Introduction

As of 2024, thousands of electric school buses (ESBs) are in operation. In the coming years, thousands more will enter our roads. This transition brings numerous benefits and also requires new skills and knowledge to safely and effectively operate and maintain ESBs. To our knowledge, no standardized training content or learning standards exist for ESBs. The World Resource Institute's Electric School Bus (ESB) Initiative identified the unmet need for standardized training and developed the idea of an ESB Training Standard informed by discussions with its ESB Manufacturing & Supply Chain Steering Committee, collaboration with CALSTART's Industry ESB Working Group, and conversations across the student transportation sector.

A common set of learning standards bridges the gap in knowledge between bus manufacturers and school bus users. Standardized learning objectives create a common understanding for people to learn from and facilitate understanding between industry staff and community members. When training standards are aligned, curricula can then be personalized for local context while achieving the same learning objectives and outcomes. Regardless of whether school bus workers are trained by a manufacturer, community college, workplace, dealer, technical school, or other entity, they should complete their respective program with a standardized set of knowledge, as defined in this document.

The ESB Training Standards define core competencies and knowledge for people interacting with ESBs and are designed to guide the development of training curricula while supporting learners. The standards are designed to ensure that people who interact with ESBs will have adequate skills and knowledge to perform their duties safely and effectively. Although these standards do connect to equity considerations, we encourage adopters to embed equity and accessibility into their training curricula and programs to serve different learning abilities (multilingual, uniquely abled, etc.) and to accommodate the needs of learners (childcare, etc.).

These ESB industry-first standards are informed by electric vehicle standards created by the American Public Transportation Association (APTA), the National Institute for Automotive Service Excellence (ASE), the Electronics Technicians Association (ETA) International, and the Electric Vehicle Standards Council (EVSC), which are designed for other segments, such as electric light-duty vehicles, zero-emission transit buses, and hybrid vehicles. Content related to ESBs is adapted from expertise of and resources published by the ESB Initiative. These standards have been peer-reviewed by over 50 industry experts, including school bus operators, school bus manufacturers, and subject matter experts.

Standards scope and purpose

What are these standards?

The ESB Training Standards outline a fundamental set of knowledge that learners should understand and skills that they should be able to perform. The standards also serve as a framework to create ESB training content. Each standard explores learning objectives or outcomes linked to important knowledge and skills. The standards do not provide any training content and cannot educate learners directly. See Figure 1 on how learning standards lead to curriculum development and then instruction.

Figure 1

Source: Adapted from EVSC 2023.

accessible. As you develop curricula and instruction, be sure to ask learners about their needs and learning styles, to use the opportunity for professional development when possible, and to solicit feedback formally and informally to make improvements for subsequent trainings.

As ESB technology evolves, these standards may need to adapt to match a changing industry. The ESB Initiative may adjust the standards and welcomes feedback. See the "Document history" section for details and contact information.

Disclaimers

The ESB Training Standards were developed by WRI's ESB Initiative to serve as a voluntary guideline, sharing industry standards and recommended learning objectives. The standards were created to familiarize community members with ESBs and those who play a role in the school bus sector. The standards are intended to guide training for individuals working on or near ESBs, including technicians, drivers, operators, fleet managers, dealers, and first responders. WRI, its employees, and reviewers of this document shall not be held liable for any personal injury, property or other damages, directly or indirectly, as a result of using or relying on the ESB Training Standards.

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The authors are grateful to the following external reviewers for their feedback and invaluable insights. Their review does not constitute an endorsement of the content.

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Document History

Version	Activity	Date
—	Initial draft shared with industry reviewers	February 29, 2024
Version 1.0	Published	July 2, 2024
Version 1.1	Updates to bibliography	August 7, 2024
Version 1.2	Added checkboxes throughout the document. Corrected bullet numbering. Added spacing to improve readability.	November 4, 2024

The Electric School Bus Initiative may update these standards as the industry evolves. If you would like to suggest changes or additions to these standards, please submit them to Stephanie Ly (stephanie.ly@wri.org) or Emmett Werthmann (emmett.werthmann@wri.org).

0.4 General ESB safety information

- ☐ 0.4.1 Recognize low-fire-risk evidence of ESBs compared to fossil fuel–burning school buses.
- ☐ 0.4.2 Describe bus body and chassis safety compliance with federal regulations.
- ☐ 0.4.3 Explain high safety standards for ESB battery and vehicle design.
- ☐ 0.4.4 Understand concerns and questions about ESBs among stakeholders.
- ☐ 0.4.5 Develop responses to questions, concerns, and common misconceptions about ESBs.

0.5 Achieving equity and sustainability

- ☐ 0.5.1 Name equity benefits offered by ESBs.
- ☐ 0.5.2 Describe the intersection of the ESB transition with historical inequities, racism, and discrimination that have factored into school busing.
- ☐ 0.5.3 Describe equity considerations in ESB route planning, such as emissions benefits and the ability to accommodate disabilities.
- ☐ 0.5.4 Define a *just and equitable transition* for ESB workers.
- ☐ 0.5.5 Describe critical mineral use and more responsible supply chains for electric vehicle (EV) batteries.
- ☐ 0.5.6 Recognize battery end-of-life options, such as secondary use and recycling to avoid landfills.
- ☐ 0.5.7 Describe ways to extend the life of an existing fossil fuel–burning school bus through repowering or reconditioning.

Level 1: ESB operation

Objective

The objective of Level 1 is to inform the development of educational curricula for individuals who interact with or have the potential to interact with ESBs through their line of work. This might include bus drivers, transportation managers/directors, dispatchers, routing specialists, bus attendants/aides, and instructors/trainers. Not all standards will apply to every role or position. Level 1 presumes learners are familiar with foundational knowledge from the ESB Awareness Standards. Level 1 learning objectives and outcomes will enable people to drive and operate ESBs but does not cover detailed high-voltage (HV) safety or maintenance work, which are addressed in Levels 2–4.

1.1 ESB basics

- ☐ 1.1.1 Identify which staff are qualified to drive, service, and maintain ESBs.
- ☐ 1.1.2 Recognize the manufacturer(s) and model(s) of ESBs at the depot, if applicable.
- ☐ 1.1.3 Describe the estimated range (miles) for ESBs at the depot.
- ☐ 1.1.4 Define *state of charge* (SOC).
- ☐ 1.1.5 Define *high voltage* (HV).
- ☐ 1.1.6 Define *electric vehicle supply equipment* (EVSE).
- ☐ 1.1.7 Describe differences between ESBs from different model years and original equipment manufacturers (OEMs), if applicable.
- ☐ 1.1.8 Explain what instantaneous torque is and the difference from fossil fuel–burning school buses.
- ☐ 1.1.9 Describe the difference between nameplate capacity and usable capacity for the HV battery.
- ☐ 1.1.10 Describe the difference between a kilowatt (kW) and a kilowatt-hour (kWh), especially in the context of the vehicle battery storing energy and charging station delivering energy.

1.2 Basic EV safety and awareness

- ☐ 1.2.1 Identify locations of OEM safety and service operating manuals.
- ☐ 1.2.2 Summarize key OEM safety recommendations (this varies by OEM).
- ☐ 1.2.3 Describe the types of labels or markings on an ESB to identify it as an EV.
- ☐ 1.2.4 Describe and point out warning labels for HV components within the ESB.
- ☐ 1.2.5 Recognize key functional and safety differences between vehicles (varies by OEM).
- ☐ 1.2.6 Describe any local department of transportation, highway patrol, or division of motor vehicles EV labeling or other requirements.
- ☐ 1.2.7 Explain the difference in weight between ESBs and fossil fuel–burning school buses as well as considerations for heavier vehicles.

1.3 Operating an ESB

Pre- and post-trip inspection

- ☐ 1.3.1 Explain differences in pre- and post-trip inspections between ESBs and fossil fuel–burning school buses.
- ☐ 1.3.2 Identify where inspection logs are located.
- ☐ 1.3.3 Explain importance of checking SOC levels prior to and after a route.
- ☐ 1.3.4 Demonstrate the ability to conduct an ESB pre- and post-trip inspection, according to the OEM owner's manual and local depot procedure.

Vehicle start-up and shutoff

- ☐ 1.3.5 Describe the difference in start-up and operating behaviors between ESBs and fossil fuel–burning school buses, including audio and visual indicators.

- ☐ 1.3.6 Demonstrate where key switches, buttons, and other interface points are located on the dashboard.
- ☐ 1.3.7 Demonstrate when the low-voltage (LV) system is energized (accessory mode).
- ☐ 1.3.8 Demonstrate when the HV system is energized (ready to drive).
- ☐ 1.3.9 Demonstrate the steps necessary to start/enable the vehicle (varies by OEM).
- ☐ 1.3.10 Identify dashboard lights and indicators (varies by OEM).
- ☐ 1.3.11 Identify activation of noisemaker and pedestrian warning devices (varies by OEM).
- ☐ 1.3.12 Compare the SOC gauge on an ESB with the fuel-level gauge on a fossil fuel–burning school bus.
- ☐ 1.3.13 Describe at what SOC the ESB will go into derate mode and what vehicle systems and capabilities will be turned off or limited (varies by OEM).
- ☐ 1.3.14 Describe at what SOC the ESB will go into emergency shutdown/shutoff mode (varies by OEM).
- ☐ 1.3.15 Explain the proper procedure if the vehicle enters derate mode or emergency shutdown/shutoff mode, according to OEM and depot guidance.
- ☐ 1.3.16 Demonstrate how to turn off and deenergize the vehicle.
- ☐ 1.3.17 Demonstrate how to turn off auxiliary loads.
- ☐ 1.3.18 Explain why some vehicle systems may still be on, even after the vehicle is powered off.

Other considerations

- ☐ 1.3.19 Describe how the LV system controls and enables the HV system.
  - ☐ a. Explain how the LV, or 12 volt (V), battery can be drained when vehicle is off, on accessory mode, or running accessory loads.
  - ☐ b. Describe how to address a discharged/drained LV (12V) battery by reenergizing (i.e., jump-starting) or replacing the LV battery.
- ☐ 1.3.20 Describe any differences in wheelchair lift operation in an ESB, if relevant.
- ☐ 1.3.21 Explain washing procedures and any special considerations.
- ☐ 1.3.22 Describe proper vehicle storage according to OEM and depot procedures.

1.4 Driving efficiency, technique, and range maximization

- ☐ 1.4.1 Define *regenerative braking.*
- ☐ 1.4.2 Explain the role of regenerative braking and its benefits.
- ☐ 1.4.3 Define *gradual acceleration and deceleration.*
- ☐ 1.4.4 Explain why driving behavior and technique affects vehicle efficiency and range.
- ☐ 1.4.5 Demonstrate regenerative breaking and high-efficiency driving techniques.
- ☐ 1.4.6 Explain why regenerative braking functionality can be limited when the HV battery has a high SOC.
- ☐ 1.4.7 Describe the relative impact that the following factors have on vehicle range:
  - ☐ a. Hilly versus flat terrain
  - ☐ b. Passenger loads
  - ☐ c. Traffic conditions, stops, and average vehicle speeds
  - ☐ d. Cabin heating, ventilation, and air-conditioning (HVAC)
  - ☐ e. Ambient air temperature
  - ☐ f. Cabin preconditioning
  - ☐ g. Battery preconditioning, if applicable
- ☐ 1.4.8 Demonstrate driving the ESB on flat terrain.

- ☐ 1.4.9 Demonstrate driving the ESB on hilly terrain.
- ☐ 1.4.10 Describe hill start assist functions, if applicable.
- ☐ 1.4.11 Demonstrate use of hill start assist, if applicable.
- ☐ 1.4.12 Describe techniques to avoid battery charge depletion and range maximization while using HVAC in ESBs, including while the vehicle is idling.
- ☐ 1.4.13 Compare how cabin heating and cooling systems differ in their impact on range.
- ☐ 1.4.14 Calculate the impact of running bus air-conditioning and heating on bus range.
- ☐ 1.4.15 Describe procedures for cold or hot weather preconditioning of the battery, if applicable (varies by vehicle and/or charging equipment OEM).
- ☐ 1.4.16 Explain battery preconditioning and its importance.
- ☐ 1.4.17 Describe the impact that battery thermal management system operation has on vehicle charging time length.
- ☐ 1.4.18 Describe procedures for cold or hot weather preconditioning of the bus cabin, if applicable.
- ☐ 1.4.19 Explain cabin preconditioning and its importance.

1.5 Vehicle charging

Charging basics

- ☐ 1.5.1 Define *alternate current* (AC) and *direct current* (DC).
- ☐ 1.5.2 Explain the difference between AC and DC.
- ☐ 1.5.3 Explain the difference between AC Level 1, AC Level 2, DC fast charging, and DC slow charging.
- ☐ 1.5.4 Compare different types of charging plug connectors.
- ☐ 1.5.5 Explain when a vehicle needs to charge.
- ☐ 1.5.6 Describe how long charging sessions last and mileage or range gained.
- ☐ 1.5.7 Describe route differences and limitations for ESBs.
- ☐ 1.5.8 Identify on-site and off-site charging stations.
- ☐ 1.5.9 Describe how different charging stations can have different recharging times.
- ☐ 1.5.10 Describe the impact of operating cabin HVAC systems on vehicle charging time length.

Charging procedures

- ☐ 1.5.11 Identify the charging port location on the ESB (varies by OEM).
- ☐ 1.5.12 Identify charger locations in the depot.
- ☐ 1.5.13 Identify the plug connector standard type on the ESB.
- ☐ 1.5.14 Define the concept of *smart* or *managed* charging.
- ☐ 1.5.15 Demonstrate steps to power off the vehicle and successfully initiate a charging session.
- ☐ 1.5.16 Identify key indicators to show that an ESB is actively charging (varies by OEM).
- ☐ 1.5.17 Describe procedures to reinitiate a failed charging session.
- ☐ 1.5.18 Explain why damage or debris in the charging system leads to safety or operational issues.
- ☐ 1.5.19 Demonstrate inspection of the charger pins, charging cords, and so forth for any damage or debris.
- ☐ 1.5.20 Demonstrate correctly and securely installing the charge port cap and door after charging.
- ☐ 1.5.21 Explain importance of checking that a charging session has started after plugging in the vehicle.
- ☐ 1.5.22 Demonstrate proper cord management to both maintain a safe working environment and protect the longevity of the cord and charger head.
- ☐ 1.5.23 Demonstrate steps to end a charging session.

- ☐ 1.5.24 Describe how estimated range (miles) is calculated for ESBs (varies by OEM).
- ☐ 1.5.25 Estimate ESB charging time at the depot and in other locations.
- ☐ 1.5.26 Describe why charging times can be affected by battery temperatures and ambient air temperatures.
- ☐ 1.5.27 Describe backup plans for charging ESBs in the event of a power outage.

1.6 Fleet manager considerations

- ☐ 1.6.1 List the types of ESBs and EVSE inspections and their frequency, according to the OEM owner's manual and depot procedure.
- ☐ 1.6.2 Describe regular preventive maintenance for ESBs and EVSE.
- ☐ 1.6.3 Explain how maintenance schedules may differ for ESBs operating in extreme conditions.
- ☐ 1.6.4 Describe driving behaviors to promote range, efficiency, and ESB longevity.
- ☐ 1.6.5 Evaluate measures to assess and promote high-efficiency driving.
- ☐ 1.6.6 Identify which personnel or staff are responsible for charging the ESBs.
- ☐ 1.6.7 Describe typical charging schedules.
- ☐ 1.6.8 Explain the utility time-of-use and demand charges for your location.
- 1.6.9 Calculate electricity fuel costs by estimating electricity rate at the hours of charging and duration of charge sessions.
- ☐ 1.6.10 Explain how the charging rate (kW) is defined by the vehicle and why this can differ from the EVSE maximum charge rate.
- ☐ 1.6.11 Evaluate and develop charging schedule considering SOC, location, time of day, electricity costs, driver schedules, and route/range needs.
- ☐ 1.6.12 Evaluate and develop procedures to report charging issues internally and externally.
- ☐ 1.6.13 Compare smart, networked, or managed charging to nonnetwork or manual charging.
- ☐ 1.6.14 Describe any smart or managed charging software or mobile apps that are used to start or end charging, if applicable.
- ☐ 1.6.15 Describe cable management systems and when they might be used.
- ☐ 1.6.16 Describe vehicle telematics and how this technology is used in school bus operations.
- ☐ 1.6.17 Demonstrate the ability to access telematics data and analyze vehicle performance using the software platform.

1.7 Emergency planning

Emergency situations (drivers, bus aides, dispatchers, instructors/trainers, etc.)

- ☐ 1.7.1 Describe basic accident and incident ESB protocols to follow for key personnel (e.g., operators, road service crews, first and second responders, dispatchers, road supervisors, and technicians).
- ☐ 1.7.2 Describe safety protocols for student riders and students with disabilities.
- ☐ 1.7.3 Describe how to use the wheelchair lift manually in case of emergency or power failure.
- ☐ 1.7.4 Demonstrate how to use the wheelchair lift manually.
- ☐ 1.7.5 Describe the manual service disconnect (MSD) function.
- ☐ 1.7.6 Identify location of the MSD, based on the OEM manual and/or National Fire Protection Association (NFPA) Emergency Response Guide.
- ☐ 1.7.7 Identify where on the vehicle the emergency response guide is located, including a QR code or quick reference card.
- ☐ 1.7.8 Describe the vehicle towing process and procedure according to the OEM.
- ☐ 1.7.9 Describe various warning signs that can present prior to a battery thermal event or fire.

☐ 1.7.10 Explain procedures as outlined in safety protocols for potential thermal events or fire.

Emergency preparedness (transportation managers/directors and planners)

☐ 1.7.11 Describe labeling for HV work areas in depots.

☐ 1.7.12 Identify manufacturer(s) of the ESBs in operation and location of service manuals and contact information for the manufacturer or dealer.

☐ 1.7.13 Describe safety protocols for student riders, students with disabilities, bus drivers, and staff riders (i.e., bus aide).

☐ 1.7.14 Describe accident and incident ESB protocols and procedures for key personnel and first and second responders.

☐ 1.7.15 Describe vehicle towing procedures and vehicle emergency response guide locations in the vehicle.

☐ 1.7.16 Describe warning signs and depot protocols for a battery thermal event or fire.

☐ 1.7.17 Describe training needs for staff based on responsibility and role.

☐ 1.7.18 Develop training implementation program for staff.

☐ 1.7.19 Develop communication and response strategy with local first responders.

Level 2: ESB safety

Objective

The objective of Level 2 is to focus on HV safety information and inform educational curricula designed for workers who may service or maintain ESBs or workers who may respond to an emergency involving an ESB. Level 2 is intended for people directly working with or potentially working with HV vehicles on non-live HV systems. The learning objectives and outcomes in Level 2 are primarily aimed at workers such as school bus maintenance technicians, dealers, first and second responders, dismantlers, upfitters, and technical training instructors. Level 2 assumes that learners are familiar with knowledge and content from the ESB Awareness Standards and Level 1 standards. Level 2 serves as foundational knowledge for Levels 3 and 4.

2.1 General safety

- ☐ 2.1.1 Describe the risks associated with ESBs and EV maintenance and repair.
- ☐ 2.1.2 Describe the difference between live and non-live electrical systems.
- ☐ 2.1.3 Describe Occupational Safety and Health Administration (OSHA) 1910.269 and Subpart S and how they apply to ESBs in the workplace.
- ☐ 2.1.4 Describe NFPA 70E and how it governs safety procedures involved with working in and around ESBs.
- ☐ 2.1.5 Explain when to remove conductive items, including jewelry, watches, belt buckles, and other metal objects, when servicing an ESB.
- ☐ 2.1.6 Explain why technicians with medical devices such as pacemakers, hearing aids, and medication pumps should consult a medical professional before working with HV.
- ☐ 2.1.7 Explain why technicians should verify the absence of voltage before work is performed and always assume that circuits are live.
- ☐ 2.1.8 Explain why technicians should never work alone on HV vehicles.
- ☐ 2.1.9 Explain why the one-hand rule—in which only a single hand should touch the vehicle, lead, or ground at any time—is important.
- ☐ 2.1.10 Describe the hazard of arc flash and how proper procedure and equipment can prevent it.
- ☐ 2.1.11 Explain the special requirements for lifting ESBs (can vary by OEM).
- ☐ 2.1.12 Describe how to safely respond to a vehicle accident with an ESB according to protocols.
- ☐ 2.1.13 Describe the minimum voltage and current that causes electrocution for AC and DC.
- ☐ 2.1.14 Identify risks on the human body for different current levels (amps).
- ☐ 2.1.15 Describe the different classes of fires, especially Classes C and D.
- ☐ 2.1.16 Identify common voltage ranges for the HV system on ESBs.

2.2 Safety equipment and requirements

Personal protective equipment (PPE)

- ☐ 2.2.1 Locate protective equipment (PPE) in the depot or facility.
- ☐ 2.2.2 Describe the ESB maintenance tasks or conditions that require HV PPE for qualified and trained personnel when working on ESBs.
- ☐ 2.2.3 List the different types of PPE required to work on EVs, including, but not limited to, the following:
    - ☐ a. Electrical rubber insulating gloves
    - ☐ b. Approved leather over gloves
    - ☐ c. Cotton liner gloves
    - ☐ d. Insulating sleeves
    - ☐ e. Insulated protective footwear

- ☐ f. Insulating rubber apron
- ☐ g. Digital multimeter (DMM) and other instruments (also see 2.4: Test instruments)
- ☐ h. Safety glasses or goggles
- ☐ i. Ear plugs or hearing protection
- ☐ j. Face shield
- ☐ k. Balaclava
- ☐ l. Rubber insulating matting
- ☐ m. Arc flash suits
- ☐ n. Helmet
- ☐ o. Electrical rescue hook
- ☐ p. Escape strap
- ☐ q. Thermal camera

☐ 2.2.4 Explain the purpose of each PPE type listed in 2.2.3.

☐ 2.2.5 Describe when and how often each PPE item requires inspection and/or replacement intervals.

☐ 2.2.6 Demonstrate proper inspection and use of each PPE.

☐ 2.2.7 Describe the storage procedures of each PPE.

☐ 2.2.8 Explain why natural fabrics or flame-resistant materials and not synthetic clothing should be used, including undergarments (see OSHA 1910.269[l][8][iii]).

☐ 2.2.9 Explain the difference between CAT ratings (i.e., CAT II, CAT III, CAT IV) that differentiate DMMs.

☐ 2.2.10 Demonstrate how to properly test a CAT III and CAT IV multimeter for lead resistance and expected test levels.

First aid and rescue

☐ 2.2.11 Explain the danger of current to the human body and the role of voltage.

☐ 2.2.12 Define *HV, arc flash,* and *shocks,* and explain the risks for serious injury.

☐ 2.2.13 Describe how an electric shock causes muscles to lock up and how the person is unable to release grip from the electric current source.

☐ 2.2.14 Explain contact release and first response procedures for individuals who have come into contact with HV.

☐ 2.2.15 Describe the need for first aid kits, defibrillators, and cardiopulmonary resuscitation (CPR) training for HV applications.

☐ 2.2.16 Describe the locations and general uses of emergency items for HV safety, including fire extinguishers, a rescue hook, first aid equipment, and defibrillators.

☐ 2.2.17 Demonstrate how to use a rescue hook and/or an escape strap.

Emergency response (first and second responders)

☐ 2.2.18 Identify where on the vehicle the emergency response guide is located, including QR codes or quick reference card that can be used to retrieve the information.

☐ 2.2.19 Describe thermal event response procedures.

☐ 2.2.20 Demonstrate proper use of PPE.

☐ 2.2.21 Describe the difference between an MSD plug and a cut loop and when it is appropriate to use them.

☐ 2.2.22 Demonstrate the proper steps to disconnect the MSD.

☐ 2.2.23 Describe setting up quarantine areas for an ESB after an accident or incident.

☐ 2.2.24 Identify appropriate methods of suppressing an EV fire.

2.3 Safe workplace and depot practices

- ☐ 2.3.1 Name where ESBs will be parked regularly, locations of chargers, and any shop areas that will conduct HV maintenance on ESBs.
- ☐ 2.3.2 Identify the person(s) responsible for implementing a PPE maintenance and certification program.
- ☐ 2.3.3 Identify responsible person(s) for ensuring PPE replacement and inventory.
- ☐ 2.3.4 Show where standard operating procedures for handling of ESBs are located.
- ☐ 2.3.5 Show where training and continuous training logs and documentation are located.
- ☐ 2.3.6 Describe a safe ESB workspace environment, including necessary HV signs, labels, and restricted areas.
- ☐ 2.3.7 Describe barricades or physical structures to prevent noncertified people from entering any HV work areas.
- ☐ 2.3.8 Describe the PPE requirements for unqualified and/or escorted personnel in and around an ESB undergoing HV work.
- ☐ 2.3.9 List the staff qualified to service and maintain LV and nonelectrical systems.
- ☐ 2.3.10 List the staff qualified to service and maintain HV systems.
- ☐ 2.3.11 Explain the safe practices for working on and around HV systems, for qualified and trained personnel.
- ☐ 2.3.12 Describe the purpose of lockboxes and the storage of equipment to perform lockout/tagout (LOTO) procedures.
- ☐ 2.3.13 Describe the staff responsible for implementing LOTO procedures for ESBs in the depot procedures, especially within the context of driver and key access.
- ☐ 2.3.14 Explain how to secure the work environment for unqualified individuals.
- ☐ 2.3.15 Describe where building switchgear is located in the depot.
- ☐ 2.3.16 Describe where charging equipment emergency shutoffs are located.

2.4 HV tooling and testing equipment

Test instruments

- ☐ 2.4.1 Describe the purpose of test instruments that may be required to work with the HV applications below:
  - ☐ a. CAT IV DMM
  - ☐ b. Laptop with isolated controller area network (CAN) adapter with appropriate OEM software installed
  - ☐ c. Meter leads
  - ☐ d. Amp clamps
  - ☐ e. Insulation meter
  - ☐ f. Proving unit
  - ☐ g. Oscilloscope
  - ☐ h. Differential scope probe
  - ☐ i. Digital scope
  - ☐ j. Infrared thermal imaging camera
  - ☐ k. Refrigerant sniffer
- ☐ 2.4.2 Explain the difference between CAT ratings (i.e., CAT II, CAT III, CAT IV) that differentiate test instruments, including working voltage and peak impulse transient.

☐ 2.4.3 Identify test instruments that are rated for safety certified by two or more independent testing laboratories, such as Underwriter Laboratories (UL), Canadian Standards Association, or Technical Inspection Association (TUV).

☐ 2.4.4 Describe the procedures for inspecting test instruments.

☐ 2.4.5 Demonstrate ability to inspect test instruments prior to use.

☐ 2.4.6 Describe the storage procedures of each test instrument.

☐ 2.4.7 Explain how a mismatch between DMM settings and testing application can damage the meter.

Insulated tools

☐ 2.4.8 Describe why insulated tools are used and identify their maximum voltage rating.

☐ 2.4.9 Explain the situations or maintenance procedures where insulated tools are needed.

☐ 2.4.10 Identify common insulated tools used to work with ESBs.

☐ 2.4.11 Explain how to identify unsafe or damaged insulated tools.

2.5 De-energizing procedures

Manual service disconnect

☐ 2.5.1 Identify key areas where HV systems and components are present on the ESB.

☐ 2.5.2 Understand that orange cables indicate HV and their potential danger.

☐ 2.5.3 Describe the HV threshold for AC and DC.

☐ 2.5.4 Define *passive and active HV dissipation*.

☐ 2.5.5 Describe how your ESB's active and passive dissipation circuits work and the time each takes to dissipate the HV system.

☐ 2.5.6 Compare and contrast risks, effects, and mitigation measures for HV AC and HV DC.

☐ 2.5.7 Identify the LV (12V) battery and battery disconnect location on the vehicle.

☐ 2.5.8 Explain the purpose of de-energizing an ESB prior to performing maintenance or repairs.

☐ 2.5.9 Define an *MSD*.

☐ 2.5.10 Identify MSD location(s) on the ESB(s) to inform trained personnel of its location (varies by vehicle OEM).

☐ 2.5.11 Explain how to verify that HV is absent, based on OEM procedures.

☐ 2.5.12 Explain why batteries/energy storage systems (ESSs) may still be live, based on OEM designs.

☐ 2.5.13 Explain how a welded contactor can allow voltage to still exist in an HV system even when powered off.

☐ 2.5.14 Demonstrate removal of the MSD.

Live-dead-live test

☐ 2.5.15 Describe a live-dead-live (LDL) test and the importance of the procedure.

☐ 2.5.16 Demonstrate the proper selection and use of electrical testing equipment and leads to verify the absence of voltage.

☐ 2.5.17 Demonstrate the ability to use a DMM and conduct an LDL test.

Lockout/tagout

☐ 2.5.18 Define *LOTO* and describe when the procedure should be used.

☐ 2.5.19 Define the different levels of LOTO that can be present on an ESB (varies by OEM).

☐ 2.5.20 Explain the difference between LV LOTO and HV LOTO procedures.

☐ 2.5.21 Demonstrate the LV LOTO procedure.

☐ 2.5.22 Demonstrate the HV LOTO procedure.

☐ 2.5.23 Explain the concept of battery lockout/tagout.

2.6 Onboard safety

☐ 2.6.1 Recognize key dashboard iconography related to safe bus operation and warnings.
☐ 2.6.2 Explain the difference between HV and LV systems in ESB applications.
☐ 2.6.3 Describe how the LV (12V) system uses the vehicle chassis for the ground.
☐ 2.6.4 Describe how the HV system is isolated and contained.
☐ 2.6.5 Explain the high-voltage interlock loop (HVIL) and its importance and function.
☐ 2.6.6 Describe the need to isolate HV grounds from the bus chassis.
☐ 2.6.7 Explain the concept of HV isolation detection in providing protection from HV system faults.
☐ 2.6.8 Explain the function of HV disconnect switches, including the MSD, battery disconnect unit, contactors, and switches.
☐ 2.6.9 Describe the differences between HV and LV disconnect.
☐ 2.6.10 Define the following safety components:
- ☐ *a. Pressure relief device*
- ☐ *b. Overpressure valves*
- ☐ *c. Vent lines*
- ☐ *d. Gauges*
- ☐ *e. Fuse protection*
- ☐ *f. Pyrofuse*
- ☐ *g. Contactors*
- ☐ *h. Crash sensor*

☐ 2.6.11 Explain the function of the following applications and components and their role for maintaining safety (varies by OEM):
- ☐ a. HV junction box (HVJB)
- ☐ b. Isolation detection/ground fault detection/isolation and isolation monitoring
- ☐ c. Battery management system (BMS)

☐ 2.6.12 Name conditions that could trigger HV disconnect.
☐ 2.6.13 Explain the passive discharge and its importance related to working on HV systems.
☐ 2.6.14 Describe how the following components carry HV current (varies by OEM):
- ☐ a. HV battery pack
- ☐ b. HVJB
- ☐ c. BMS
- ☐ d. HV battery charging equipment
- ☐ e. HV cables, connecting components
- ☐ f. Inverter power electronics
- ☐ g. Capacitors inside the vehicle's inverter-rectifier assembly
- ☐ h. DC/DC converter
- ☐ i. AC/DC inverter
- ☐ j. Modules/electronic control unit(s)
- ☐ k. Electric motor(s)
- ☐ l. Air compressor(s) for air conditioning, brakes, or suspension
- ☐ m. HV heater(s)

- ☐ n. Power steering pump
- ☐ o. Other HV components, as applicable

☐ 2.6.15 Explain the role of thermal sensors in the battery pack.

☐ 2.6.16 Explain active discharge and its importance for working on HV systems.

☐ 2.6.17 Identify other EV regulations and independent standards that may be relevant for training, including the following:

- ☐ a. ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electric Safety Certification Standards
- ☐ b. American Public Transportation Association (APTA) Standards: Zero-Emission Bus Maintenance Training
- ☐ c. OSHA 1910.269 and Subpart S
- ☐ d. Federal Motor Vehicle Safety Standards, Standard 305
- ☐ e. NFPA 70E: Standard for Electrical Safety in the Workplace
- ☐ f. Electronics Technicians Association International, 2012 Electric Vehicle Technician (EVT) Competency Requirements
- ☐ g. Electric Vehicle Standards Council (EVSC), High Academic & Technical Standards for the Electric Vehicle Industry
- ☐ h. Society of Automotive Engineers (SAE) Standards
  - i. SAE J1715, Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
  - ii. SAE J2344, Guidelines for Electric Vehicle Safety
  - iii. SAE J2910, Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety
  - iv. SAE J2990, Hybrid and EV First and Second Responder Recommended Practice
  - v. SAE J3108, xEV Labels to Assist First and Second Responders, and Others
  - vi. SAE J1766, Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing
  - vii. SAE J3040, Electric Vehicle (E-Vehicle) Crash Test Lab Safety Guidelines
  - viii. SAE J2929, Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-Based Rechargeable Cells
  - ix. SAE J1634, Battery Electric Vehicle Energy Consumption and Range Test Procedure
  - x. SAE J2836, Instructions for Using Plug-In Electric Vehicle (PEV) Communications, Interoperability and Security Documents
  - xi. SAE J1715/2, Battery Terminology
  - xii. SAE J1772, Electric Vehicle and Plug-In Hybrid Electric Vehicle Conductive Charge Coupler
  - xiii. SAE J3400, North American Charging System Electric Vehicle Coupler
  - xiv. SAE J2293-2, Energy Transfer System for Electric Vehicles—Part 2: Communication Requirements and Network Architecture

Level 3: Electrical theory and ESB systems

Objective

The objective of Level 3 is to inform the development of educational curriculum on basic electrical theory and the systems/componentry present in ESBs for workers who will service and maintain ESBs. Level 3 is intended for people working directly or potentially working with HV vehicles on non-live systems. This level is primarily aimed at ESB maintenance technicians (supervisor, lead technician, journeyperson technician, assistant technician), dealers, dismantlers, upfitters, and technical training instructors. Not all standards will apply to every role or sector, and users should make this determination. Level 3 assumes that learners are familiar with knowledge and content from the ESB Awareness Standards and Level 1 and Level 2 standards, and it serves as foundational knowledge for Level 4.

3.1 EV fundamentals and theory (advanced)

EV fundamentals

- ☐ 3.1.1 Explain various electrical waveforms found in ESBs.
- ☐ 3.1.2 Explain how to convert horsepower ratings to kW ratings.
- ☐ 3.1.3 Explain how to convert kW ratings to British thermal unit ratings.
- ☐ 3.1.4 Explain how electricity passes from the charger to the ESB.

Electrical theory

- ☐ 3.1.5 Apply understanding of metric system prefixes (i.e., giga-, mega-, kilo-) and conversions as related to energy density and electrical power.
- ☐ 3.1.6 List common metric conversions of US standards.
- ☐ 3.1.7 Identify common symbols and show competency in reading electrical schematics.
- ☐ 3.1.8 Define fundamental electricity terms and units, such as the following:
    - ☐ a. Power (W)
    - ☐ b. Kilowatt (kW)
    - ☐ c. Kilowatt-hours (kWh)
    - ☐ d. Electromotive force (EMF)
    - ☐ e. Volts (V)
    - ☐ f. Intensity of current (I)
    - ☐ g. Amperes-amps (A)
    - ☐ h. Resistance (R)
    - ☐ i. Ohms (Ω)
    - ☐ j. Resistors
    - ☐ k. Capacitors
    - ☐ l. Diodes
    - ☐ m. Contactors
    - ☐ n. Relays
    - ☐ o. Alternating current (AC)
    - ☐ p. Direct current (DC)
    - ☐ q. Nominal voltage
- ☐ 3.1.9 Examine fundamental laws of electricity:
    - ☐ a. Ohm's law
    - ☐ b. Watt's law

- ☐ c. Kirchhoff's current and voltage laws
- ☐ d. Lenz's law

☐ 3.1.10 Describe an electrical circuit and the role of resistors, capacitors, inductors, transistors, diodes, contactors, and relays.

☐ 3.1.11 Demonstrate ability to measure current, voltage, and resistance using an appropriately rated DMM.

☐ 3.1.12 Demonstrate ability to perform a voltage drop measurement using an appropriately rated DMM.

☐ 3.1.13 Understand and explain the difference between a series and parallel circuit, especially within the context of battery cells, packs, and modules.

☐ 3.1.14 Compare the differences between AC, DC, 110V, 220V, and 480V.

☐ 3.1.15 Explain the function of grounding and bonding points.

Applying electrical theory

☐ 3.1.16 Demonstrate the ability to calculate power.

☐ 3.1.17 Compare kWh battery capacity in an ESB to volume of fuel in a fossil fuel–burning bus.

☐ 3.1.18 Describe kWh/mile efficiency and how it relates to miles per gallon.

☐ 3.1.19 Calculate ESB charging time by understanding kW and kWh application.

☐ 3.1.20 Calculate power use over time (kWh) by a given HV component or system.

3.2 Electrical systems and components

Key components

☐ 3.2.1 Locate the common ESB subsystems and components below (varies by OEM):

- ☐ a. HV cables
- ☐ b. ESS
- ☐ c. HV batteries
- ☐ d. BMS
- ☐ e. HV MSD(s)
- ☐ f. LV MSD(s)
- ☐ g. Electric powertrain
- ☐ h. Electric traction motor(s)
- ☐ i. Electric axle (eAxle) (if applicable)
- ☐ j. Transmission (if applicable)
- ☐ k. HVJB/HV distribution module
- ☐ l. Precharge circuit
- ☐ m. AC/DC inverter
- ☐ n. DC/DC converter (accessory power module)
- ☐ o. LV battery
- ☐ p. Charge port
- ☐ q. Onboard charger module
- ☐ r. Power train control module
- ☐ s. Supervisory/system control module
- ☐ t. HV A/C air compressor
- ☐ u. Battery coolant heater
- ☐ v. Battery coolant chiller

- ☐ w. Heat pump (if applicable)
- ☐ x. Brakes (air/hydraulic)
- ☐ y. Coolant reservoir(s)
- ☐ z. Electric coolant pump(s)
- ☐ aa. Oil-to-coolant heat exchanger (if applicable)
- ☐ bb. Cabin heater and/or fuel-fired heater (if applicable)

☐ 3.2.2 List the components found on both ESBs and fossil fuel–burning school buses.

HV cables and boxes

☐ 3.2.3 Describe the color (orange) used to color-code HV cables in EVs, the voltage level, and their potential danger.

☐ 3.2.4 Describe what an HVJB is and how it functions, and identify the subcomponents.

☐ 3.2.5 Explain what a precharge circuit is and how it works.

☐ 3.2.6 Explain the relationship between the charge port, onboard charger, and HV battery.

☐ 3.2.7 Describe the difference between grounding and bonding points.

☐ 3.2.8 Identify grounding and bonding points.

☐ 3.2.9 Explain the basic design and function of AC and DC HV cables.

☐ 3.2.10 Compare onboard charger characteristics and functions to those of an off-vehicle charging station.

☐ 3.2.11 Explain the function and operation of shielding on HV cables to protect vehicle control systems from electromagnetic interference.

☐ 3.2.12 Explain the purpose of contactor/electrical switching devices and where they are used in an ESB.

☐ 3.2.13 Explain the purpose of bus bars fusing/distribution blocks.

☐ 3.2.14 Explain the rationale behind insulation testing and the importance of reference points.

☐ 3.2.15 Explain the relationship between American Wire Gauge wire gauges and their ratings and metric wire sizes.

☐ 3.2.16 Provide at least three examples of where differing DC voltages are needed (e.g., multiplexing, CAN, power steering, etc.).

Motors and auxiliary systems

☐ 3.2.17 Explain the function of traction motors in an ESB.

☐ 3.2.18 Explain motor control and composition, including permanent magnet and synchronous field controls.

☐ 3.2.19 Describe the difference between a three-phase, six-phase, and nine-phase electric motor.

☐ 3.2.20 Explain the purpose of an inverter.

☐ 3.2.21 Describe how the traction motor captures energy through regenerative braking.

☐ 3.2.22 Explain the relationship between the HV battery, inverter, and electric motor.

☐ 3.2.23 Explain why many ESBs do not use a transmission.

☐ 3.2.24 Describe the purpose of a DC/DC converter and its relationship with the LV battery.

☐ 3.2.25 Explain how the LV system controls and enables the HV system.

Heating and cooling systems

☐ 3.2.26 Explain why inverters, motors, and power electronic subcomponents need to be cooled and how that cooling is achieved.

☐ 3.2.27 Explain the function of a coolant loop.

☐ 3.2.28 List the types of components commonly found in a coolant loop.

☐ 3.2.29 Explain why an ESB may have more than one coolant loop.

- ☐ 3.2.30 Explain the difference between cabin HVAC and battery thermal management systems.
- ☐ 3.2.31 Explain the pros and cons of different cabin heating systems (positive temperature coefficient (PTC coolant heaters, PTC air heaters, heat pumps).
- ☐ 3.2.32 Explain how an HV component coolant loop may be integrated with the cabin HVAC system.

3.3 Batteries

- ☐ 3.3.1 Define an *ESS*.
- ☐ 3.3.2 Explain the general construction of a battery pack (module, string, cell, BMS).
- ☐ 3.3.3 Explain the difference between cylindrical, pouch, and prismatic battery cells.
- ☐ 3.3.4 Define *depth of discharge* (DOD).
- ☐ 3.3.5 Define *battery throughput.*
- ☐ 3.3.6 Describe what anodes and electrodes are and their differences.
- ☐ 3.3.7 Describe the energy characteristics of the following lithium-ion battery chemistries commonly found in ESBs:
  - ☐ a. Lithium iron phosphate (LFP)
  - ☐ b. Lithium nickel manganese cobalt (NMC)
- ☐ 3.3.8 Identify the battery chemistries for ESBs in the depot.
- ☐ 3.3.9 Describe the energy characteristics of non-lithium-ion battery chemistries:
  - ☐ a. Lead acid
- ☐ 3.3.10 Describe the impacts of ambient outdoor temperature on SOC and DOD.
- ☐ 3.3.11 Explain thermal management for battery heating and cooling, and explain the optimal temperatures for storage and operation.
- ☐ 3.3.12 Identify correct battery coolant per OEM instructions.
- ☐ 3.3.13 Describe the difference between battery coolant or forced air coolant systems.
- ☐ 3.3.14 Define *thermal runaway,* and explain thermal runaway safety practices.
- ☐ 3.3.15 Explain the safest methods to extinguish a lithium-ion battery fire.
- ☐ 3.3.16 Describe battery degradation over time.
- ☐ 3.3.17 Describe various procedures for the battery at the end of life.
- ☐ 3.3.18 Describe optimal temperatures for ESB storage.
- ☐ 3.3.19 Explain methods for calculating and measuring SOC for NMC and LFP batteries.
- ☐ 3.3.20 Describe the potential inaccuracy of a voltmeter in measuring LFP battery SOC.

3.4 Charging

- ☐ 3.4.1 Identify the type of current and kW rating of on-site chargers.
- ☐ 3.4.2 Explain the purpose and composition of EVSE.
- ☐ 3.4.3 Describe the concept of grounding on the EVSE.
- ☐ 3.4.4 Describe what constitutes a handshake signal to initiate charging.
- ☐ 3.4.5 Describe how the charge rate (kW) varies while a vehicle charges.
- ☐ 3.4.6 Describe the primary functions of a plug-in charge connector.
- ☐ 3.4.7 Define SAE J1772 and how it applies to plug-in connectors.
- ☐ 3.4.8 Identify differences between different US plug-connector standards:
  - ☐ a. Combined Charging System (CCS)
  - ☐ b. North America Charging Standard (NACS)
  - ☐ c. Megawatt Charging Standard (MCS)

- ☐ 3.4.9 Describe mobile chargers and stud-mounted chargers and their potential uses.
- ☐ 3.4.10 Describe other types of charging that could be applicable to ESBs in the future, such as inductive, off-grid, pole-mounted, or overhead pantograph charging.
- ☐ 3.4.11 Describe the utility connection between pole and meter for charging stations.
- ☐ 3.4.12 Describe the ground path through meters and importance of minimization.
- ☐ 3.4.13 Describe vehicle-to-grid (V2G) and vehicle-to-everything (V2X) applications.

3.5 Miscellaneous

- ☐ 3.5.1 Explain how the telematics system places an additional load and communicates with the vehicle's 12V system through multiplexing (MUX).
- ☐ 3.5.2 Describe the function of CANs.
- ☐ 3.5.3 Understand how ESBs with wheelchair lifts interact with the LV or HV vehicle systems.

- ☐ 4.3.8 Demonstrate correct OEM inspection of HVAC system and auxiliary heat system, if applicable.
- ☐ 4.3.9 Demonstrate correct OEM inspection of fire suppression system, if applicable.
- ☐ 4.3.10 Demonstrate ability to isolate failures within the LV electrical harness(es).
- ☐ 4.3.11 Demonstrate ability to isolate failures within the HV electrical harness(es).
- ☐ 4.3.12 Demonstrate correct service procedures for checking and maintaining ESB coolants.
- ☐ 4.3.13 Demonstrate inspection procedures for telemetry hardware and determine if any failure codes are present.

4.4 System controls

- ☐ 4.4.1 Describe voltage-sensing stages, including voltage comparators and regulators.
- ☐ 4.4.2 Describe digital and analog data signals.
- ☐ 4.4.3 Describe voltage regulator circuits.
- ☐ 4.4.4 Explain motor power control strategies through software algorithms.
- ☐ 4.4.5 Explain the wiring harness function.
- ☐ 4.4.6 Explain how LV and HV components work together to power the vehicle and communicate signals.

4.5 Fault detection and troubleshooting

- ☐ 4.5.1 Describe and demonstrate the diagnostic process.
- ☐ 4.5.2 Demonstrate the ability to analyze a fault and trace data.
- ☐ 4.5.3 Demonstrate the ability to perform a root cause analysis for a fault.
- ☐ 4.5.4 Justify a solution to a root cause analysis and defend reasoning with evidence from findings.
- ☐ 4.5.5 Demonstrate understanding of the causes and effects from shorts, grounds, opens, and resistance issues in electrical circuits.
- ☐ 4.5.6 Explain how to diagnose issues with the HVIL circuit.
- ☐ 4.5.7 Demonstrate the ability to diagnose and troubleshoot control system faults.
- ☐ 4.5.8 Name two HV system faults that can be caught by isolation detection.
- ☐ 4.5.9 Demonstrate the ability to interpret OEM schematics and guidelines when determining control system faults.
- ☐ 4.5.10 Describe isolation fault circuits in terms of resistors or operational amplifiers.
- ☐ 4.5.11 Demonstrate the ability to troubleshoot traction motor faults.
- ☐ 4.5.12 Diagnose problems caused by damaged or failed harnesses, connectors, and terminals.
- ☐ 4.5.13 Demonstrate the ability to test, diagnose, and repair HV leaks, loss of isolation, and parasitic voltage draw.
- ☐ 4.5.14 Demonstrate the ability to troubleshoot power inverter and power electronic faults.
- ☐ 4.5.15 Demonstrate the ability to follow OEM guidelines for troubleshooting ESS faults.
- ☐ 4.5.16 Demonstrate the ability to identify ESS thermal management system faults and troubleshooting steps.

4.6 Charging and power

- ☐ 4.6.1 Demonstrate the ability to inspect and maintain bus-side charging components and interfaces.
- ☐ 4.6.2 Demonstrate the ability to inspect and maintain HV cables and bus bar components.
- ☐ 4.6.3 Demonstrate the ability to troubleshoot faults and replace damaged components.
- ☐ 4.6.4 Demonstrate the ability to differentiate charger versus bus-related faults and to repair/troubleshoot as necessary.

Abbreviations and acronyms

AC	alternating current
APTA	American Public Transportation Association
ASE	National Institute for Automotive Service Excellence
BMS	battery management system
CAN	controller area network
CAT	PPE category rating
CCS	Combined Charging System
CPR	cardiopulmonary resuscitation
DC	direct current
DCFC	direct-current fast charger
DMM	digital multimeter
DOD	depth of discharge
ESB	electric school bus
ESS	energy storage system
ETA	Electronics Technicians Association International
EV	electric vehicle
EVSE	electric vehicle supply equipment
EVSC	Electric Vehicle Standards Council
HV	high voltage
HVAC	heating, ventilation, and air-conditioning
HVIL	high-voltage interlock loop
HVJB	high-voltage junction box
IP	ingress protection
kW	kilowatt
kWh	kilowatt-hour
LDL	live-dead-live test
LFP	lithium iron phosphate
LOTO	lockout/tagout
LV	low voltage
MCS	Megawatt Charging Standard
MSD	manual service disconnect
MUX	multiplexing
NACS	North American Charging Standard
NFPA	National Fire Protection Association
NMC	nickel manganese cobalt
OBCM	onboard charger module
OBDII	On-Board Diagnostic II
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
SAE	Society of Automotive Engineers
SOC	state of charge
TUV	Technical Inspection Association
UL	Underwriter Laboratories
V2G	vehicle-to-grid
V2X	vehicle-to-everything
WRI	World Resources Institute