE J1742, SAE J1797, SAE J2344, SAE J2464, SAE J2758, SAE J2910, SAE J2929, SAE J2936, and SAE J2990.

The literature review also included a review of interim USDOT guidance related to electric and hybrid-electric vehicles; USDOT research on minimum sound standards for hybrid and electric vehicles; safety regulations related to electric drive vehicles that have been adopted by the State of New York (CCR-NY), Canada (Transport Canada), and UNECE; and FMVSSs applicable to light-duty vehicles.¹⁴ Full citations for all documents included in the literature review are provided in Appendix B.

U.S. and international standards provide very detailed requirements for the design and testing of high-voltage vehicle electrical systems. The summary below provides a high-level overview of the major issues identified in the literature review. A more complete summary of the documents reviewed was provided to FMCSA in a separate document, which was the first deliverable under this project.

3.1 CODES, STANDARDS, AND BEST PRACTICES

For this project, the researcher reviewed 11 SAE documents, and 1 ISO document (in 3 parts), related to components and systems used in electric drive vehicles. In addition, the researcher reviewed several sections of the NEC developed by NFPA.

Most of these documents include very detailed design standards and testing procedures for various subsystems or components, in particular for RESS. Verification of compliance with most of the requirements of these recommended practices would require highly specialized knowledge, training, and equipment. As such, it would be extremely difficult for a commercial vehicle inspector to verify them during an annual or roadside safety inspection.

With respect to potential changes to FMCSA in-use safety standards, inspection procedures, and OOS criteria, the most relevant reviewed documents are SAE J2910, “Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety,” and ISO 6469, “Electrically Propelled Road Vehicles—Safety Specifications.” These documents have broadly similar requirements, including:

- A vehicle carrying high-voltage components shall contain labeling or marking to “clearly identify to emergency and service personnel that the vehicle contains potentially hazardous voltage”; the labeling or marking shall be visible to a person standing beside the vehicle and should be legible from 50 feet in daylight. It is recommended that the

¹⁴The researcher also searched for electric vehicle safety regulations promulgated by the State of California, but none exist.

yellow “hazardous voltage triangle” (as shown in Figure 1) be affixed in the following locations: lower-right rear, front of the vehicle, and below the USDOT number on both the right and left sides of the vehicle. For alternative fuel hybrids, this labeling shall be in addition to, and next to, any alternative fuel labeling required.

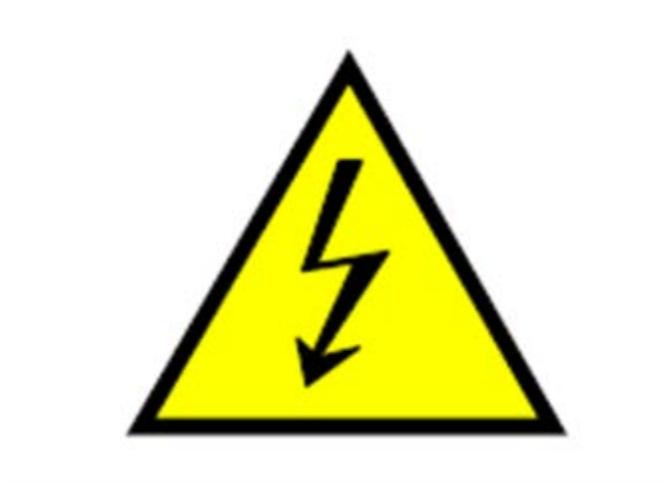


Figure 1. Image. Hazardous voltage symbol.
IEC 60417

- For hybrid vehicles, the driver’s compartment should contain labeling that clearly identifies the vehicle as a hybrid vehicle and is visible to the driver from the driver’s seat.¹⁵ Manufacturer badging that contains the word “hybrid” satisfies this requirement.
- A hybrid vehicle shall contain a label identifying the means and method of disconnecting and de-energizing the high-voltage distribution system. This label shall include: symbols for “high voltage” and “warning;” a description of the shock hazard; a top-view diagram of the vehicle depicting locations of high-voltage components; text identifying the model of the HEV system and its manufacturer; and a phone number for questions and assistance. The label shall have orange background and black text (as shown in Figure 2).

¹⁵Note that SAE J2990, “Hybrid and EV First and Second Responder Recommended Practice,” which applies specifically to light-duty vehicles, recommends that all electric drive vehicles contain both interior and exterior badging that consistently incorporates one of the following words: HYBRID, ELECTRIC, or EV.” Combinations that contain the above characters are also allowed, for example PLUG-IN HYBRID, PHEV, and BEV.” See SAE International, http://standards.sae.org/j2990_201211/.

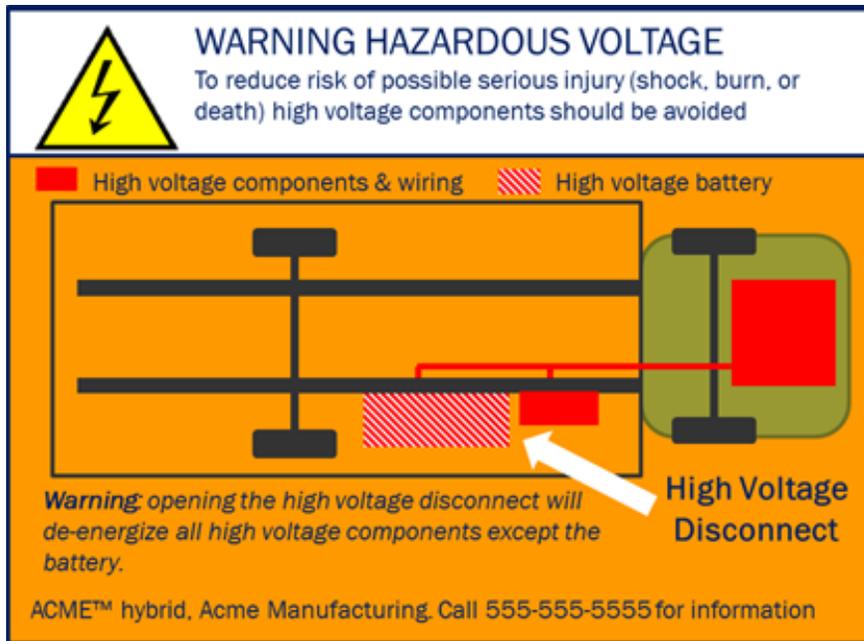


Figure 2. Image. Mock-up of high-voltage service disconnect label.
SAE J2910

- If special towing procedures are required to keep the electric drive motor from generating high voltage during towing (i.e., disconnect drive shaft, tow with drive wheels elevated, etc.), then a label should be placed inside the driver’s door—or near the vehicle entrance for vehicles without a driver’s door—with the towing instructions.
- Symbols or labels should be posted on all high-voltage components and enclosures. Labels should incorporate the International Electromechanical Commission (IEC) “hazardous-voltage triangle” and warning text (as shown in Figure 3).



Figure 3. Image. Hazardous-voltage warning labels.

- All high-voltage cables shall be identified as such by an orange color on the exterior surface.
- The vehicle design shall provide at least two reliable and readily identifiable means to de-energize the high-voltage distribution system by emergency personnel. De-energized

means that the energy storage will be isolated from the rest of the system, and capacitive voltage in the energy distribution system will be discharged to a low-voltage level (less than 30 VAC or less than 60 VDC) within 120 seconds of activating the disconnect methods. Actuation of the disconnect methods shall not require any special tools or the removal of any intermediate panel or truck part; the disconnect methods must still be accessible if the vehicle has rolled over onto its side or roof. The recommended practice is that one disconnect method should be a “manual switch or mid-pack fuse integrated on a top or side surface of the energy storage enclosure.” The recommended practice is that “high-voltage relays should not be relied on as the sole means for de-energizing the systems, based on the possibility that high-voltage relay contacts can weld together and maintain an unintended connection.”

- Turning off the vehicle ignition switch or disconnecting the vehicle’s 12 VDC or 24 VDC battery should disable high-voltage contactors and de-energize the high-voltage distribution system.
- The cabin dashboard shall contain two warning lights:
 - A yellow/amber “Check Hybrid” light to indicate faults that require service.
 - A red or flashing light to indicate critical hybrid system faults that require operator to bring the vehicle to a stop immediately.
- The insulation of high-voltage wire harnesses, buss bars, and other high-voltage conductors must be greater than 500 ohms per volt for conductors carrying high-voltage AC electricity, and 100 ohms per volt for conductors carrying DC electricity, measured between the high-voltage conductors and the vehicle chassis. The complete system needs to meet the 500 ohms per volt level; consequently, individual components should be specified to levels greater than 500 ohms per volt.
- Recommended practice is that the vehicle system includes electrical isolation detection for both energy storage and power distribution on the vehicle.
 - In the event that isolation falls to less than 500 ohms/volt the yellow/amber “Check Hybrid” warning light should be illuminated, and when the vehicle next comes to a stop, the drive system should be disabled and the high-voltage system disconnected.
 - In the event that isolation falls to less than 100 ohms/volt, the red or flashing hybrid warning light should be illuminated and the drive system should immediately be disabled and the high-voltage system disconnected.
- If the vehicle can be plugged in to charge the energy storage system, it should include a light, preferably at the location of the charging port, to indicate that the vehicle is charging.
- The design should implement open-circuit detection for high-voltage circuits. In the event an open circuit is detected, the red hybrid warning light should be illuminated and the high-voltage distribution system should be de-energized.
- The high-voltage system shall be protected from over-current conditions using a fuse or circuit breaker.

- The vehicle should be designed to disconnect high voltage within 5 seconds of the vehicle coming to rest in the event of a crash, using an inertial impact sensor. This requirement for trucks and buses, “should be the same as those for automobiles under FMVSS 305” (see Section 3.3).
- Energy storage devices shall meet the requirements of FMVSS 305 in the event of a crash (see Section 3.3).
- In the event of damage, the energy storage system should leak less than 10 percent of its hazardous liquid materials, or no more than 5 liters, whichever is less. Any liquid discharge should be directed away from occupants, routine service locations, or expected nearby personnel.
- Any discharge of gas from the energy storage system should be directed away from occupants, routine service locations, reasonably expected nearby personnel, or any potential ignition sources. The recommended practice is that the “remote energy storage system is not mounted in a passenger compartment.”
- If an energy storage system may discharge a flammable gas with a concentration within the gas’s flammability limits, the energy storage system shall incorporate a flame arrestor.
- High-voltage cables and components shall use terminations that are not finger-accessible after connector removal.
- Any service access panel that covers high voltage should be protected by an interlock circuit.
- An electric drive system shall not produce torque to the wheels without a command from the driver. Unintentional acceleration, deceleration, or reversal of the drive train shall be prevented.
- Hybrid or electric commercial vehicles should be subject to specific “system or vehicle level validation of the high-voltage system,” including the following tests:¹⁶
 - Applied withstand voltage.
 - Insulation resistance.
 - Actuation of isolation detection.
 - High-voltage interlock validation.
 - Over-temperature operation.
 - Accessibility of high-voltage terminals.
 - Visibility and accessibility of high-voltage disconnect.
 - Actuation of high-voltage disconnect.
 - Actuation of short-circuit protection.
 - Water exposure tests for insulation breakdown.

¹⁶SAE J2910 includes detailed test procedures for all of the specified validation tests. All these validation tests require specialized equipment and knowledge to be performed correctly.

- Radiated susceptibility.

The NFPA has not developed standards specific to electric drive vehicles. The standards reviewed for this project include sections 480, 490, and 625 of NFPA 70, the NEC (2011), which respectively deal with stationary installations of storage batteries, stationary equipment more than 600 VDC nominal, and off-board (stationary) electric vehicle charging systems. None of these standards are relevant to FMCSA in-use safety standards, inspection procedures, and OOS criteria for commercial vehicles with high-voltage systems.

NFPA has developed a *Hybrid and Electric Vehicle Emergency Field Guide* that is intended primarily for use by firefighters and other first responders who may respond to the scene of an accident involving one or more light-duty vehicles equipped with a high-voltage electric drive system. This document provides both generic information that is generally applicable to all electric drive vehicles and specific information for 86 light-duty electric and hybrid-electric cars, light-duty trucks, and sport utility vehicles sold in the United States. The NFPA field guide currently does not include specific information about any medium- or heavy-duty vehicles.

The field guide provides information about the following subjects: how to identify an electric drive vehicle, how to immobilize an electric drive vehicle, how to disable the drive system of an electric drive vehicle, crash response and extrication, electric vehicle fire suppression, electric vehicle submersion, and electrolyte spill hazards.

With respect to in-use safety of medium- and heavy-duty electric drive vehicles, the lessons that may be learned from the NFPA guide include:

- The importance of consistent labeling so that emergency responders may identify vehicles with high-voltage drive systems and energy storage devices.
- The need to have a means—accessible to emergency responders from outside the vehicle and labeled—of shutting off the drive system and de-energizing high-voltage components.
- The importance of labeling and marking high-voltage cables and equipment on the vehicle.

3.2 USDOT GUIDANCE AND RESEARCH

NHTSA has produced “Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped with High-Voltage Batteries” (DOT HS 811 574, January 2012), which addresses vehicle safety in the event of a crash. This document includes sections addressed to vehicle owners, first responders (e.g., police, fire, medical), and towing companies.

The content of this guidance is consistent with the NFPA *Hybrid and Electric Vehicle Emergency Field Guide*, though much less detailed. The main points made are that both vehicle owners and emergency responders need to be aware of the following:

- There is a potential for high-voltage shock hazards from exposed or damaged “electrical components, wires, and high-voltage batteries.”

- There is a potential for “immediate or delayed release of toxic and/or flammable gases and fire” from damaged high-voltage batteries.
- “Venting/off-gassing high-voltage battery vapors are potentially toxic and flammable.”
- A high-voltage battery and associated components may be energized even if a vehicle is off.

3.3 FMVSS

There are currently no FMVSSs dealing with high-voltage hazards or electric drive components or systems that are applicable to medium- and heavy-duty commercial vehicles. FMVSS 305, “Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection” (49 CFR 571.305), is the only Federal standard that specifically addresses vehicles with high-voltage electric drive systems; however, this standard applies only to light-duty vehicles with a gross vehicle weight rating of 10,000 pounds (4,536 kg) or less. These vehicles are not included in FMCSA regulations.

FMVSS 305 and an associated laboratory test procedure (TP-305-01) address standards for how “electrical energy storage/conversion devices” should perform during the mandatory vehicle crash tests specified in FMVSS 208, FMVSS 214, and FMVSS 301, which include dynamic side impact tests, front and rear impact tests, and static rollover tests.

FMVSS 305 mandates that during each crash test the electrical energy storage system:

- Must not leak any electrolyte into the passenger compartment and must not leak more than 5 liters of electrolyte outside of the passenger compartment.
- Must remain attached to the vehicle; in addition if located inside the passenger compartment, it must not move from its position, or if located outside the passenger compartment, it must not enter the passenger compartment.
- Must maintain at least 500 ohms per volt electrical isolation of all high-voltage components, or at least 100 ohms per volt isolation, if the vehicle is equipped with continuous electrical isolation monitoring.

While the safety concepts of FMVSS 305 can be applied to medium- and heavy-duty vehicles, the specific requirements of this standard cannot, because those vehicle types are not subject to the specified vehicle crash tests.

In January 2013, NHTSA published a notice of proposed rulemaking that would set minimum sound standards for hybrid and electric vehicles. The proposed rules would apply to all vehicles, including medium- and heavy-duty vehicles, capable of forward or backward propulsion without an internal combustion engine running. This would include BEVs, FCVs, and some HEVs.

Beginning in September 2015, these vehicles would be required to emit sounds that meet specified minimum criteria (e.g., loudness, frequency range) when the vehicles are operating in specified scenarios (i.e., start-up, backing, and low-speed forward operation). The intent of the

proposed rule is to “ensure that blind, visually-impaired, and other pedestrians are able to detect and recognize nearby hybrid and electric vehicles, as required by the Pedestrian Safety Enhancement Act, by requiring that hybrid and electric vehicles emit sound that pedestrians would be able to hear in a range of ambient environments and contain acoustic signal content that pedestrians will recognize as being emitted from a vehicle.”⁽⁷⁾

In February 2014, NHTSA published a notice of proposed rulemaking that would require standardized vehicle badging on light-duty “alternative fuel vehicles,” including electric vehicles.⁽⁸⁾ The proposed rules would require that natural language minimal descriptions of the alternative fuel used by the vehicle be incorporated into a permanent vehicle badge, to be located on the rear of the vehicle, either directly below or to the right of the vehicle model name.

These badges would be required for new passenger cars, low-speed vehicles, and light-duty trucks rated less than 8,500 pounds gross vehicle weight. The purpose of the proposed labels would be to “increase consumer awareness regarding the use and benefits of alternative fuels, as required by the Energy Independence and Security Act of 2007 (EISA).” The purpose of these proposed labels is not related to safety and is not to alert emergency responders to any hazards associated with the alternative fuels being used.

The natural language minimal descriptions proposed by NHTSA for electric drive vehicles include the word “electric” for BEVs and the words “plug-in hybrid electric” for plug-in HEVs. Note that per this proposed rulemaking, HEVs that cannot be plugged into the grid are not considered “alternative fuel vehicles” and would not be subject to this requirement. As such, NHTSA did not specify a natural language minimal description for non-plug-in hybrid vehicles.

3.4 NEW YORK STATE, CANADA, AND EUROPEAN UNION REGULATIONS

3.4.1 New York State

The State of New York has adopted safety regulations that are applicable specifically to electric powered buses, including electric buses and hybrid-electric buses. These regulations, codified in Title 17, Chapter IV, Subchapter D, Article 3, Part 720.9 of the CRR of the State of New York (17 CCR-NY 720.9), are generally consistent with SAE J2910 and ISO 6469 (see Section 3.1), and they require that for electric-powered buses:

- Vehicles must be labeled as electric powered on both sides of the exterior (as shown in Figure 4). *Note that this label does not convey a warning that the bus operates at a hazardous voltage.*



Figure 4. Image. New York State required label for electric drive buses.

- All doors or covers that provide immediate access to high-voltage areas must be locked or otherwise secured to prevent unauthorized access and must be labeled to say: WARNING—HIGH VOLTAGE or DANGER—HIGH VOLTAGE.
- All buses must be equipped with two methods to disconnect high-voltage power from the propulsion circuit. One must be a switch or key operable from the driver’s seat, and one must be operable from outside the vehicle. The location of the second switch must be clearly labeled on the vehicle exterior.
- All propulsion batteries must be located in compartments isolated from the passenger compartment behind an electrically insulated enclosure or cover.
- Battery compartments must be constructed of materials that can withstand corrosive effects from battery leakage for the types of batteries included in the manufacturer’s design of the vehicle.
- Battery compartments must have ventilation sufficient to maintain the concentration of hydrogen at less than 4 percent volume in air during battery charging.
- Battery compartments must be designed to prevent any battery fluids, including toxic gases or fumes, from entering the passenger compartment when the vehicle is subject to a moving contoured barrier crash test using a contoured barrier as described in FMVSS 301, Figure 2. (FMVSS 301 only applies to light duty vehicles.) Such a test would simulate a 4,000-pound light-duty vehicle striking the bus at up to 30 mi/h.
- All battery compartments must include a permanent label that states the following:
 - Battery manufacturer’s name
 - Battery model or specification number
 - Number of batteries located in each compartment
 - A wiring schematic showing battery cable connections and indicating positive or negative ground.
- All high-voltage circuits must include protection against over-current, using fuses, circuit breakers, or ground fault interruption.
- A device must be installed on the vehicle to prevent driving the vehicle when it is connected to an external battery charging power source.
- The vehicle shall have a range selector accessible from the driving position which clearly indicates that the vehicle is in park, forward, neutral, or reverse.
- The drive system shall allow drive motor(s) to be energized only by the accelerator and only when the range selector is in the forward or reverse position. The system shall not allow shifting from forward to reverse, or vice-versa, without coming to a complete stop (speed = 0 mi/h).
- The propulsion system shall be designed to sense high temperature at critical points, to activate a driver high temperature warning light, and to reduce or turn off propulsion

current to protect the system from damage when a critical high-temperature condition is reached.

- Regenerative braking systems shall include a master on-off switch, which is operable from the normal driving position.
- Electric buses must be equipped with a backup alarm, which activates when the range selector is placed in the reverse position, and a second alarm, which activates when the bus rolls more than 3 feet backward, regardless of the location of the range selector.

3.4.2 Canada

As part of its Motor Vehicle Safety Regulations, Transport Canada has adopted Technical Standards Document No. 305, Revision 3, “Electrolyte Spillage and Electrical Shock Protection.” This standard is based on FMVSS 305 and, for light-duty vehicles, imposes virtually the same requirements as described in Section 2.2.1.1.

As in the United States, Canada does not have any vehicle safety standards related specifically to high-voltage electric drive components or systems that are applicable to medium- and heavy-duty vehicles.

3.4.3 European Union

UNECE, Regulation No. 100, Addendum 99, Revision 2 (August 12, 2013), specifies “Uniform Provisions concerning the Approval of Vehicles with regard to Specific Requirements for the Electric Power Train,” to be used by the various approval authorities of European countries. These approval provisions apply to all vehicles with at least four wheels used to carry passengers or goods¹⁷ that are “equipped with one or more traction motor(s) operated by electric power.”

These regulations are consistent with the requirements of ISO 6469 (see Section 3.1). To be approved, vehicles must meet the following minimum requirements:

- All electrically live parts shall be protected against direct contact using a solid insulator, barrier, enclosure, or other device that shall not be able to be opened, disassembled, or removed without the use of tools. The level of protection in accordance with the IEC International Protection Code shall be IPXXD in the passenger or luggage compartment and IPXXB in other parts of the vehicle.¹⁸
- All RESS and all enclosures or barriers which when removed expose live parts of high-voltage circuits must be labeled with a yellow triangular hazardous voltage symbol (as shown in Figure 1, above).
- High-voltage cables not located within enclosures must have an orange-colored outer covering.

¹⁷These are vehicle types M and N as defined in the Consolidated Resolution of the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev. 2.

¹⁸IPXXD and IPXXB refer to the tests required to demonstrate compliance. In effect, IPXXB means that a live part could not be contacted by a person’s finger, and IPXXD is a higher level of protection in which a live part could not be contacted by a metal wire 1 mm diameter by 100 mm long.

- Exposed conductive parts—such as high-voltage barriers—must be grounded to the vehicle chassis.
- If the vehicle can be connected to a grounded external power supply through a conductive connection, a device must be included that will create a galvanic connection between the vehicle electrical chassis and earth ground.
- High-voltage components must maintain at least 100 ohms per volt electrical isolation from the electrical chassis for DC components and 500 ohms per volt for AC components.
- For FCVs, if required minimum electrical isolation cannot be maintained over time, components must be shielded with double-layer barriers, or an isolation resistance monitoring system must be installed which will warn the driver if isolation resistance drops below the required minimum value.
- Containers for traction batteries that can produce hydrogen gas must have a ventilation fan or duct that will preclude accumulation of gas.
- Except under conditions when an internal combustion engine directly or indirectly provides propulsion power, “at least a momentary indication” must be given to the driver when the vehicle is in “active driving possible mode.” When exiting the vehicle, the driver must be given a signal (optical or audible) if the vehicle is still in active driving possible mode.
- If the vehicle can be connected to an external electrical power supply, the vehicle must be incapable of moving under its own propulsion power when the external supply is connected.
- The “state of the drive direction control unit” shall be identified to the driver.
- RESSs shall be subjected to specific approval tests to demonstrate minimum performance requirements for: hydrogen emissions in the event of battery charger failures, fire, explosion, mechanical integrity, electrolyte spillage and maintenance of electrical isolation when subject to vibration, thermal cycling, mechanical shock and crush loads, flame exposure, external short-circuit, over-charge and over-discharge, over-temperature, and vehicle crash tests.¹⁹

3.5 OPERATIONAL SAFETY FOCUS FOR ELECTRIC DRIVE VEHICLES

Based on the literature review summarized above, the most important areas of focus for safety of operations and maintenance of in-use commercial vehicles with high-voltage electric drive systems include the following:

- Vehicle and component/system labeling to alert emergency first responders and maintenance personnel to a potential shock hazard from vehicle components energized to a hazardous electrical potential.

¹⁹The test methods and minimum performance criteria for vehicle crash tests are similar to those mandated by FMVSS 305.

- Inclusion and labeling of disconnect methods to allow emergency first responders to de-energize the vehicle's high-voltage distribution system.
- Location, securement, and protection of RESSs (i.e., battery packs) and other high-voltage components to preclude loss of electrical isolation, fire, electrolyte spillage, or intrusion of toxic or combustible gases into the passenger compartment during normal operation or in a vehicle crash.
- Operation of systems to alert the vehicle operator, and in certain circumstances automatically remove power from the high-voltage distribution system, in the event of a loss of high-voltage electrical isolation or other critical system fault that could result in personal injury or vehicle damage.
- Operation of systems designed to provide an audible signal to alert pedestrians to the presence of an electric drive vehicle when no internal combustion engine is operating.

3.6 GAP ANALYSIS

This section summarizes an analysis of areas where current FMCSRs, NAS inspection procedures, and OOS criteria do not fully address the unique safety issues of commercial vehicles with high-voltage electric drive systems. The intent is to highlight areas where current regulations and procedures should be strengthened, in accordance with industry standards and best practices, to ensure that commercial BEVs, HEVs, and FVCs are maintained and operated in a manner that provides the highest level of public safety.

3.6.1 Federal Motor Carrier Safety Regulations

The current FMCSRs do not address the unique safety aspects of onboard high-voltage vehicle electrical systems in any way.

In particular, the current FMCSRs do not require in-use electric drive vehicles to be equipped with high voltage-specific safety features/systems recommended by industry standards and best practices, which include the following:

- Continuous monitoring of high-voltage electrical isolation, and a method to alert the vehicle operator in the event that electrical isolation falls below a set threshold (i.e., 500 ohms per volt), and to automatically de-energize the high-voltage distribution system in the event that electrical isolation falls below a lower set threshold (i.e., 100 ohms per volt).
- Multiple manual methods to de-energize the high-voltage distribution system on the vehicle, which are accessible to emergency responders from the vehicle exterior.
- Panels or covers to preclude casual contact with all energized high-voltage components.
- An audible sound signature to alert pedestrians when a vehicle is moving at low speed but no internal combustion engine is operating.

The current FMCSRs do not include mandatory installation details for high-voltage systems and components. In particular, there are no requirements for location, installation, and protection of

RESSs (battery packs) or other high-voltage equipment to prevent damage and loss of electrical isolation in a vehicle crash, or from impact by road hazards or vehicle loads.

The current FMCSRs do not require electric drive vehicles and components to be labeled (as recommended by industry standards and best practices) to alert vehicle operators, maintenance personnel, and emergency first responders to a potential high-voltage shock hazard.

3.6.2 NAS Inspection Procedures

The current NAS inspection procedures do not require inspectors to verify that vehicle labels recommended by industry standards and best practices are in place on commercial vehicles with high-voltage electrical systems.

The current NAS inspection procedures do not require inspectors to evaluate the condition of high-voltage components or systems on the vehicle—for example, that the RESS and other high-voltage components are securely attached to the vehicle and undamaged, or that exposed high-voltage cables are undamaged.

The current NAS inspection procedures do not require inspectors to verify that high-voltage safety systems required by industry standards and best practices are in place and operable on commercial vehicles with electric drive systems. Items that could be checked include the following:

- Covers or barriers protecting high-voltage components are in place and undamaged.
- High-voltage disconnect switches or fuses are in place and undamaged.
- A system is operational that produces an audible sound when the vehicle is moving at low speed when the internal combustion engine is not on.

It may not be practical for safety inspectors to verify that a system to continuously monitor the electrical isolation of high-voltage components is operational. See further discussion of this issue in Sections 4 and 6 below.

3.6.3 OOS Criteria

The NAS inspection OOS criteria currently do not address in-use conditions that could present a significant safety hazard for commercial vehicles with high-voltage electrical systems, including the following:

- Cut, chafed, or damaged high-voltage wiring and connectors.
- RESS or other high-voltage components not securely attached to the vehicle.
- Energized high-voltage components directly accessible (covers or barriers missing or damaged).
- Manual high-voltage disconnect switches or fuses missing or damaged.
- High-voltage electrical isolation less than some set safe threshold (e.g., 100 ohms per volt).

- No vehicle sound signature when the vehicle is moving at low speed but the internal combustion engine is not operating.

4. SITE VISITS AND INDUSTRY CONSULTATIONS

This section summarizes the stakeholder outreach conducted as part of this project, to collect feedback on potential changes to the FMCSRs and NAS inspection procedures from the companies and organizations that would be most affected by the changes.

4.1 SUMMARY OF SITE VISITS

As part of this project, the researcher convened a series of meetings to gather feedback on preliminary recommendations for changes to the FMCSRs and NAS inspection procedures from a representative sample of organizations that would be most affected by any changes, including: companies involved in the design and manufacture of medium- and heavy-duty BEVs and HEVs and the components used in their electric drive systems; commercial fleet owner/operators or renters/lessors that currently use medium- and heavy-duty BEVs and HEVs; and other State and Federal Government agencies involved with development and/or enforcement of regulations for commercial vehicles.

A total of 14 meetings were conducted with 57 representatives from 18 different companies/organizations. The following organizations participated in the meetings (a complete list of the individuals who participated is included at Appendix C):

- Federal Agencies.
 - Federal Motor Carrier Safety Administration.
 - National Highway Traffic Safety Administration.
 - Federal Transit Administration.
- State Agencies.
 - New York State Department of Transportation.
 - New York State Police.
- Commercial Vehicle Manufacturers that Produce Electric Drive Vehicles.
 - Daimler Trucks North America (hybrid-electric).
 - Electric Vehicles International (battery electric).
 - Hino Trucks USA (hybrid-electric).
 - Peterbilt Motors Company (hybrid-electric).
 - Smith Electric Vehicles (battery electric).
- High-Voltage System Suppliers.
 - BAE Systems.
 - Eaton Corporation.
- Commercial Vehicle Fleets that Currently Operate Electric-Drive Vehicles.
 - Coca-Cola Refreshments (hybrid-electric).

- Frito-Lay (hybrid-electric, battery electric).
- San Francisco Municipal Transportation Agency (hybrid-electric).
- United Parcel Service (hybrid-electric, battery electric).

In addition to meetings with representatives of the above organizations, a presentation was made at the 2014 Commercial Vehicle Safety Alliance (CVSA) Workshop in Los Angeles, CA, on April 10, 2014, to the CVSA Vehicle Committee. At the CVSA Vehicle Committee meeting, approximately 25 individuals from various enforcement agencies involved with commercial vehicle inspections attended the presentation.

At each meeting, the researcher presented background information on the project and a summary of the preliminary recommended changes to the FMCSRs, NAS inspection procedures, and OOS criteria to address commercial vehicles with electric drive systems. The presentation used at the meetings is included in Appendix D.

Meeting participants were encouraged to ask questions and provide feedback on the preliminary recommendations, both verbally and in writing, as a follow-up to the meeting. A summary of the feedback received during the stakeholder consultations is provided below.

4.2 SUMMARY OF SITE VISIT COMMENTS

All the individuals and organizations who participated in the site visits for this project recognized and agreed that there are gaps in the current FMCSRs, inspection procedures, and OOS criteria related to the safety of in-use vehicles with high-voltage electrical systems. All agreed that some changes are warranted to fill the gaps, including specification of minimum safety features required for in-use electric drive vehicles, specification of minimum standards for in-use condition of high-voltage components on in-use electric drive vehicles, specification of vehicle labeling requirements for in-use vehicles, and accident reporting requirements.

All participants agreed that many of the voluntary standards codified in SAE J2910, “Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety,” are an appropriate starting point for development of in-use standards by FMCSA. All vehicle and electrical system manufacturers indicated that their current products generally comply with the intent, and with many of the specific provisions, of SAE J2910 when manufactured. However, all also agreed that many of the design requirements of SAE J2910 are difficult to verify, and that verification requires specialized knowledge, equipment, and procedures. As such, it would be impractical for commercial vehicle inspectors to evaluate compliance with many of the specific recommendations of SAE J2910 during annual and roadside inspections.

With respect to vehicle labeling, there was general agreement that some type of labeling is required on electric-drive commercial vehicles, to alert vehicle operators and emergency responders to a potential high-voltage shock hazard. However, there was little consensus as to the form or format that such labeling should take, and there was significant disagreement about the specific label recommended by SAE J2910. Many participants were in favor of using the “high-voltage triangle” (see Figure 1, Section 3.1) on the sides of the vehicle as recommended by

SAE J2910. However, one manufacturer objected, because the high-voltage triangle has an established meaning of “there is high voltage located behind this specific panel” not “this vehicle contains high voltage somewhere,” and this particular manufacturer felt that the use of this figure as a general warning rather than a specific locational warning could be confusing. Several others felt that this symbol could be unnecessarily alarming to, or have negative connotations for, the general public.

Some recommended developing a new standardized image specific to this purpose, perhaps by incorporating the high-voltage triangle superimposed on a generic vehicle outline. Another option would be to follow the general labeling format used for alternative fuel vehicles, by putting text such as “electric” or “hybrid-electric” inside a blue diamond label. One manufacturer suggested that bar codes could be used, which could incorporate a lot of information for emergency responders. There are free applications available for virtually all smart phones that can be used to read bar codes.

Others preferred the use of manufacturer-defined “badging” on the exterior of the vehicle, as is done on light-duty vehicles to identify a vehicle as having a high-voltage electrical system; however, some were concerned that potential inconsistencies in manufacturer terminology could be confusing to emergency personnel.²⁰ Some fleet operators were also concerned about the difficulty and expense of replacing manufacturer-designed badging in the event of vehicle damage, and therefore preferred a standardized decal label. On the other hand, other fleets expressed support for manufacturer-designed badging instead of a specific label, because they felt it would be less obtrusive and less likely to clash with their own vehicle color schemes and company branding.

Despite disagreement about the specific details of a required exterior label to identify commercial vehicles as electric drive vehicles, there was general agreement about the functional requirements for any exterior label(s) required by FMCSA. There was consistent interest that any FMCSA exterior labeling requirement should be:

- Clear, concise, and unambiguous.
- Consistently applicable to all manufacturers and types of commercial vehicle types.
- To the extent possible, consistent with required labeling for light-duty vehicles.
- Not rigid with respect to required label location in order to accommodate the range of commercial vehicle styles and company vehicle branding.

There was general support for the other exterior label recommended by SAE J2910, which would show, for emergency responders, the method and location of de-energizing the high-voltage distribution system from the exterior of the vehicle. One manufacturer felt it would be burdensome to create a specific label for every vehicle configuration, and would prefer flexibility to create a single generic label that could be applied to multiple configurations. There was also some concern that FMCSA would need to allow significant flexibility with respect to the

²⁰For a recent notice of proposed rulemaking related to mandatory vehicle badging of alternative fuel vehicles, NHTSA surveyed the badging used by light-duty vehicle manufacturers for natural gas and electric drive vehicles and found significant inconsistency among manufacturers with respect to the terminology used. (See reference 8.)

required location of the label, to accommodate the range of commercial vehicle configurations. In addition, several fleet operators expressed concern about putting such a label in a location that would be clearly visible to the general public; they were concerned that vandals could follow the label's instructions out of malice, and render a vehicle inoperable unnecessarily. One fleet operator indicated that this has been a problem in the past—vandals turning off the disconnect switch on the low-voltage vehicle power supply—so they have already removed from their vehicles the exterior label showing where this switch is located. These fleet operators would like to see FMCSA allow such a label to be located behind a door or panel on the exterior of the vehicle.

Many site visit participants felt that the recommendation in SAE J2910 to have manufacturer vehicle badging in the driver compartment, visible from the driver's seat, to identify the vehicle as electric drive is unnecessary and potentially problematic. Many felt that such badging is unnecessary specifically for commercial vehicles because commercial drivers are required to do a walk-around inspection of their vehicles every day and would routinely see mandatory exterior vehicle labeling, and as such there would be little chance that they would not know that their vehicle was electric drive. Several fleet operators pointed out that the interiors of their vehicles are damaged frequently—they were concerned about the difficulty and expense of replacing manufacturer-created interior badging if it were made mandatory by FMCSA regulation.

There was almost universal support for the other interior label recommended by SAE J2910—a label to identify “special” towing procedures for electric drive vehicles, to preclude generation of high voltage by the drive motor during towing. However, the location for this label specified by SAE J2910—on the driver's door—was universally identified as problematic. Both manufacturers and fleet operators pointed out that modern driver doors on commercial vehicles are almost always equipped with insert panels that get damaged and are frequently replaced. There was no consensus on the best location for such a label, but suggestions included: on the driver's sun visor, on the vehicle dashboard, and near the gear shift lever.

There were also questions raised about what would constitute a “special” towing procedure that would trigger the requirement for a label. Several participants indicated that it is standard practice to remove the drive shaft from all commercial vehicles prior to towing, so if that was all that was required to isolate the drive motor then that should not be considered a “special” procedure, and no label should be required. However, one hybrid system manufacturer indicated that a tow operator towing a hybrid bus with their system installed had failed to remove the drive shaft and destroyed the drive motor, because it was not isolated and generated high voltage while being towed. At least this tow operator did not consider it standard procedure to remove the drive shaft before towing a bus.

All site visit participants were supportive of the idea that all panels or covers behind which live high-voltage components are located should be labeled with the hazardous voltage triangle and warning text, and that any exposed high-voltage cables should be identified by an orange-colored exterior cover, as recommended by SAE J2910. All manufacturers indicated that this is their current standard practice.

There was general agreement with the recommendation of SAE J2910 that “the vehicle design shall provide a reliable means to identify and de-energize the high-voltage system by emergency

personnel,” that “at least two means of disconnect be provided,” and that “the means to disconnect the high voltage shall be readily identifiable and accessible.” Most (but not all) manufacturers incorporate a manual switch or fuse located on, or in the vicinity of, the RESS as one method, as specifically recommended by SAE J2910; other manufacturers rely solely on electrically-activated contactors to disconnect the high voltage. One manufacturer incorporates a disconnect switch on the battery pack, but it is behind a metal plate held in place by four screws. As currently configured, this switch is only useful for maintenance personnel and cannot easily be used by emergency responders.

Regardless of whether a manual disconnect switch (method 1) is provided, all manufacturers also incorporate electrically activated contactors that open automatically whenever the ignition switch is turned off (method 2) and also open if power from the low-voltage battery to the vehicle’s 12/24 volt electrical system is disrupted, either by activating a disconnect switch or by cutting the low-voltage battery cable (method 3).

One manufacturer questioned the practicality of the SAE J2910 requirement that “the high voltage distribution system shall be de-energized and voltage shall be discharged to less than 60 VDC or 30 VAC RMS in 120 seconds after the disconnect is actuated.” They noted that their maintenance procedure indicates that one should wait 5 minutes after actuating the high-voltage disconnect before testing to ensure that the high voltage has discharged to a safe level.

It was also noted that on some specific hybrid vehicles already in service, the high-voltage disconnect switch is not easily accessible from the vehicle exterior.

As noted above, several fleet operators reiterated that labeling the location of the high-voltage disconnect on the exterior of the vehicle could be problematic, because it could invite vandals to operate the disconnect switch maliciously.

All site visit participants agreed that it would be appropriate for FMCSA to specify minimum standards for location, installation, and in-use condition of RESSs and other high-voltage components on vehicles, to ensure that they are properly protected from road hazards, from vehicle loads, and in the event of a crash. With respect to the recommendation of SAE J2910 that “the remote energy storage system is not mounted in a passenger compartment,” one manufacturer noted that on some electric drive buses, the energy storage system is mounted under passenger seats, but that it is separated from the passenger compartment by a barrier of “firewall quality,” and that physical access to the battery pack is only possible from the vehicle exterior. They wanted to clarify that such an arrangement should be considered to meet the requirement that an energy storage system not be installed in the passenger compartment.

There was significant discussion about whether or not FMCSA should specify that a RESS on an in-use vehicle should exhibit no signs of “electrolyte leakage.” It was noted by most participants that the vast majority of advanced batteries used on electric drive commercial vehicles today do not contain liquid electrolyte. Also, a number of participants questioned how a commercial vehicle inspector would verify that liquid seen on the outside of, or dripping from, a battery pack was in fact electrolyte as opposed to water. One participant suggested that the criterion should instead be that no in-use vehicle should have significant corrosion on the exterior of the battery pack enclosure, which would likely indicate electrolyte leakage.

There was also significant discussion about the recommendation of SAE J2910 that all electric drive vehicles have the ability to monitor continuously high-voltage electrical isolation and to warn the driver and/or de-energize the high-voltage system when isolation falls below set thresholds. All participants agreed that continuous monitoring of high-voltage electrical isolation is critical for electric vehicle safety, and all manufacturers indicated that it is their current practice to implement the intent of SAE J2910 on all of their vehicles. However, not all manufacturers currently comply with all of the specific details of SAE J2910 with respect to driver warning and vehicle shutdown.

SAE J2910 recommends that when high-voltage electrical isolation falls below 500 ohms per volt, an amber “Check Hybrid” warning light should be illuminated in the driver compartment, but that vehicle mobility should be maintained until the driver next brings the vehicle to a stop. At that point, the “hybrid drive system should be disabled and high-voltage system should be disconnected.” SAE J2910 recommends that in the event that high-voltage electrical isolation falls below 100 ohms per volt, a red “stop hybrid” warning light should be illuminated in the driver compartment and “the energy storage system should be (immediately) disabled and disconnected.”

All participants agreed that the final threshold of 100 ohms per volt was appropriate for identifying a dangerous condition that should put a vehicle OOS. However, several manufacturers questioned the need to remove high-voltage power immediately in this condition if a vehicle is moving. They indicated that such a condition would not put the vehicle’s driver in any danger, and that the only potential danger would be to an individual contacting an energized part or component on the exterior of the vehicle. As such, they believed that immediately disabling the vehicle drive system—potentially stranding the vehicle in an active drive lane—would create a greater hazard than the hazard being avoided.

In addition, one manufacturer questioned the need for an intermediate warning at 500 ohms per volt. The manufacturer indicated that it is their practice to deliver new vehicles with less than 500 ohms per volt electrical isolation of the main high-voltage power control module. They believe that the 500 ohms per volt intermediate threshold is a holdover from electric trolleys—where it is appropriate—but that it is not appropriate or necessary for HEVs or BEVs. The difference is that the high-voltage system on a trolley, which gets its power from an overhead catenary system, is referenced to earth ground. A sufficient loss of electrical isolation at a single location (single point failure) could therefore expose any person standing on the ground and touching any metal component on the vehicle to high-voltage electrical current. On a BEV or HEV, the high-voltage system is referenced to chassis ground, which is isolated from earth ground by the vehicle’s tires. Even with a loss of high-voltage electrical isolation, a person would only be exposed to high-voltage current if he simultaneously touched a metal component on the vehicle chassis and a conductive component of the high-voltage system (i.e., an exposed electrical wire or electrical terminal).

In addition, numerous participants questioned how a commercial vehicle inspector could realistically check or confirm the high-voltage electrical isolation of an in-use vehicle with electric drive. While virtually all manufacturers allow technicians to check high-voltage isolation using their diagnostic software, every manufacturer’s software is different, and it would not be

realistic to assume that commercial vehicle inspectors could procure and be trained on all of their systems.

Most participants, including both manufacturers and fleet operators, agreed that it would be appropriate for the Federal Government to set minimum standards for monitoring and fault reporting of high-voltage electrical isolation on electric drive vehicles. Such standards would need to include: methods to measure high-voltage electrical isolation; a standardized open-source electronic format for continuously reporting the measured value of high-voltage electrical isolation; threshold(s) to trigger mandatory fault code reports when measured electrical isolation falls below a set level; minimum actions (e.g., vehicle shutdown) associated with each fault code; standardized open-source electronic reporting format for each fault code, including specific text wording for each fault code; and a hardware standard for the connector required to access electronic fault code information.²¹ With such standards in place, standardized driver fault warnings applicable to all vehicles could be created. In addition, a simple and inexpensive open-source scan tool could be created that would allow any technician or commercial vehicle inspector to determine the high-voltage electrical isolation of any vehicle.

It should be noted, however, that it would not be appropriate for FMCSA to lead the effort to develop the necessary standards related to high-voltage electrical isolation monitoring and reporting. The appropriate agency to lead such an effort would be NHTSA, in conjunction with one or more industry standards development organizations, such as SAE and/or ISO. Final standards should be incorporated into the FMVSSs that are applicable to new vehicles when manufactured. With appropriate FMVSSs in place, FMCSA could then modify its FMCSRs accordingly.

SAE J2910 recommends that electric drive vehicles “shall be designed to disconnect high voltage within 5 seconds of the vehicle coming to a rest in the event of a crash” and that “the requirement should be the same as those for automobiles, as covered under FMVSS 305.” The recommended practice envisions the use of an inertial sensor to initiate the opening of high-voltage contactors to comply with this requirement. There was near universal agreement among all site visit participants that such a mandatory requirement for in-use vehicles would be impractical and potentially counterproductive in the current environment.

Although SAE J2910 anticipates a “crash event” as specified in FMVSS 305, as noted in Section 3.3 above, FMVSS 305 currently does not apply to medium- and heavy-duty vehicles, and such vehicles are not routinely tested in these types of crash situations. As such, there currently are no inertial sensors specifically designed for compliance with these requirements for medium- and heavy-duty vehicles. In addition, the extreme diversity of configurations and low production volumes of medium- and heavy-duty commercial vehicles compared to light-duty vehicles would make the cost of compliance with such a mandate significantly higher than the costs for light-duty vehicles. Several manufacturers indicated that they have integrated inertial sensors into some vehicles equipped with their electric drive systems. Both the manufacturers and fleet

²¹The standards required would be similar in format and content to the onboard diagnostic (OBD) requirements imposed on heavy-duty engine manufacturers by the U.S. Environmental Protection Agency with respect to mandatory fault reporting related to engine emission control systems. However, standards related to high-voltage electrical isolation monitoring and reporting probably would be significantly less complicated than current OBD requirements.

operators reported that these sensors have been the cause of a significant number of nuisance road calls, when the sensor tripped and shut down the electric drive system after the vehicle went over a large pothole. In such a situation, the unnecessary activation of the inertial sensor can create its own hazard by stranding a vehicle in traffic with no way to move it to a safer location.

As noted in Section 3.3, NHTSA soon intends to issue requirements that newly manufactured electric drive vehicles be equipped with a system to emit a specific sound during low-speed operation if there is no internal combustion engine operating. All site visit participants agreed that if NHTSA does issue such regulations, then FMCSA should enforce that requirement by mandating that in-use electric drive vehicles must be equipped with such a system, and that it should be operational at all times. Several people noted, however, that while commercial vehicle inspectors could verify whether such a system was present on a vehicle, and determine whether the system was making any sound, they could not be expected (without specialized equipment and training) to verify that the specific sound mandated by NHTSA (sound level, frequency distribution) was being produced.

Virtually all site visit participants agreed with the researcher's preliminary recommendation that FMCSA should modify 40 CFR 396.11 to add "RESS (battery pack)" to the list of parts and accessories that a commercial vehicle operator must inspect and report on daily at the end of a shift. Several noted, however, that FMCSA should be careful with the wording of the requirement, to ensure that the driver would only be required to do a visual inspection of easily accessible components, and would not be required to crawl under the vehicle or to open or remove any covers or barriers. One manufacturer recommended that battery state of charge should be a required check during pre-trip inspections of BEVs. The manufacturer noted that driving a vehicle with insufficient battery charge could create a safety hazard if it stops in a travel lane when the charge is depleted in service.

Virtually all site visit participants agreed with the researcher's preliminary recommendation that FMCSA should work with CVSA to modify the current NAS Inspection procedures to add inspection items specific to electric drive vehicles. There was general agreement that added inspection items should include:

- Visual examination of the RESS and other high-voltage components to ensure that they are securely attached to the vehicle and undamaged, and that covers or barriers are in place and undamaged so as to prevent any contact with live high voltage.
- Visual examination of exposed high-voltage cables and connectors to ensure that they are not damaged.
- Verification that required exterior and interior labels are in place and legible.
- Verification that there is at least one method readily identifiable and available to emergency responders from the exterior of the vehicle to de-energize the high-voltage distribution system.
- Verification that the vehicle produces a sound when operating at low speed with no internal combustion engine operating, per NHTSA requirements.

It was generally agreed by all site visit participants that while it would be a desirable goal for commercial vehicle inspectors to verify that the high-voltage electrical isolation on electric drive vehicles is above some safe threshold, in the current environment it would be impractical to do so. As discussed above, in order for commercial vehicle inspectors to be able to verify high-voltage electrical isolation, consistent driver warning lights or an inexpensive and open-source electronic scan tool would be required. Such tools do not currently exist and are unlikely to be developed without a Federal mandate and accompanying standards related to high-voltage isolation measurement and fault reporting. FMCSA does not have a mandate to initiate such a requirement, and an effort in this area should be led by NHTSA and codified in an FMVSS rather than an FMCSR.

It was also agreed by all site visit participants that commercial vehicle inspectors should not be asked to test the functionality of the method(s) available to de-energize the high-voltage electrical distribution system by emergency personnel. High-voltage switches and contactors tend to weld together when operated under load, and even when they are designed to be operated under load during emergency conditions, they can typically withstand only a limited number of such cycles. Regular testing of high-voltage disconnect functionality—especially with the vehicle operating and the system under load—is therefore not recommended.

There was general agreement from all site visit participants that the following issues identified during a commercial vehicle safety inspection would warrant a repair order but are not significant enough to place a vehicle OOS:

- Missing interior, exterior, or high-voltage component warning labels.
- Lack of, or inoperable, system to provide sound signature when the vehicle is operating at low speed but no internal combustion engine is operating, per NHTSA requirements.²²
- RESS or other high-voltage component with minor damage to exterior covers or panels.
- Amber “Check Hybrid” or “Check High-voltage System” light illuminated in operator cab.

There was also general agreement from all site visit participants that the following issues identified during a commercial vehicle safety inspection are significant enough to warrant putting a vehicle OOS:

- RESS or other high-voltage components not securely attached to the vehicle.
- Any energized high-voltage component directly accessible because covers or barriers are missing or are damaged such that one could have finger access to the interior.
- Any exposed high-voltage cable or connector cut or damaged to expose high-voltage conductors.

²²Several participants posited the idea that if an inoperable back-up alarm on a commercial vehicle would not put it OOS, then an inoperable electric vehicle low-speed sound system also should not place a vehicle OOS, because they serve a similar safety function.

- No method readily identifiable and available from the vehicle exterior for emergency personnel to de-energize the high-voltage distribution system.²³
- Red “Stop Hybrid” or “High-voltage Fault” light illuminated in operator cab.

There was significant discussion as to whether “RESS leaking electrolyte” should warrant placing a vehicle OOS. While a vehicle that was leaking liquid electrolyte from a battery pack would pose a significant hazard, many site visit participants were concerned that in practical terms, commercial vehicle inspectors could not reliably tell the difference between leaking liquid electrolyte and water without specialized tools and training. There was a concern that vehicles would be placed OOS unnecessarily by untrained inspectors. One participant suggested that the criteria could be “RESS with significant exterior corrosion,” because this would be a reliable method of differentiating leaking liquid electrolyte (which is usually corrosive) from water.

In addition, virtually all participants agreed that conceptually any vehicle with high-voltage electrical isolation below some minimum threshold (e.g., 100 ohms per volt) should be placed OOS. However, as discussed above, there is currently no practical way for commercial vehicle inspectors to evaluate high-voltage electrical isolation, and at best they could only rely on manufacturer-defined fault reporting via amber and red telltale lights in the vehicle cab. However, all agreed that different manufacturers currently have different thresholds and formats for fault reporting, which are not consistent from vehicle to vehicle.

In addition, there was some discussion of what level of “damage” to high-voltage cables would be sufficient to place a vehicle OOS. Most high-voltage cables have several layers of plastic insulation over the copper conductors, and a cut through the outermost layer would not necessarily result in loss of dielectric strength sufficient to create a hazard. Several participants posited the idea that any cable with exposed copper conductors should place a vehicle OOS. However, another participant pointed out that some high-voltage cables are shielded to prevent electromagnetic interference (EMI), and that the shielding is typically a fine copper mesh layer under the outermost cable insulation layer. Exposure of this copper mesh shielding layer would not create a shock hazard, but it could be misidentified by an untrained inspector as “exposed copper conductors,” thus placing a vehicle OOS unnecessarily.

The researcher included as a preliminary recommendation that FMCSA modify current accident reporting requirements under 49 CFR 390.15 to require that, for all reportable accidents involving electric drive vehicles, commercial vehicle operators report the vehicle type (battery electric, hybrid electric), as well as the results of a post-crash inspection of the high-voltage electrical system. Such an inspection would need to be conducted by a qualified technician and would include:

- Thorough visual examination of all high-voltage components and cables.
- Confirmation of the functionality of method(s) to de-energize the high-voltage distribution system by emergency personnel.

²³Or, if the available method is actuation of a physical switch, any significant damage to the switch such that it would likely not operate properly would also be grounds for placing the vehicle OOS.

- Verification—using manufacturer diagnostic software—that component-level and system-level high-voltage isolation is maintained above a minimum safe threshold (i.e., 100 ohms per volt or other higher level as defined by the manufacturer).

Currently, reportable accidents include those involving a fatality, bodily injury requiring medical attention away from the scene, or one or more involved vehicles incurring disabling damage.

In general, most site visit participants agreed with this recommendation, but some expressed concern that the properly trained and certified “qualified technicians” needed to conduct these inspections do not exist. Others were concerned that the inspection procedures and criteria for “passing” the inspection would need to be fully defined by FMCSA.

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5. FINAL RECOMMENDATIONS

This section presents the final recommendations for changes to the FMCSRs, NAS inspection procedures, and OOS criteria to accommodate commercial vehicles with high-voltage electric drive systems (i.e., BEV, HEV, PHEV, and FCV). These recommendations are based on the literature review and gap analysis summarized in Section 3, taking into account feedback gathered during the site visits/industry consultations (Section 4) and considering comments received from peer reviewers. The starting points for most of the recommendations are the voluntary standards and best practices articulated in SAE J2910, “Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety.”

To the extent that there was a diversity of opinion expressed during site visits, or significant disagreement between site visit participants and peer reviewers with respect to a recommendation, or if a recommendation deviates significantly from the requirements of SAE J2910, the disagreement or deviation is highlighted.

5.1 Federal Motor Carrier Safety Regulations

5.1.1 Specify Minimum Safety Requirements for In-use Vehicles with High-voltage Systems

FMCSA should set minimum standards for the operational and maintenance condition of electric drive systems installed on in-use commercial vehicles. These standards should apply to all high-voltage electrical systems installed on such vehicles, including systems that supply vehicle motive power and systems that supply power to any vehicle auxiliary functions or vehicle-mounted equipment (e.g., refrigeration units).

For the most part, these standards should be based on the requirements of SAE J2910; however, consistent with feedback received during site visits, FMCSA should not adopt the full language of SAE J2910 by reference in any revised FMCSRs. Rather, FMCSA should extract from the most recent version of SAE J2910 the most critical items, with a focus on components/systems most likely to be damaged in use or subject to modification by the vehicle owner/operator during maintenance. In addition, FMCSA should be mindful of the practical limitations on the conduct of annual and roadside safety inspections by commercial vehicle inspectors. Verification of compliance with many of the specific requirements of SAE J2910 requires specialized knowledge and equipment, which would not normally be available to a commercial vehicle inspector.

The following items are recommended to be included in the list of minimum standards for in-use vehicles with high-voltage electrical systems:

- Each vehicle shall be equipped with a manual switch or fuse that may be used to disconnect the high voltage and de-energize the high-voltage distribution system on the vehicle (SAE J2910, Section 4.1.3). Such switch or fuse shall be accessible from the vehicle exterior. Actuation of the switch or fuse shall not require special tools or the removal of any vehicle panel or part. If the vehicle includes more than one RESS, one disconnect switch or fuse may be used for each system. For vehicles in which the

RESS(s) and other high-voltage components are located behind body panels, the disconnect switch(es) may be located inside an access door in the exterior body panel.

- In addition to the manual disconnect switch, each vehicle shall be equipped with contactor(s) designed to open when:
 - The vehicle ignition switch is turned off.
 - Power from the low-voltage 12/24V battery is disconnected by operation of a disconnect switch or by removing or severing a battery cable. Opening of these contactors shall disconnect the high voltage and de-energize the high-voltage distribution system.
- All high-voltage cables not protected by a solid cover or barrier that is fixed to the vehicle frame and which cannot be removed without tools shall be identified as carrying high voltage by an orange color on the outermost surface of the cable. If exposed high-voltage cables are protected by a conduit, and the outermost surface of the conduit shall be orange in color.
- No RESS shall be installed in the driver or passenger compartment unless separated from the rest of the compartment by a solid metal barrier with no openings or access panels accessible from inside the compartment.
- All RESSs and other high-voltage components or enclosures shall be securely mounted to the vehicle frame.
- All RESSs and other high-voltage components or enclosures shall be constructed so that access to electrically-energized components will require removal of a cover or barrier using a maintenance key or tools.
- No part of any RESS or any enclosure housing high-voltage components shall extend beyond the widest part of the vehicle or extend below the lowest vehicle frame member or axle housing.
- Each vehicle shall be equipped with a system designed to produce a unique sound designed to alert pedestrians when the vehicle is moving at low speed and no internal combustion engine is operating. Such a system shall comply with the relevant FMVSS promulgated by NHTSA (pending).
- Each vehicle shall be equipped with a system to monitor continuously the electrical isolation of high-voltage components and systems installed on the vehicle and to warn the driver in the event that electrical isolation is less than 100 ohms per volt. The warning shall be by means of a red indicator lamp in the vehicle cab visible from the normal driving position. In the event that measured electrical isolation falls below 100 ohms per volt, the system shall cause the following actions to occur:
 - Driver warning light shall be lit and shall stay lit until vehicle ignition is turned off.
- When the vehicle next comes to a stop, the high-voltage system shall be disconnected and de-energized. Note that the above requirement is not fully consistent with the recommended practice of SAE J2910. SAE J2910 recommends two levels of warning to the driver, one when high-voltage isolation falls below 500 ohms per volt and another

when isolation falls below 100 ohms per volt. In addition, SAE J2910 recommends that if high-voltage isolation falls below 100 ohms per volt the high-voltage system be de-energized immediately, rather than waiting until the vehicle next comes to a stop. There was disagreement among site visit participants and peer reviewers as to whether the intermediate warning at 500 ohms volt is really required. In addition, several site visit participants indicated that even if there is a loss of high-voltage isolation, immediately disconnecting the high voltage could create a greater hazard than the one being avoided, if a vehicle is disabled while in a travel lane.

In Section 5.1.5, it is recommended that these issues should be further explored by NHTSA with respect to high-voltage isolation detection and fault reporting for new vehicles. FMCSA should follow the recommendations/requirements of NHTSA when finalizing revised FMCSRs applicable to in-use vehicles.

5.1.2 Specify Minimum Labeling Requirements for In-use Vehicles with High-voltage Systems

FMCSA should specify minimum labeling requirements for commercial vehicles with high-voltage electric drive systems. Labeling is required to alert vehicle operators, maintenance personnel, and emergency responders to the presence of high voltage on the vehicle, so that they can take appropriate actions to avoid the possibility of injury or death due to electric shock during routine maintenance activities and during a vehicle accident or other emergency. Labeling is also required to alert commercial vehicle inspectors to the presence of high-voltage components on the vehicle so that they can modify their inspection procedures accordingly (see Section 5.2).

The following are the recommended minimum labels required for in-use commercial vehicles with onboard high-voltage components or systems:

- **A label that identifies the vehicle as having onboard high-voltage systems.** Such label shall appear on both sides of the vehicle in the vicinity of the USDOT number required by 49 CFR 390.21, and the letters shall be large enough to be readily legible, during daylight hours, from a distance of 50 feet (15.24 meters) while the vehicle is stationary. Note that SAE J2910 (4.1.14.1) specifically recommends the use of the IEC 60417 hazardous voltage triangle (as shown in Figure 1) for this label. Many site visit participants objected to the use of this image for this purpose, and a consensus could not be reached among the stakeholders and peer reviewers on what format should be used for this label. Some stakeholders suggest that OEM “branding” that identifies a commercial vehicle as “electric,” “hybrid-electric,” or “fuel cell” should be accepted (see Figure 5), because this branding serves the same purpose as a label, in that it helps emergency responders to recognize that vehicle systems could expose them to potentially hazardous voltage. The potential problem with this approach is that different manufacturers do not always use consistent terminology for their branding. Another suggestion is that the label should be in the shape of a blue diamond that follows the format of NFPA 52, Section 6.11 (recommended labels for alternative fuel vehicles) (see Figure 6) and includes one of the following words, as appropriate: ELECTRIC, HYBRID ELECTRIC, PLUG-IN HYBRID ELECTRIC, or FUEL CELL. Another suggestion is to have the label bear the outline or shape of a “generic” truck or bus overlaid with the IEC thunderbolt (see Figure

7). The problem with this option is that not all trucks (single-unit trucks, tractor-trailers, “bobtails,” flatbeds, etc.) look the same, and not all buses look the same (e.g., transit buses, shuttle vans, school buses, and motorcoaches). There is simply no standard generic truck, bus, or commercial vehicle to be used for the label image. The researcher is unable to provide a definitive recommendation to FMCSA as to the format for this electric drive identification label without greater industry consensus. Specification of the exact format for this identification label must be deferred to a future rulemaking, in coordination with NHTSA.



Figure 5. Image. Example of hybrid vehicle “branding.”

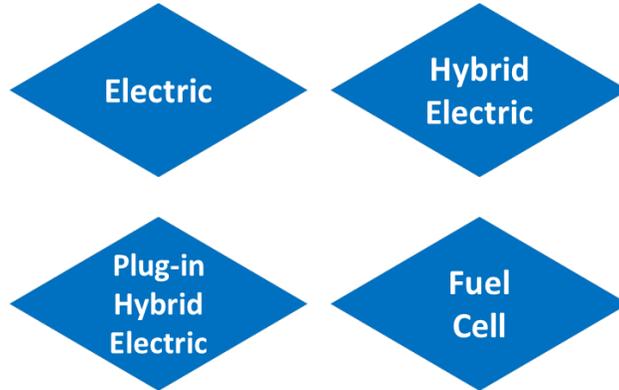


Figure 6. Image. Potential format for electric drive vehicle label.

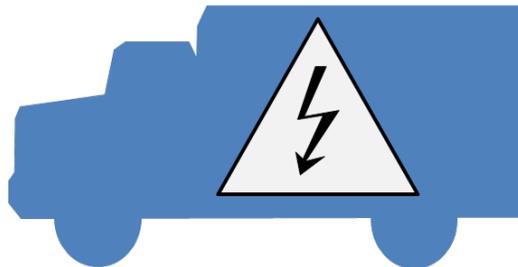


Figure 7. Image. Potential format for electric drive vehicle label.

- **A label that includes a high-voltage warning, a diagram showing the location of high-voltage components on the vehicle, and the means of de-energizing the high-voltage system by emergency personnel, including the specific location of any high-voltage disconnect switch(es) or fuse(s).** Such a label shall be located on the vehicle exterior in the vicinity of the RESS or the high-voltage disconnect switch(es). The format and content of the label shall follow the recommendation of SAE J2910, Section 4.1.14.4 (also see Figure 2 in this document). For vehicles in which the RESS and other high-voltage components are located behind exterior body panels, this label may be located inside an access door in the exterior body panel. Opening of the access door shall not require any tools. The exterior of the access door must be labeled “High-Voltage Disconnect.”
- **A label that indicates procedures required to preclude generation of high voltage when the vehicle is towed.** Such a label shall be mounted in the driver compartment in a location that is visible to a person sitting in the driver’s seat. Such a label shall be required in the event that any action other than putting the transmission in neutral is required to isolate the electric motor(s) and preclude generation of high voltage while the vehicle is being towed.

Labels shall be posted on all covers, barriers, or enclosures which when opened or removed allow access to cables, connectors, or components with live high voltage. These labels shall incorporate the IEC hazardous voltage triangle and warning text (see Figure 3).

5.1.3 Modify Requirements for Driver Inspections and Reports, to Include High-voltage Components

49 CFR 396.11, “Driver Vehicle Inspection Report(s),” mandates that every commercial driver make a written report at the end of his shift specifying whether or not certain specific components/systems on his vehicle are in good working order.

49 CFR 396.13, “Driver Inspection,” mandates that at the beginning of his shift a commercial driver review the report written by the previous driver, and ensure that the vehicle is “in safe working condition” by, among other things, ensuring that defects noted previously have been repaired.

FMCSA should modify the current language of 49 CFR 396.11, to specifically add to the list of components and systems to be checked: “RECHARGEABLE ENERGY STORAGE SYSTEM (BATTERY PACKS) AND OTHER HIGH-VOLTAGE EQUIPMENT (for electric, hybrid electric, plug-in hybrid electric, and fuel cell vehicles only).”

5.1.4 Require Accident Reporting for Vehicles with High-voltage Systems

Motor carriers are currently required under 49 CFR 390.15 to maintain a register of vehicle accidents. With respect to this requirement, 49 CFR 390.5 defines an “accident” as follows:

Accident means—

- (1) Except as provided in paragraph (2) of this definition, an occurrence involving a commercial motor vehicle operating on a highway in interstate or intrastate commerce which results in:

- (i) A fatality;
- (ii) Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident; or
- (iii) One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle(s) to be transported away from the scene by a tow truck or other motor vehicle.

(2) The term accident does not include:

- (i) An occurrence involving only boarding and alighting from a stationary motor vehicle;
- (ii) An occurrence involving only the loading or unloading of cargo.

When vehicles with high-voltage electrical systems are involved in an accident, it is possible that they could sustain damage to those systems that would not be obvious to the vehicle operator. In order to help ensure that electrical system inspections by a qualified technician are completed after a commercial vehicle is involved in an accident, FMCSA should modify the current language of 49 CFR 390.15 as follows to require additional information to be reported for vehicles with high-voltage electrical systems. Proposed additions are underlined and italicized:

Section 390.15 Assistance in investigations and special studies:

(a) A motor carrier must make all records and information pertaining to an accident available to an authorized representative or special agent of the Federal Motor Carrier Safety Administration, an authorized State or local enforcement agency representative, or an authorized third-party representative upon request or as part of any investigation within such time as the request or investigation may specify. A motor carrier shall give an authorized representative all reasonable assistance in the investigation of any accident, including providing a full, true, and correct response to any question of the inquiry accident register for 3 years after the date of each accident. For accidents that occurred on or prior to April 29, 2003, motor carriers must maintain an accident register for a period of 1 year after the date of each accident. Information placed in the accident register must contain at least the following:

(1) A list of accidents as defined at Section 390.5 of this chapter containing for each accident:

- (i) Date of accident.
- (ii) City or town, or most near, where the accident occurred and the State where the accident occurred.
- (iii) Driver Name.
- (iv) Number of injuries.
- (v) Number of fatalities.
- (vi) Whether hazardous materials, other than fuel spilled from the fuel tanks of motor vehicle involved in the accident, were released.

(vii) Fuel type of vehicle involved: diesel, gasoline, CNG, LNG, LPG (propane), electricity, or other (if “other,” please specify).

(viii) If the vehicle involved has on-board high-voltage components or systems, indicate the type of vehicle as ELECTRIC, HYBRID-ELECTRIC, PLUG-IN HYBRID-ELECTRIC, or FUEL CELL. An electric vehicle is one that includes one or more rechargeable energy storage systems (battery packs) and other high-voltage equipment or systems but does not include an internal combustion engine. A hybrid-electric vehicle is one that has both an internal combustion engine and a rechargeable energy storage system and other high-voltage components or systems. A plug-in hybrid electric vehicle is a hybrid vehicle with the capability to plug into the electric grid to charge the onboard rechargeable energy storage system. A fuel cell vehicle is one that includes a fuel cell engine which directly produces electricity via low-temperature oxidation of hydrogen using galvanic cells; fuel cell vehicles may also include a rechargeable energy storage system and other high-voltage components or systems.

(viii) If the commercial vehicle involved in the accident was an ELECTRIC, HYBRID-ELECTRIC, PLUG-IN HYBRID-ELECTRIC, or FUEL CELL vehicle and it sustained disabling damage in the accident, the date after the accident that the high-voltage system was inspected for damage by a qualified technician shall be reported with the accident.

(2) Copies of all accident reports required by State or other governmental entities or insurers:

(i) If the commercial vehicle involved in the accident was an ELECTRIC, HYBRID-ELECTRIC, PLUG-IN HYBRID-ELECTRIC, or FUEL CELL vehicle and it sustained disabling damage in the accident, a copy of the high-voltage system inspection report completed by a qualified technician after the accident shall be included or attached to the accident report. Such inspection must include, at a minimum:

- (i) Thorough visual inspection of all high-voltage components and cables;
- (ii) Confirmation of the functionality of method(s) to de-energize the high-voltage distribution system by emergency personnel; and
- (iii) Verification—using manufacturer diagnostic software—that component-level and system-level high-voltage isolation is maintained above a minimum safe threshold of 100 ohms per volt or other higher level as defined by the manufacturer.

5.1.5 Recommend NHTSA to Set Standards for High-voltage Isolation Detection and Fault Reporting for New Vehicles

Industry standards and best practices for electric drive vehicles require continuous monitoring of high-voltage electrical isolation, reporting to the driver (via dashboard lights), and shutdown of high voltage if electrical isolation falls below a safe level.

FMCSA has a strong interest in ensuring that all vehicles used for interstate commerce are equipped with such capability, and that vehicle systems to provide this functionality are operational at all times when a vehicle is in use on public roadways. As such, a check of high-voltage isolation should ideally be included in commercial vehicle inspections of electric drive vehicles, and OOS criteria should include a provision to put vehicles OOS when electrical isolation is below a safe level.

However, virtually all companies consulted during site visits for this project agreed that there is no practical way for commercial vehicle inspectors to evaluate high-voltage electrical isolation during roadside inspections. Virtually all manufacturers implement high-voltage isolation detection and warning on their vehicles, but they do so in different ways—with different thresholds for fault reporting and different visual formats and terminology for the driver “warning” if there is a loss of electrical isolation. Virtually all manufacturers also provide the ability for technicians to check high-voltage isolation using diagnostic software, but every manufacturer’s software is different.

It would not be realistic to assume that commercial vehicle inspectors could procure and be trained on the diagnostic software systems from all electric and hybrid-electric vehicle manufacturers, or be trained to interpret the inconsistent driver fault warning signals from different manufacturers. In order for a check of high-voltage isolation to be included in commercial vehicle inspections, all newly manufactured vehicles would need to comply with a specific standard for high-voltage electrical isolation monitoring and fault reporting. Such a standard would need to include:

- Methods to measure high-voltage electrical isolation.
- A standardized open-source electronic format for continuously reporting the measured value of high-voltage electrical isolation.
- Threshold(s) to trigger mandatory fault code report(s) when measured electrical isolation falls below a set level(s).
- Minimum actions (e.g., high-voltage shut down) associated with each fault code.
- Standardized open-source electronic reporting format for each fault code, including specific text wording for each fault code.
- A hardware standard for a connector required to access the onboard network to receive fault messages.

Most companies consulted for this project, including both manufacturers and fleet operators, agreed that it would be appropriate for the Federal Government to set such minimum standards for monitoring and fault reporting of high-voltage electrical isolation on electric drive vehicles. However, it would not be appropriate for FMCSA to lead the effort to develop such standards. The appropriate agency to lead such an effort would be NHTSA, in conjunction with one or more industry standards development organizations, such as SAE and/or ISO. Final standards should be incorporated into FMVSSs applicable to new vehicles when manufactured. With appropriate FMVSSs in place, FMCSA could then modify its FMCSRs accordingly, to

implement appropriate inspection requirements and OOS criteria related to high-voltage electrical isolation for in-use vehicles.

5.2 NAS INSPECTION PROCEDURES AND OOS CRITERIA

5.2.1 High-voltage Electrical System Inspection

FMCSA should work with CVSA to modify the NAS inspection procedures in order to clarify what items an inspector should look for when inspecting a commercial vehicle with a high-voltage electrical system.

The following is a list of recommended inspection items to add:

- Inspect RESS(s) and other accessible high-voltage components to ensure that they are securely attached to the vehicle, and that covers or barriers are in place and undamaged.
- Inspect accessible, exposed high-voltage cables and connectors to ensure that they are not damaged.
- Verify that required interior and exterior labels are in place and legible.
- Verify that there is a manual switch(es) or fuse(s) accessible from the exterior of the vehicle that can be used to disconnect the high-voltage and de-energize the high-voltage distribution system, and that the switch is undamaged. Note that inspectors should not test the switch for functionality. These switches are designed for a limited number of actuations, particularly when under load, and regular actuations to test functionality are not recommended.
- Verify that the vehicle makes a sound to warn pedestrians when moving at low speed and when no internal combustion engine is operating, per pending NHTSA requirements.

5.2.2 OOS Criteria

FMCSA should modify the Code of Federal Regulations, Title 49, Chapter III, Subchapter B, Appendix G to add the following additional “defects or deficiencies” which would cause a commercial vehicle to “not pass an inspection” during an annual commercial vehicle inspection:

14. High-Voltage Electrical System

a. Rechargeable Energy Storage System and Other High-Voltage Components

- (1) Rechargeable energy storage system or other high-voltage components or cables not securely attached to the vehicle frame.
- (2) Normally energized high-voltage components accessible due to missing covers or barriers, or due to covers or barriers with damage sufficient to allow finger access to interior components.
- (3) Covers or barriers over normally energized high-voltage components not identified by a label that includes the IEC 60417 hazardous voltage triangle and warning text.

b. High-Voltage Cables and Connectors

- (1) High-voltage cables cut, chafed, or damaged so as to expose the metal conductors.
- (2) High-voltage connectors cracked, broken, or with exposed metal conducting components.
- (3) High-voltage cables with other than orange color of outermost exterior surface.

c. High-Voltage Disconnect

- (1) Lack of, or nonfunctional, switch or fuse accessible from the vehicle exterior, which can be used by emergency personnel to disconnect high voltage and de-energize the high-voltage distribution system.
- (2) Location and function of high-voltage disconnect switch is not labeled on vehicle exterior.

d. Pedestrian Warning Sound System

- (1) Vehicle does not produce a pedestrian warning sound when moving at low speed with no internal combustion engine operating, in accordance with the requirements of FMVSS XXX (pending).

e. Required Vehicle Labels

- (1) Vehicle is not identified as containing high-voltage components by a label on each side of vehicle cab in the vicinity of the USDOT number required by 49 CFR 390.21, with letters that are large enough to be readily legible, during daylight hours, from a distance of 50 feet (15.24 meters) while the vehicle is stationary.

In addition, FMCSA should work with CVSA to modify the OOS criteria used with the NAS inspection procedures to identify additional defects in high-voltage electrical systems that would be cause for a vehicle to be given a repair ticket or be put OOS during a roadside safety inspection.

Consistent with feedback received during the site visits, the researcher recommends that CVSA identify two levels of defects in high-voltage vehicle systems: “Significant Defects” that pose an imminent hazard and for which a vehicle would be placed immediately OOS, and “Minor Defects” that do not pose an imminent hazard but must be corrected within a specific time period.

The recommended list of “Significant Defects” in high-voltage systems includes:

- RESS or other high-voltage components or cables not securely attached to the vehicle.
- Normally energized high-voltage components finger-accessible due to missing or damaged covers or barriers.
- Exposed high-voltage cables or connectors chafed, cut, or damaged so as to expose metal conductors.

- No high-voltage disconnect switch or fuse accessible to emergency personnel from the exterior of the vehicle, or switch or fuse damaged such that it would not be operable.
- Red “High-voltage Fault” or “Stop Hybrid” or “Stop System” light illuminated on driver console.

Note that this recommended list of significant defects does not include “high-voltage electrical isolation less than 100 ohms per volt” because there is currently no practical way for commercial vehicle safety inspectors to evaluate high-voltage electrical isolation during road side inspections, as discussed in Section 5.1.5.

While minor defects have not previously been part of the OOS criteria identified by FMCSA, they are discussed here because minor defects, if not corrected, can lead to major defects that will pose an imminent hazard in the future. The researcher recommends that FMCSA and/or commercial vehicle enforcement agencies establish deadlines for repair of minor defects and policies that will lead automatically to an OOS order for the subject vehicle if minor defects are not repaired prior to the established deadline.

The recommended list of “Minor Defects” in high-voltage systems includes:

- Missing interior or exterior labels that identify:
 - The vehicle as having high voltage onboard.
 - Locations of high-voltage components and method of high-voltage disconnect.
 - Recommended towing procedures.
 - Covers or enclosure under which there is a live high-voltage component.
- RESS or other high-voltage components with damage or corrosion to exterior cover or barrier which is not severe enough to allow finger access to interior components
- Vehicle does not make a pedestrian warning sound when moving at low speed with no internal combustion engine operating
- Amber “Check High Voltage,” “Check Hybrid,” or “Check System” light illuminated on driver console.

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APPENDIX A: CURRENT FEDERAL MOTOR CARRIER SAFETY REGULATIONS RELATED TO ELECTRIC DRIVE VEHICLES

Title 49: Transportation

PART 374—PASSENGER CARRIER REGULATIONS

§374.313 Equipment

(a) Temperature control. A carrier shall maintain a reasonable temperature on each bus (except in commuter service).

(b) Restrooms. Each bus (except in commuter service) seating more than 14 passengers (not including the driver) shall have a clean, regularly maintained restroom, free of offensive odor. A bus may be operated without a restroom if it makes reasonable rest stops.

(c) Bus servicing. Each bus shall be kept clean, with all required items in good working order.

Title 49: Transportation

PART 392—DRIVING OF COMMERCIAL MOTOR VEHICLES

Subpart A—General

§ 392.7 Equipment, inspection and use.

(a) No commercial motor vehicle shall be driven unless the driver is satisfied that the following parts and accessories are in good working order, nor shall any driver fail to use or make use of such parts and accessories when and as needed:

Service brakes, including trailer brake connections.

Parking (hand) brake.

Steering mechanism.

Lighting devices and reflectors.

Tires.

Horn.

Windshield wiper or wipers.

Rear-vision mirror or mirrors.

Coupling devices.

Title 49: Transportation

PART 393—PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION

Authority: Sec. 204, Interstate Commerce Act, as amended, 49 U.S.C. 304; sec. 6, Department of Transportation Act, 49 U.S.C. 1655; delegation of authority at 49 CFR 1.48 and 389.4.

§ 393.7 Matter incorporated by reference.

(a) Incorporation by reference. Part 393 includes references to certain matter or materials, as listed in paragraph (b) of this section. The text of the materials is not included in the regulations contained in part 393. The materials are hereby made a part of the regulations in part 393. The Director of the Federal Register has approved the materials incorporated by reference in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. For materials subject to change, only the specific version approved by the Director of the Federal Register and specified in the regulation are incorporated.

(b) Matter or materials referenced in part 393. The matter or materials listed in this paragraph are incorporated by reference in the corresponding sections noted.

(14) Automobile, Truck, Truck-Tractor, Trailer, and Motor Coach Wiring, SAE J1292, October 1981, incorporated by reference approved for §393.28.

§ 393.28 Wiring systems.

Electrical wiring shall be installed and maintained to conform to SAE J1292—Automobile, Truck, Truck-Tractor, Trailer, and Motor Coach Wiring, October 1981, except the jumper cable plug and receptacle need not conform to SAE J560. The reference to SAE J1292 shall not be construed to require circuit protection on trailers. (See § 393.7(b) for information on the incorporation by reference and availability of this document.)

§ 393.30 Battery installation.

Every storage battery on every vehicle, unless located in the engine compartment, shall be covered by a fixed part of the motor vehicle or protected by a removable cover or enclosure. Removable covers or enclosures shall be substantial and shall be securely latched or fastened. The storage battery compartment and adjacent metal parts which might corrode by reason of battery leakage shall be painted or coated with an acid-resisting paint or coating and shall have openings to provide ample battery ventilation and drainage. Wherever the cable to the starting motor passes through a metal compartment, the cable shall be protected against grounding by an acid and waterproof insulating bushing. Wherever a battery and a fuel tank are both placed under the driver's seat, they shall be partitioned from each other, and each compartment shall be provided with an independent cover, ventilation, and drainage.

§ 393.65 All fuel systems.

(a) *Application of the rules in this section.* The rules in this section apply to systems for containing and supplying fuel for the operation of motor vehicles or for the operation of auxiliary equipment installed on, or used in connection with, motor vehicles.

(b) *Location.* Each fuel system must be located on the motor vehicle so that—

- (1) No part of the system extends beyond the widest part of the vehicle;
- (2) No part of a fuel tank is forward of the front axle of a power unit;
- (3) Fuel spilled vertically from a fuel tank while it is being filled will not contact any part of the exhaust or electrical systems of the vehicle, except the fuel level indicator assembly;

(4) Fill pipe openings are located outside the vehicle's passenger compartment and its cargo compartment;

(5) A fuel line does not extend between a towed vehicle and the vehicle that is towing it while the combination of vehicles is in motion; and

(6) No part of the fuel system of a bus manufactured on or after January 1, 1973, is located within or above the passenger compartment.

(c) *Fuel tank installation.* Each fuel tank must be securely attached to the motor vehicle in a workmanlike manner.

(d) *Gravity or syphon feed prohibited.* A fuel system must not supply fuel by gravity or syphon feed directly to the carburetor or injector.

(e) *Selection control valve location.* If a fuel system includes a selection control valve which is operable by the driver to regulate the flow of fuel from two or more fuel tanks, the valve must be installed so that either—

(1) The driver may operate it while watching the roadway and without leaving his/her driving position; or

(2) The driver must stop the vehicle and leave his/her seat in order to operate the valve.

(f) *Fuel lines.* A fuel line which is not completely enclosed in a protective housing must not extend more than 2 inches below the fuel tank or its sump. Diesel fuel crossover, return, and withdrawal lines which extend below the bottom of the tank or sump must be protected against damage from impact. Every fuel line must be—

(1) Long enough and flexible enough to accommodate normal movements of the parts to which it is attached without incurring damage; and

(2) Secured against chafing, kinking, or other causes of mechanical damage.

(g) *Excess flow valve.* When pressure devices are used to force fuel from a fuel tank, a device which prevents the flow of fuel from the fuel tank if the fuel feed line is broken must be installed in the fuel system.

[36 FR 15445, Aug. 14, 1971, as amended at 37 FR 4341, Mar. 2, 1972; 37 FR 28752, Dec. 29, 1972]

Title 49: Transportation

PART 396—INSPECTION, REPAIR, AND MAINTENANCE

§ 396.3 Inspection, repair, and maintenance.

(a) *General.* Every motor carrier and intermodal equipment provider must systematically inspect, repair, and maintain, or cause to be systematically inspected, repaired, and maintained, all motor vehicles and intermodal equipment subject to its control.

(1) Parts and accessories shall be in safe and proper operating condition at all times. These include those specified in part 393 of this subchapter and any additional parts and accessories which may affect safety of operation, including but not limited to, frame and frame assemblies, suspension systems, axles and attaching parts, wheels and rims, and steering systems.

§ 396.7 Unsafe operations forbidden.

(a) *General.* A motor vehicle shall not be operated in such a condition as to likely cause an accident or a breakdown of the vehicle.

(b) *Exemption.* Any motor vehicle discovered to be in an unsafe condition while being operated on the highway may be continued in operation only to the nearest place where repairs can safely be effected. Such operation shall be conducted only if it is less hazardous to the public than to permit the vehicle to remain on the highway.

§ 396.9 Inspection of motor vehicles in operation.

(a) *Personnel authorized to perform inspections.* Every special agent of the FMCSA (as defined in appendix B to this subchapter) is authorized to enter upon and perform inspections of a motor carrier's vehicles in operation and intermodal equipment in operation.

(b) *Prescribed inspection report.* The Driver Vehicle Examination Report shall be used to record results of motor vehicle inspections and results of intermodal equipment inspections conducted by authorized FMCSA personnel.

(c) *Motor vehicles declared "out of service."* (1) Authorized personnel shall declare and mark "out of service" any motor vehicle which by reason of its mechanical condition or loading would likely cause an accident or a breakdown. Authorized personnel may declare and mark "out of service" any motor vehicle not in compliance with §385.811(d). An "Out of Service Vehicle" sticker shall be used to mark vehicles "out of service."

§ 396.11 Driver vehicle inspection report(s).

(a) *Report required—(1) Motor Carriers.* Every motor carrier shall require its drivers to report, and every driver shall prepare a report in writing at the completion of each day's work on each vehicle operated, except for intermodal equipment tendered by an intermodal equipment provider. The report shall cover at least the following parts and accessories:

- Service brakes including trailer brake connections
- Parking brake
- Steering mechanism
- Lighting devices and reflectors
- Tires
- Horn
- Windshield wipers
- Rear vision mirrors
- Coupling devices
- Wheels and rims
- Emergency equipment.

§ 396.13 Driver inspection.

Before driving a motor vehicle, the driver shall:

- (a) Be satisfied that the motor vehicle is in safe operating condition;
- (b) Review the last driver vehicle inspection report; and
- (c) Sign the report, only if defects or deficiencies were noted by the driver who prepared the report, to acknowledge that the driver has reviewed it and that there is a certification that the required repairs have been performed. The signature requirement does not apply to listed defects on a towed unit which is no longer part of the vehicle combination.

[44 FR 76526, Dec. 27, 1979, as amended at 48 FR 55868, Dec. 16, 1983; 63 FR 33280, June 18, 1998]

§ 396.17 Periodic inspection.

(a) Every commercial motor vehicle must be inspected as required by this section. The inspection must include, at a minimum, the parts and accessories set forth in appendix G of this subchapter. The term *commercial motor vehicle* includes each vehicle in a combination vehicle. For example, for a tractor semitrailer, full trailer combination, the tractor, semitrailer, and the full trailer (including the converter dolly if so equipped) must each be inspected.

(b) Except as provided in §396.23 and this paragraph, motor carriers must inspect or cause to be inspected all motor vehicles subject to their control. Intermodal equipment providers must inspect or cause to be inspected intermodal equipment that is interchanged or intended for interchange to motor carriers in intermodal transportation.

....

(f) Vehicles passing roadside or periodic inspections performed under the auspices of any State government or equivalent jurisdiction or the FMCSA, meeting the minimum standards contained in appendix G of this subchapter, will be considered to have met the requirements of an annual inspection for a period of 12 months commencing from the last day of the month in which the inspection was performed. If a vehicle is subject to a mandatory State inspection program, as provided in §396.23(b)(1), a roadside inspection may only be considered equivalent if it complies with the requirements of that program.

....

(h) Failure to perform properly the annual inspection required by this section shall cause the motor carrier or intermodal equipment provider to be subject to the penalty provisions of 49 U.S.C. 521(b).

[73 FR 76825, Dec. 17, 2008]

Title 49: Transportation

PART 399—EMPLOYEE SAFETY AND HEALTH STANDARDS

Appendix G to Subchapter B of Chapter III—Minimum Periodic Inspection Standards

A vehicle does not pass an inspection if it has defects or deficiencies in one of the following categories of equipment:

- Brake Systems
- Coupling devices
- Exhaust System
- Fuel System
- Lighting devices
- Safe Loading
- Steering Mechanism
- Suspension
- Frame
- Tires
- Wheels and rims
- Windshield wipers.

Comparison of Appendix G, and the new North American Uniform Driver-Vehicle Inspection Procedure (North American Commercial Vehicle Critical Safety Inspection Items and OOS Criteria)

The vehicle portion of the FMCSA's North American Uniform Driver-Vehicle Inspection Procedure (NAUD-VIP) requirements, CVSA's North American Commercial Vehicle Critical Safety Inspection Items and OOS Criteria and appendix G of subchapter B are similar documents and follow the same inspection procedures. The same items are required to be inspected by each document. FMCSA's and CVSA's OOS criteria are intended to be used in random roadside inspections to identify critical vehicle inspection items and provide criteria for placing a vehicle(s) OOS. A vehicle(s) is placed OOS only when by reason of its mechanical condition or loading it is determined to be so imminently hazardous as to likely cause an accident or breakdown, or when such condition(s) would likely contribute to loss of control of the vehicle(s) by the driver. A certain amount of flexibility is given to the inspecting official whether to place the vehicle OOS at the inspection site or if it would be less hazardous to allow the vehicle to proceed to a repair facility for repair. The distance to the repair facility must not exceed 25 miles. The roadside type of inspection, however, does not necessarily mean that a vehicle has to be defect-free in order to continue in service.

In contrast, the Appendix G inspection procedure requires that all items required to be inspected are in proper adjustment, are not defective and function properly prior to the vehicle being placed in service.

APPENDIX B: LITERATURE REVIEW SOURCES

- American National Standards Institute, ANSI EVSP “Standardization Roadmap for Electric Vehicles” (Version 1.0).
- Code of Federal Regulations, Title 49, Section 571.305 [49 CFR 571.305], also known as FMVSS 305, “Electric Powered Vehicles, Electrolyte Spillage and Electrical Shock Protection.”
- International Standards Organization, ISO 6469-1, “Electrically Propelled Road Vehicles—Safety Specifications—Part 1: Onboard RESS (RESS),” Second edition, 2009-09-15.
- International Standards Organization, ISO 6469-2, “Electrically Propelled Road Vehicles -- Safety Specifications -- Part 2: Vehicle Operational Safety Means and Protection Against Failures,” Second edition, 2009-09-15.
- International Standards Organization, ISO 6469-3, “Electrically Propelled Road Vehicles -- Safety Specifications -- Part 3: Protection of Persons Against Electric Shock,” Second edition, 2011-12-01.
- International Standards Organization, ISO 16750, “Environmental Conditions and Testing for Electrical and Electronic Equipment,” Second edition, 2006-08-01.
- National Fire Protection Association, NFPA 70—Article 480, “Storage Batteries,” 2011.
- National Fire Protection Association, NFPA 70—Article 490, “Equipment, Over 600 volts, Nominal,” 2011.
- National Fire Protection Association, NFPA 70—Article 625, “Electric Vehicle Charging System,” 2011.
- National Fire Protection Association, “Hybrid and Electric Vehicle Emergency Field Guide,” 2013 Edition.
- New York Department of State, Division of Administrative Rules, “Codes, Rules and Regulations of the State of New York, Title 17 Department of Transportation, Chapter IV Transportation Regulations, Subchapter D Motor Carriers of Passengers, Article 3 Safety, Part 720 Bus and Passenger Carrying Vehicle Safety Regulations, Section 720.9 Electric powered motor vehicles” [17 CCR-NY 720.9].
- Society of Automotive Engineers, SAE J1654, “High Voltage Primary Cable,” Oct 2012.
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- Society of Automotive Engineers, SAE J1742, “Connections for High Voltage Onboard Road Vehicle Electrical Wiring Harnesses—Test Methods and General Performance Requirements,” March 2010.
- Society of Automotive Engineers, SAE J1797, “Recommended Practice for Packaging of Electric Vehicle Battery Modules,” June 2008.

- Society of Automotive Engineers, SAE J2344, “Guidelines for Electric Vehicle Safety,” March 2010.
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- Society of Automotive Engineers, SAE J2910, “Recommended Practice for the Design and Test of Hybrid Electric and Electric Truck and Buses for Electrical Safety” (draft July 2013).
- Society of Automotive Engineers, SAE J2929, “Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Safety Standard—Lithium-based Rechargeable Cells,” February 2013.
- Society of Automotive Engineers, SAE J2936, “SAE Electrical Energy Storage Device Labeling recommended Practice,” December 2012.
- Society of Automotive Engineers, SAE J2990, “Hybrid and Electric Vehicle First and Second Responder Recommended Practice,” November 2012.
- Transport Canada, Technical Standards Document No. 305, Revision 3, “Electrolyte Spillage and Electrical Shock Protection,” October 8, 2011.
- United Nations Economic Commission for Europe, ECE R100 “Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train” Rev 2.
- U.S. Department of Transportation, DOT HS 811 496, “Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure Sounds,” October 2011.
- U.S. Department of Transportation, DOT HS 811 574, “Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries,” January 2012.
- U.S. Department of Transportation, National Highway Traffic Safety Administration, NHTSA/NVS-300, “Research on Minimum Sound Specifications for Hybrid and Electric Vehicles,” June 2012.
- U.S. Department of Transportation, National Highway Traffic Safety Administration, “Notice of Proposed Rulemaking, Minimum Sound Requirements for Hybrid and Electric Vehicles”; 49 CFR 571,585; Docket number NHTSA-2011-0148; RIN 2127-AK93; January 1, 2013.
- U.S. Department of Transportation, National Highway Traffic Safety Administration, “Notice of Proposed Rulemaking, Alternative Fuel Vehicle Badging, Fuel Compartment Labels and Consumer Information on Alternative Fuel Usage,” 49 CFR Part 575, Federal Register Volume 79, Number 34, February 20, 2014.

APPENDIX C: LIST OF SITE VISIT PARTICIPANTS

MEETING 1: Department of Transportation, Washington DC, December 23, 2013

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Christina Gikakis	Federal Transit Administration	General Engineer
Gregory Rymarz	Federal Transit Administration	TRI- Bus Testing
Sean Ricketson	Federal Transit Administration	TRI- NFCBP
Stephen Brady	Booz-Allen	Bus Testing Consultant
Michael Huntley	Federal Motor Carrier Safety Administration	MC-PSV
Deborah Freund	Federal Motor Carrier Safety Administration	MC-PSV
Uzmaa Balbale	National Highway Traffic Safety Administration	Structures & Restraints Research

MEETING 2: Coca-Cola Refreshments, Atlanta, GA, February 19, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Tony Eiermann	Coca-Cola Refreshments	Fleet Manager, Asset & Value Management
Dan Daly	Coca-Cola Refreshments	Director Fleet
Nathan Gaunt	Coca-Cola Refreshments	Fleet Manager, Southeast Region

MEETING 3: San Francisco Municipal Transportation Agency, San Francisco, CA, February 24, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Elson Hao	San Francisco MTA	Fleet Procurement & Maintenance Engineer
Rick Gonzales	San Francisco MTA	Electrical Technician
Louis Guzzo	San Francisco MTA	Woods Division, Maintenance Superintendent

MEETING 4: Electric Vehicles International, Stockton, CA, February 25, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Steve Nikulin	Electric Vehicles International	Director of Engineering
Jamie Zhu	Electric Vehicles International	Engineering Manager

MEETING 5: Daimler Trucks North America, Portland, OR, February 26, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Bryce Nash	Daimler Trucks North America	Senior Engineer
Mark Siddal	Daimler Trucks North America	Senior Engineer
Greg Nightingale	Daimler Trucks North America	Service Manager
Nasser Zamani	Daimler Trucks North America	Senior Manager Compliance
David Kayes	Daimler Trucks North America	Executive Engineer

MEETING 6: United Parcel Service, San Bernardino, CA, February 27, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Dale Morin	UPS	Automotive Engineer
Robert Filosa	UPS	Southern California Automotive Manager
Scott Lavery	UPS	VP West Region Automotive
Mike Britt	UPS	Director of Maintenance & Engineering
Ruben Arados	UPS	Automotive Fleet Manager
David J. Romero	UPS	Regional Automotive Training Manager

MEETING 7: Frito Lay, Plano TX, March 18, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
John Poakeart	Pepsico/FritoLay	Legal Director
Mike O'Connell	Pepsico/FritoLay	Senior Director, Fleet
Steve Hanson	Pepsico/FritoLay	Engineering Director

MEETING 8: Peterbilt Motors Company, Denton, TX, March 18, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Wayne Wilson	Peterbilt Motors Company	Engineering Supervisor
Rod Curbo	Peterbilt Motors Company	Product Safety & Compliance Manager
Girma Gebrehana	Peterbilt Motors Company	Project Engineering Lead
Don Winn	Peterbilt Motors Company	Powertrain Manager

MEETING 9: Smith Electric Vehicles, Kansas City, MO, March 19, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Jaques Schira	Smith Electric Vehicles	General Council
Dale Unglesbee	Smith Electric Vehicles	Manager R&D and Regulatory Affairs
Joseph D. Greenley	Smith Electric Vehicles	Electrical Engineering Manager
Jacob Brann	Smith Electric Vehicles	Newton Engineering Program Manager
Robin Mackie	Smith Electric Vehicles	President & CTO
Doug MacAndrew	Smith Electric Vehicles	VP Engineering
Alan Malby	Smith Electric Vehicles	Driveline Program Manager
Jan Coulter	Smith Electric Vehicles	Chief Engineer Development
Terry Nicoletti	Smith Electric Vehicles	National Parts & Service Director

MEETING 10: CVSA Vehicle Committee, Los Angeles, CA, April 10, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Kerri Wirachowski	CVSA Vehicle Committee	Chairman
CVSA Vehicle Committee members		

MEETING 11: New York State Agencies, Albany, NY, April 22, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Terry McDonnell	NY State Police	Staff Sergeant
Tom Fuller	NY State Police	Technical Sergeant
Rusty Seastrum	NYS DOT	Chief Technician
Larry Scotto	NYS DOT	Director, Passenger Carrier Safety Bureau

MEETING 12: BAE Systems, Endicott, NY, April 23, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Steve Tilyou	BAE Systems	Program Manager
Larry Munson	BAE Systems	Product Safety
Sean Murphy	BAE Systems	Laboratory Lead
Jeff Altmire	BAE Systems	Applications Manager
Derek Matthews	BAE Systems	Senior Principal Systems Engineer

MEETING 13: Eaton Corporation, Galesburg, MI, April 24, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Quon Kwan	Federal Motor Carrier Safety Administration	MC-RRT
Eric Smith	Eaton Corporation	Engineering Manager
Julie Marshaus	Eaton Corporation	Hybrid Product Technical Lead
Scott Davis	Eaton Corporation	Aftermarket & Technical Support
Chris Hess	Eaton Corporation	Director of Government Affairs

MEETING 14: Hino Trucks USA, Novi, MI, May 12, 2014

NAME	COMPANY	TITLE
Dana Lowell	M.J. Bradley & Associates	Senior Consultant
Glenn Ellis	Hino Motor Sales USA	Vice President – Marketing Dealer Operations and Product Planning

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2. U.S. Department of Energy, Energy Information Administration, *Alternative Fuel Vehicles in Use 2011*; American Public Transportation Association, *Public Transit Fact Book, 2012*; CalStart, *Demand Assessment of First-Mover Hybrid and Electric truck Fleets*, 2012.
3. CalStart, *Demand Assessment of First-Mover Hybrid and Electric truck Fleets*, 2012.
4. Commercial Vehicle Safety Alliance website, www.cvsa.org.
5. U.S. Department of Transportation, Federal Motor Carrier Safety Administration, North American Standard Driver/Vehicle Inspection Levels (<http://www.fmcsa.dot.gov/safety-security/safety-initiatives/mcsap/insplevels.htm>).
6. Commercial Vehicle Safety Alliance, North American Standard Out-Of-Service Criteria, *2011 Handbook and Out-of-Service Pictorial Edition*, April 1, 2011.
7. National Highway Traffic Safety Administration, Notice of Proposed Rulemaking, “Minimum Sound Requirements for Hybrid and Electric Vehicles,” 49 CFR 571,585; Docket number NHTSA-2011-0148; RIN 2127-AK93; January 1, 2013.
8. National Highway Traffic Safety Administration, Notice of Proposed Rulemaking, “Alternative Fuel Vehicle Badging, Fuel Compartment Labels and Consumer Information on Alternative Fuel Usage,” *Federal Register*, February 20, 2014.