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Guidebook for Deploying Battery Electric Buses

PREPARED BY

Center for Urban Transportation Research

AUGUST 2023

U.S. Department of Transportation
Federal Transit Administration

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Guidebook for Deploying Battery Electric Buses

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PREPARED BY
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Metric Conversion Table

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
VOLUME				
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
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT
As part of FTA's effort to promote continuous safety and operational improvements in the public transit industry, *Guidebook for Deploying Battery Electric Buses* was developed to provide bus transit agencies with leading transit industry practices for performing these activities. The supporting research report, *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices*, is a resource for the industry that offers a summary of industry reports highlighting the challenges and opportunities with battery electric bus (BEB) deployments and the outcomes of federally sponsored deployments, existing standards from the American Public Transportation Association (APTA) and the Society of Automotive Engineers (SAE), as examples, and lessons learned through case studies. It also includes a series of findings associated with BEB and charging station procurements, system efficiency and interoperability considerations, and maintenance standards and guidelines. Additionally, the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* supporting research was conducted to give bus transit agencies helpful information on the requirements of a Safety and Security Certification (SSC) program to verify the unique identified risks that will be introduced to a transit agency as a result of initiating a BEB fleet transition. The findings are useful to transit agencies as tools to identify likely challenges that should be considered before embarking on the transition to bus fleet electrification, such as specific language to include in procurements to reduce challenges associated with part availability, and battery warranty ambiguity.

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Abstract

As part of FTA's effort to promote continuous safety and operational improvements in the public transit industry, *Guidebook for Deploying Battery Electric Buses* was developed to provide bus transit agencies with leading transit industry practices for performing these activities. The supporting research report, *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices*, is as a resource for the industry that offers a summary of industry reports highlighting the challenges and opportunities with battery electric bus (BEB) deployments and the outcomes of federally sponsored deployments, existing standards from the American Public Transportation Association (APTA) and the Society of Automotive Engineers (SAE), as examples, and lessons learned through case studies. It also includes a series of findings associated with BEB and charging station procurements, system efficiency and interoperability considerations, and maintenance standards and guidelines. Additionally, the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* supporting research was conducted to give bus transit agencies helpful information on the requirements of a Safety and Security Certification (SSC) program to verify the unique identified risks that will be introduced to a transit agency as a result of initiating a BEB fleet transition. The findings are useful to transit agencies as tools to identify likely challenges that should be considered before embarking on the transition to bus fleet electrification, such as specific language to include in procurements to reduce challenges associated with part availability, and battery warranty ambiguity.

Executive Summary

Purpose

As part of FTA's effort to promote continuous safety and operational improvements in the public transit industry, this guidebook was developed to provide bus transit agencies with leading transit industry practices for deploying battery electric buses. The supporting research report, *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices*, is an industry resource that offers a summary of industry reports highlighting the challenges and opportunities encountered during battery electric bus (BEB) deployments. It also discusses the outcomes of federally sponsored deployments, existing standards from the American Public Transportation Association (APTA) and the Society of Automotive Engineers (SAE), and lessons learned through case studies. Also included are findings associated with BEB and charging station procurements, system efficiency and interoperability considerations, and maintenance standards and guidelines.

Additionally, the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* supporting research was conducted to give bus transit agencies helpful information on the requirements of a Safety and Security Certification (SSC) program to verify the unique identified risks that will be introduced to a transit agency as a result of initiating a BEB fleet transition. With FTA's adoption of the Safety Management System (SMS) framework,[1] shifting from a reactive to a proactive approach, change management programs such as SSC are critical to ensuring risk is identified and mitigated proactively.

This guidebook will assist transit agencies in identifying likely challenges that should be considered before transitioning bus fleets to electrification, such as specific language to include in procurements to reduce challenges associated with part availability, and battery warranty ambiguity. When considered together, the findings provide a compilation of best practices in terms of procurement language, training, interoperability, resiliency, and change and safety risk management approaches.

Methodology

With an understanding that agencies need specific guidance that is succinct yet detailed enough to be valuable, the main findings were extracted from the *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices* and *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* reports to develop the *Guidebook for Deploying Battery Electric Buses*. Additionally, Appendix A contains "Recommended Expanded Request for Proposal (RFP) Language for Providing Training for Zero-Emission Buses"

[1] https://www.transit.dot.gov/regulations-and-guidance/safety/office-system-safety

from the International Transportation Learning Center's final report *Providing Training for Zero Emission Buses: Recommended Expanded RFP Language.*

Conclusions and Findings

Guidebook for Deploying Battery Electric Buses was developed to support transit agencies as they implement BEB deployments through an integrated Safety Management System (SMS) process. The guidance and findings presented in this document are not intended to be prescriptive. All transit agencies should develop procurement, maintenance, and comprehensive SSC programs tailored to their unique operating environments and characteristics. The combined findings from peer agencies provides insight to allow transit agencies to learn from others and avoid similar difficulties or prepare for the challenges ahead.

Safety and Security Certification is a risk-based process paralleling the project's life cycle and schedule. While the process is often misunderstood, SSC acts in the best interest of the bus agency to ensure all hazards and vulnerabilities are appropriately mitigated, and any calculated risk is reduced to the lowest practical level. As such, the evolving dynamics of the battery electric market demand that agencies implement a robust verification process through SSC to identify and mitigate BEB-specific hazards. While most BEB components are similar to conventional fuel alternatives, new considerations must be made that may not have been incorporated into existing or past BEB and associated infrastructure procurement processes.

Managing the recognized gaps in the Safety Risk Management processes of SSC requires agencies to employ several operational strategies to mitigate unwanted risks. For example, the current code does not specify specific BEB fleet fire protection requirements. More specifically, nationally recognized codes such as the National Fire Protection Association (NFPA) and International Fire Code (IFC) do not provide the direct language typically used to prescriptively design Fire Life Safety (FLS) systems that would adequately mitigate unacceptable hazardous conditions. This results in inconsequential conditions in past design and installation phases of the procurement's life cycle.

In preparing this guidebook, the literature reviews, surveys, data analysis, and reports led to many valuable findings and identified challenges that agencies should consider when transitioning their fleet to BEBs. This guidance will be most beneficial to agencies considering or planning their next BEB procurement in the near future. The literature review revealed common themes that occurred throughout various agencies during BEB procurement. The recommended practice themes include:

- SSC
- Procurement
- Coordinating with utility providers
- Necessary facilities considerations
- Charging infrastructure
- Parts and batteries
- Training
- Operations

Section 1

Required Elements and Resources for BEBs

An examination of existing standards, recommended practices, and guidance documents associated with the procurement or maintenance of battery electric buses and charging systems revealed certain requirements for BEB testing and purchasing when utilizing FTA funding. In addition, there are many resources available to support transit agencies implementing a BEB program.

FTA Bus Test Reports – Altoona Testing

All buses must pass FTA Bus Testing in accordance with Section 317 of the Surface Transportation and Uniform Relocation Assistance Act of 1987 (STURAA). The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) amended section 317 of STURRA by explicitly adding alternative fuel buses to those required to be tested, and adding braking performance and emissions to the set of tests to be performed at the bus testing facility.[2] The Altoona Bus Testing Center has had facilities in place for testing and repairing vehicles that use battery-power electricity since 1997.[3] The energy economy test that is performed on battery electric buses at Altoona provides accurate comparable energy consumption data on battery electric transit buses produced by different manufacturers. The test measures the energy consumed by a

Source: AdobeStock_421570091

[2] https://www.transit.dot.gov/research-innovation/program-history
[3] https://www.altoonabustest.psu.edu/

vehicle as it is operated on a chassis dynamometer over three driving cycles representative of typical transit operation.[4]

Low and No-Emission Component Assessment Program (LoNo-CAP)

FTA offers competitive funds to support the introduction of low- and no-emission transit buses into transit system fleets through voluntary component assessments to document the maintainability, reliability, performance, structural integrity, efficiency, and noise of the tested components.[5]

APTA Standards Guidelines, Reports, and Resources

Standard Bus Procurement Guidelines – APTA BTS-BPG-GL-001-13 (Rev.2.2)

In August 2022, the APTA *Standard Bus Procurement Guidelines*[6] were updated to include a battery electric bus option that uses depot-based charging and/or on-route charging. The guidelines provided in this document are designed to assist agencies through the decision-making process of battery electric bus procurement, noting that there is not a one-size-fits-all model, particularly as this technology continues to evolve. The BEB related sections in the Technical Specifications are highlighted below, while the full *Standard Bus Procurement Guidelines* are available online.

- *TS Section 5.10 Fire Suppression*. No fire suppression system is needed for battery electric buses.
- *TS Section 5.11 Respect for the Environment*. The contractor should provide a plan for reuse or recycling of replaced battery cells, modules, and/or physical packs.
- *TS 7.3.1 Acceleration (Hybrid or Battery Electric Coach)*. Braking application and performance should be consistent and the performance may be reduced at extreme state of charge (SoC) or temperatures. However, any reductions should be smooth and predicable. Additionally, the system should be programmable to allow optimization of acceleration and deceleration rates. Manufacturers should supply performance data.
- *TS Section 8.1.5 Altoona Fuel Economy Tests (Battery Electric)*. The Altoona Energy Economy and Range Test is conducted to determine if the operating range between charging passes or fails in comparison to the minimum

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[4] https://www.altoonabustest.psu.edu/bus-tests/Fuel-Economy.aspx
[5] https://www.transit.dot.gov/research-innovation/lonocap
[6] https://www.apta.com/wp-content/uploads/APTA-BTS-BPG-GL-001-13_R2_1.docx

defined range. The agency should define minimum operating range and time between charges as the default recommended practice, and the OEM (original equipment manufacturer) provided solution in terms of range and time between charges as alternative.

- *Section TS 8.2. Agency Operating Profile (Battery Electric Bus)*. In addition to the Altoona defined tests, the bus must also meet the agency operating profile. The proposer must validate the proposed bus will meet the agency operating profile, under maximum loads at a GVWR (gross vehicle weight rating), using sound mathematical modeling and simulation or empirical methods. Proposers should also demonstrate the agreement of their mathematical models against Altoona results.
    - It is assumed that buses will start at maximum SoC and will not deplete below minimum standard SoC during operations. Minimum standard SoC will allow for reserve battery capacity that the bus can draw upon to reach the closest charging point.
    - Normal conditions are defined as an ambient temperature of 68˚F and a SLW (safe working load) bus weight. Worst case conditions are based on agency defined ambient temperatures (based on NOAA.com or weather.gov) and a bus weight of GVWR.
    - The agency should define the operating profile characteristics for each route inclusive of:
        - Average nominal route speed in mph
        - Average worst case route speed in mph
        - Average miles between stops
        - Maximum required trip duration
        - Average required trip duration
        - Distance from depot to start of route
        - Longest distance from depot
        - Average miles per day
        - Longest miles per day
        - Minimum layover time for charging during the day
        - Average layover time for charging during the day
        - Available depot charge time in hours
        - Minimum depot charge time required for full charge in hours
        - Maximum number of buses required to operate daily

When developing the RFP document, agencies should require responding contractors to provide the following narratives with their technical proposals:

- Narrative of methods used to validate the performance meets agency operating profile worst-case conditions in terms of expected range, fuel economy, and auxiliary loads.
- Projected performance on agency profile when the battery reaches end of life, including expectations of battery life, end of life battery capacity, and end of life bus range.

  - Description of recommended and required charge strategies, on-route charging requirements, bus blocking requirements, or other bus operational requirements necessary to meet the agency operating profile.
  - Description of the flexibility to place the proposed bus and its charging solution on any agency route.
- *Section TS 9.3.2 Propulsion System Description (All Electric)*. The electric propulsion system of the electric bus should conform to SAE J2910 and SAE J2344 to the greatest extent practical. The propulsion system should not be supplemented by any onboard range extender such as internal combustion engines, gas turbines, and/or hydrogen fuel cells. The OEM should ensure the suitability of the bus structure for the electric propulsion to be operated safely within the design profile for the service life of the bus without structural failure. High-voltage devices should be labeled in such a way that the labels are visible when access doors are open or closed to protect both emergency and maintenance personnel.
  - The proposal should include a detailed description of the propulsion system, including a written narrative, block diagram, layout illustration including wiring, and detailed electrical schematic for the high-voltage system. The proposer should provide a list of the applicable industry standards.
- *Section TS 9.3.5 Energy Storage System*. The energy storage system (ESS) should be designed for commercial use and be capable of operating in the transit environment. The ESS should be proven safe and designed/sized to ensure performance and compatibility with charging and other related requirements. The ESS should comply with ECE R100 Revision 2, UN/DOT 38.3, and/or SAE J2464 requirements for lithium batteries. For non-lithium batteries, the ESS should comply with similar applicable standards.

  When developing the RFP document, agencies should require responding contractors deliver the bus with a tested, installed, and functioning ESS charged with sufficient usable energy to be delivered and maneuvered around the agency's property. The design of the ESS and the components should be described in the proposal, along with maintenance and periodic charge requirements for cell balancing. The proposal should also include warranty terms, battery life and associated factors, and a cost cycle analysis. Additional details about recommended ESS capacity, safety, battery containers, battery management systems, battery thermal management, and battery charging are included in the complete linked *Standard Bus Procurement Guidelines*.[7]

[7] https://www.apta.com/research-technical-resources/standards/procurement/apta-bts bpg-gl-001-13/

- *Section TS 19.1 Emissions (All-Electric)*. The bus should not have any EPA-regulated exhaust emissions except as noted in TS 55.1, "Auxiliary Heater."
- *Section TS 42. General Electrical Requirements*.

Preparing to Plug In Your Bus Fleet

Designed as a guide for working with local electric companies, the 2019 APTA report *Preparing to Plug In Your Bus Fleet: 10 Things to Consider*[8] provides 10 key considerations for transit agencies that are looking to electrify their bus fleets, shown in Figure 1-1.

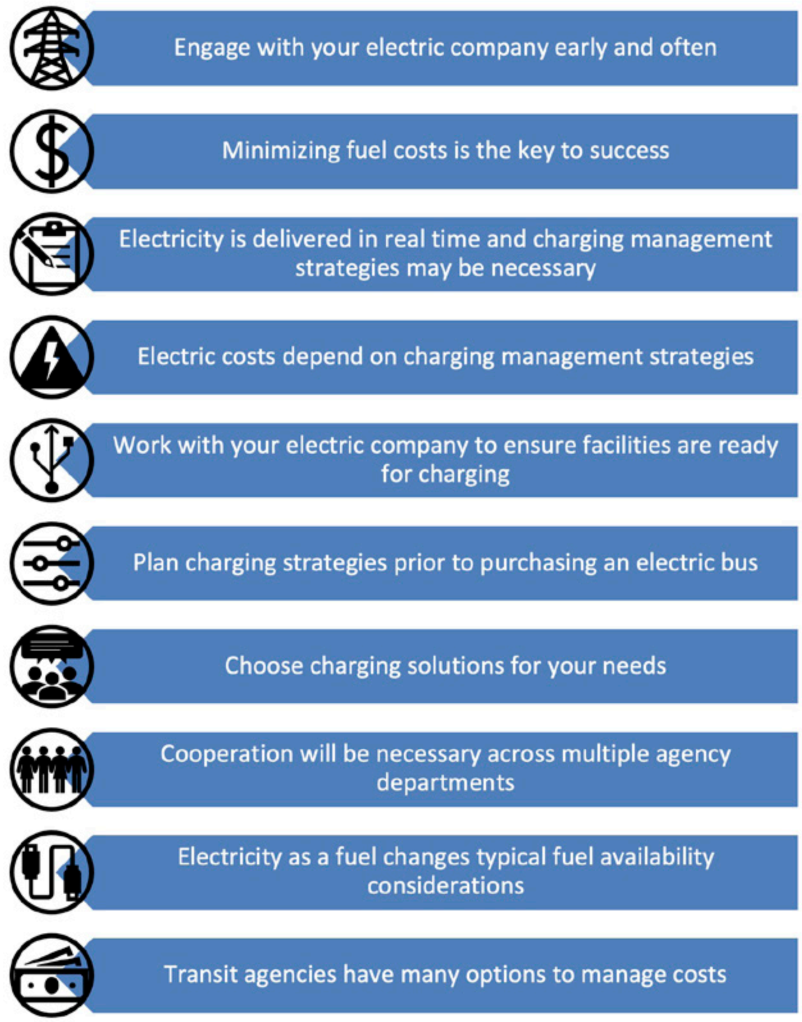

Figure 1-1 *Key considerations for fleet electrification*

[8] https://www.apta.com/wp-content/uploads/PreparingToPlugInYourBusFleet_FINAL_2019.pdf

The appendix of the APTA guide includes a service evaluation template to help transit agencies that are embarking on a fleet electrification project and are ready to begin evaluating their electricity needs. It contains basic questions related to location information, vehicle and operating profiles, and charging infrastructure. Additional questions in the template ask if agencies are considering connecting vehicles to existing building electrical service or dedicating a separate electrical service to vehicle charging, and if they are planning or interested in integrating on-site electricity generation.

Society of Automotive Engineers (SAE) International Recommended Practice

SAE Recommended Practice J-3105 Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices[9]

This recommended practice was published in 2020 to promote the safe testing and performance of mechanized conductive power transfer systems. SAE J-3105 was written for buses and heavy-duty vehicles, encompassing the general physical, electrical, functional, testing, and performance requirements for conductive power transfer for vehicles using an automated-charging device connection to transfer DC power.

In addition to Recommended Practice J-3105, there are three supplemental Recommended Practices that address requirements for a specific interface defined in the supporting document. All three use the common requirements outlined in SAE Recommended Practice J-3105.

SAE J-3105-1: Infrastructure-Mounted Cross Rail Connection – covers the relevant interface requirements for an electric vehicle power transfer system using a cross-rail design.

SAE J-3105-2: Vehicle-Mounted Pantograph Connection – covers the relevant interface requirements for an electric vehicle power transfer system using a conventional rail vehicle pantograph design.

SAE J-3105-3: Enclosed Pin and Socket Connection – covers the relevant interface requirements for an electric vehicle power transfer system using an enclosed pin and socket design.

[9] https://www.sae.org/news/2020/02/sae-j3105-promotes-safe-charging-for-buses-and-heavy-duty-vehicles

Best Practices for Implementing Battery Electric Buses into Your Fleet (2019)[10]

This APTA Emerging Leaders presentation provides best practices for agencies considering adoption of BEBs. Below is a summary of the best practices identified by practitioners in the report.

- Identify clear performance indicators to assess implementation and operation of BEBs.
- Understand where there is available funding (federal, state, and local levels) and the associated requirements of the funding.
- Know the needed infrastructure and limitations of that infrastructure.
- A pilot program may help to understand and test operational demands and procedures.
- Plan for scalability.
- Engagement with partners—including boards, public officials, and utilities—is key before, during, and after BEB integration.
- Communicate regularly with other transit agencies and share lessons learned.
- Establish relationships with BEB OEMs.
- Demand management can reduce electricity costs and ensure that the plan for charging optimizes utility pricing.
- Plan ahead for facility expansions and upgrades to accommodate BEB and charging infrastructure.
- To extend BEB range, utilize opportunistic charging.
- When analyzing BEB routes, ensure compatibility with optimal range and performance criteria.
- Ensure that the BEB and charging infrastructure procurement strategy considers service demands and schedules.
- Determine how BEBs will integrate with the agency's fleet management planning.
- Plan for maintenance. BEBs need a higher storage capacity at maintenance bays due to range and charging restrictions.
- Institute training programs for maintenance staff, operators, and emergency responders.
- Develop programs that track efficient driving behaviors to maximize BEB efficiency.

[10] https://www.apta.com/wp-content/uploads/Group-5_Implementing-BEB.pdf

Resiliency for Battery Electric Buses: Best Practices & Future Strategies[11]

When planning to integrate BEBs into a fleet, agencies should consider the resiliency of electricity as a primary fuel source. While grid resiliency continues to improve through advancements in energy storage technologies and efficiency improvements, planning resiliency strategies for ensuring continuity of power availability continues to be necessary with the integration of BEBs. Key considerations for BEB resiliency included in this APTA Emerging Leaders presentation are:

- Plug-in depot charging can provide 40–125 kW of power, and charge time may vary between one and eight hours. Depot charging requires less upfront investment, incurs lower electricity chargers, and is less impactful to operations should a charger go down, if there are chargers available at the depot.
- On-route fast charging delivers higher power (125–500 kW) with reduced charge time (5–20 minutes per charge). On-route fast charging allows buses to run on longer routes, requires smaller onboard battery packs, and reduces the number of total chargers required to support a fleet compared to depot plug-in charging.
- Diversifying the fleet by incorporating backup diesel and/or CNG buses provides contingency in the event of power outage and operation disruption of the BEBs.
- Ensure backup power sources are available at facilities, including diesel or CNG-powered generators.
- Work with utilities to set up multiple connections to the grid so bus chargers may have access to power if only part of the grid is compromised.
- Some agencies are implementing on-site battery storage/microgrid projects to lower demand charges and provide backup power in the event of a power outage.

Source: AdobeStock_299838788

[11] https://www.apta.com/wp-content/uploads/ELP-Presentation-Electric-Bus-Resiliency.pdf

Summary

An examination of existing standards, recommended practices, and guidance documents associated with the procurement or maintenance of battery electric buses and charging systems revealed certain requirements for BEB testing and purchasing when utilizing FTA funding. The energy economy test that is performed on battery electric buses at Altoona provides accurate comparable energy consumption data on battery electric transit buses produced by different manufacturers, while the APTA *Standard Bus Procurement Guidelines* have been updated to include many BEB considerations, such as fire suppression, respect for the environment, acceleration, Altoona fuel economy tests, agency operating profile, the propulsion system, the energy storage system, emissions, and general electric requirements.

Beyond the Altoona requirements and the recommended procurement language, APTA has produced many other resources that offer valuable considerations and lessons learned for transit agencies as they embark on their fleet electrification transition. Resiliency is a key theme throughout the BEB research, specifically focused on the need for agencies to consider the resiliency of electricity as a primary fuel source.

Altoona – All buses must pass FTA bus testing.

LoNo-CAP Testing – Voluntary component testing is available through competitive funding from FTA.

APTA Standard Bus Procurement Guidelines – Refer to BEB specific sections added in 2022.

Engage with Utility Company – Collaborate in the planning phase and ensure multiple grid connections.

Communicate – Internal, amongst transit agencies, and all stakeholders.

Performance Indicators – Identify and track clear performance indicators to assess implementation and operation of BEBs.

Charging Management – Minimize costs, time management / demand management, availability of charging infrastructure.

Charging Options – Depot charging may be augmented with on-route charging.

Pilot Programs – Pilot programs identify operational demands and potential challenges.

Plan to Scale – Plan for scalability in the future.

Compatibility – Ensure compatibility with all charging infrastructure and compatibility of routes with operating abilities of BEB.

Interoperability – Ensure interoperability with all current technologies on the bus.

Training – Institute training programs for maintenance, operators, and emergency responders.

Diversification – Incorporating backup diesel and/or CNG buses provides contingency in emergency power outage situations.

Section 2

Guidelines for Procuring Battery Electric Buses and Charging Systems

Recommended Practices and Considerations

The overall benefits of this report focus on key challenges agencies should expect as they initiate their transition to battery electric bus fleets. This guidance will be most beneficial to agencies that are planning their next BEB procurement. The literature review revealed common themes that occurred through various agencies during BEB procurement. The recommended practice themes include planning, training, cost, space, charger efficiency and interoperability, and challenges accessing parts. Additionally, there were other lessons learned related to procurement, coordinating with utility providers, necessary facilities considerations and/or modifications, charging infrastructure, parts and batteries, training, and operations.

Planning

When considering BEB procurement, it is important to start planning early and engage with stakeholders from the initial discussions. This inclusion and communication among stakeholders will help identify expected challenges and create a working relationship to assist in tackling the unexpected challenges that arise. Planning should also consider backup power sources so that agencies are not parked during emergencies with no way of powering their fleet. Additionally, planning for operations and route modeling must accommodate

Source: AdobeStock_134175578

charging layovers on-route or performance limitations of a BEB, thus it is important that operations, planning, dispatch, and route modelers are aware of the operating characteristics and differences from traditional diesel buses. As bus battery efficiency depends on driving characteristics, operators should not feel rushed so that they are not tempted to accelerate abruptly, which can reduce the expected efficiency and therefore range of the BEB.

Training

In addition to the operations supervisors, planners, dispatchers and route modelers, the operators and technicians will require safety training at the very least. It is a best practice to incorporate operator training that focuses on efficiency and expectations, specifically any differences the BEB may have. Operators should also be trained on how to communicate charge challenges with dispatchers. Operators, technicians, and first responders must be trained on how to respond in case of a battery fire. Technicians should also be trained to understand the dangers and the differences that they will encounter when maintaining a BEB. In addition, technician training would benefit from including ways in which technicians can test their safety equipment prior to each use. This will help to reduce unintentional hazards and increase maintenance technicians' confidence. Understanding that people learn at different speeds, it may be necessary to expand some technician training to ensure all are trained to confidence. The training will lead to a more qualified workforce, so it is important to continue focusing efforts on workforce development.

Cost

There are many cost considerations involved when transitioning to BEB fleets beyond the initial procurement cost, including but not limited to additional training, post-warranty maintenance, and demand/electricity charge costs. The literature review identified a variation from early reported costs to long-term post-warranty maintenance costs. It is also important to determine optimal charging to reduce demand charges. Demand charges and time of use charges can increase electricity costs, leading back to the importance of adequate training to ensure the BEBs operate as efficiently as expected. There are variable charging costs that change dependent upon demand, time, use levels, and difficulties negotiating reasonable rates with utility providers.

Space

In addition to cost considerations, many transit agencies struggle with finding adequate space within their existing facilities to charge and maintain BEBs. There are also space challenges associated with on-route chargers, which may lead to unintended additional costs or accommodations. Specialized tools are required to work on BEBs, which require space. Many agencies retrofit their depots to accommodate the maintenance of their BEB fleet; for instance, to allow for work on the top of the bus, agencies may have to install lifts or elevated work areas.

Charger Efficiency and Interoperability

Agencies may find the need to scale up charging to meet increased demand and it will be necessary to ensure adequate charging levels are maintained. Some agencies require an on-route charging system to operate the bus for an entire shift. Moreover, as fleets expand and agencies choose more than one vendor to procure BEBs from, agencies need to ensure the chargers are interoperable to avoid exacerbating space limitations by the challenges associated with charger placement in the depot. Charger interoperability will also greatly reduce the complexity of any charging optimization efforts that are initiated to control costs.

Parts Availability

While the pandemic intensified the challenges of part availability, this was occurring long before the pandemic was in the United States, meaning the challenges of obtaining needed BEB parts are not newfound. The literature review and subsequent interviews revealed that many agencies waited several months to receive necessary parts, leaving their BEB fleet, or portions of it, inoperable. This is a significant cost to have buses taking up space and aging while unable to be in revenue service. These challenges are substantial, and thus agencies may benefit from including part availability language in their procurement language.

Procurement

If agencies can coordinate procurement efforts at a regional or statewide scale, the potential to benefit from economies of scale increases. Using consistent negotiated procurement language is beneficial as it reduces variation by agency, which can lead to improved cost estimations. Furthermore, pooled funding opportunities may lead to leveraging the economies of scale.

Procurement language has a significant impact on BEB implementation. Agencies recommend incorporating additional tooling, personal protective equipment, and training in procurement language. Third-party analytics should be installed on BEBs and their charging infrastructure to ensure understanding and identify potential issues before a thermal event or other undesired outcome occurs.

Utility Providers

Transit agencies may have limited negotiating strength with utility providers. When negotiating agreements with utility providers, variations in utility rates by time of day should be considered. Utility rate variability may lead to inconsistent charging costs and budget challenges.

Fuel diversification and backup power availability may be beneficial when power is unavailable for extended periods of time, such as during hurricanes events or other natural disasters. Transit agencies may want to consider partnering with utilities to expand grid connections and implement battery storage and microgrids. FTA's Bus Exportable Power Systems (BEPS) program[12] enables public transportation agencies, communities, and states to access resilient and flexible power options through hybrid electric bus fleet vehicles during major power disruptions. The eligible activities of the BEPS program include all efforts leading to the development of interoperable BEPS standards. Transit agencies may also benefit from state backup power plans to assist locally when needed or from working with relevant state agencies to determine access to backup power.

Facilities

Whether planning for an agency's first BEB procurement or a BEB fleet expansion, facilities require charging infrastructure installation, lifts that are rated for the weight of a BEB, fire suppression systems, and storage space for batteries and spare parts, all of which accumulate space. BEBs that have roof-mounted equipment also need personnel lifts to accommodate top-of-bus maintenance and additional fall protection.

Furthermore, interoperability challenges exacerbate space limitations for charging infrastructure. As agencies begin to mix fleets though subsequent procurements, the need for interoperability regardless of the make/manufacturer of the vehicle or charging system will become more pronounced, thus it may be beneficial to address interoperability in procurement documents. It is not only important that various mixes of fleets can operate harmoniously, but it is also important to consider any interoperability challenges that may arise due to new generations of technology. With the increasing speed of technology maturity, there are incentives to investing in upgraded technologies. However, the interoperability of the older generations of the technology should remain supported throughout their life cycles.

Charging Infrastructure

Transit agencies do not have to own and maintain charging infrastructure for BEB equipment. Agencies should compare the costs of leasing agreements with charging equipment vendors and utility companies versus owning and maintaining this infrastructure.

Transit agencies may want to consider purchasing higher power ultra-fast charging systems if the systems can be supported by the local utility provider.

[12] https://www.transit.dot.gov/funding/grants/BEPS#:~:text=FTA's%20Bus%20Exportable%20Power%20Systems,vehicles%20during%20major%20power%20disruptions

These systems have entered the market with the promise of reducing dwell time for charging, which may allow BEBs to serve longer routes. Additionally, using smart charging, managed charging, or other charging optimization techniques may lead to greater cost savings, especially as a BEB fleet size increases.

Parts and Batteries

Transit agencies may want to include OEM parts availability expectations in contract negotiations or procurement language. This will increase the likelihood that required parts will be available when needed and will reduce vehicle out-of-service time.

To reduce the likelihood of battery warranty ambiguity, clear language in the warranty should dictate whether the warranty applies to the battery system versus individual battery packs, cells, and/or battery management systems within the system.

It is beneficial to include battery storage, disposal, and/or recycling details in procurement language to reduce unexpected challenges associated with repurposing or disposal when the battery system or individual battery packs reach the end of their useful life.

Training Considerations

Operator training—beyond the general vendor-provided training—may improve operator performance and increase BEB efficiency. Technician training—beyond the general vendor-provided training—may improve the confidence of technicians who work on BEBs and reduce technician shortages. First responder training to provide familiarization of BEB designs may reduce unanticipated hazards and challenges when emergencies occur. Agencies should work with their local first responders to schedule and provide this training.

Operations

Depending upon fleet conversion goals, agencies may have to redesign routes and/or operating parameters to accommodate the BEB performance capabilities (or to accommodate on-route charging). Additionally, performance capabilities may vary with extreme weather, thus route design methodology may need to vary by season in some geographies.

Summary

There is great value in understanding the issues and successes of peer transit agencies, especially through a fleet electrification transition that introduces many unknown and unique operating characteristics and challenges. The guidance in this section is most beneficial to agencies that are planning their next BEB procurement. The recommended practice themes include planning, training, cost, space, charger efficiency and interoperability, and difficulties in accessing parts. Additionally, lessons learned in procurement, coordinating with utility providers, necessary facilities considerations and/or modifications, charging infrastructure, parts and batteries, training, and operations were presented. This section provides a brief overview of these considerations discussed in more detail in the report *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices*.

Planning – Engage with stakeholders initially, consider backup power, and identify expected challenges.

Training – Train operators, supervisors, planners, dispatchers, route modelers, technicians, and operators on hazards and fire mitigation at a minimum.

Cost – Beyond initial procurement, consider costs for training, post-warranty maintenance, and demand charging price variations.

Space – Space to charge BEBs, store additional tools, and allow for top-of-bus maintenance if necessary.

Charger Efficiency and Interoperability – On-route charging may become necessary as fleets transition, and interoperability will be critical to reduce complications of bus assignments.

Parts Availability – Parts availability remains challenging and was exacerbated by the pandemic.

Procurement – Potential benefits of economies of scale exist in regional or statewide procurement contracts. Procurement language impacts implementation.

Utility Providers – In utility negotiations, consider variations in utility rates by time of day. Fuel diversification may be beneficial.

Facilities – Facility upgrades may include charging space, lift requirements, fire suppression systems, and storage space for spare parts and batteries.

Charging Infrastructure – Consider costs of owning versus leasing charging infrastructure.

Parts and Batteries – Including OEM part availability in procurement language may reduce parts challenges. Warranty language should be unambiguous, and battery disposal should be considered at procurement.

Operations – Route redesigns may need to be accommodated.

Section 3

Guidelines for Safety and Security Certifications for BEBs and Charging Systems

Safety and Security Certification of Electric Bus Fleets – Industry Best Practices[13] presents guidelines that are designed to improve a bus transit agency's ability to recognize BEB fleets' unique hazards and vulnerabilities and associated infrastructure, which are summarized in this section. Agencies are still required to abide by all local and state codes affecting their certification process and any federal requirements set forth by the FTA or other regulators.

Figure 3-1 illustrates the regulatory framework affecting the safety and security verification of BEBs. Identified regulations were used to direct the many recommendations presented in this guidebook. However, agencies must be aware of other local and state requirements applicable to their procurement efforts.

Source: AdobeStock_363542837

[13] https://www.transit.dot.gov/research-innovation/fta-reports-and-publications

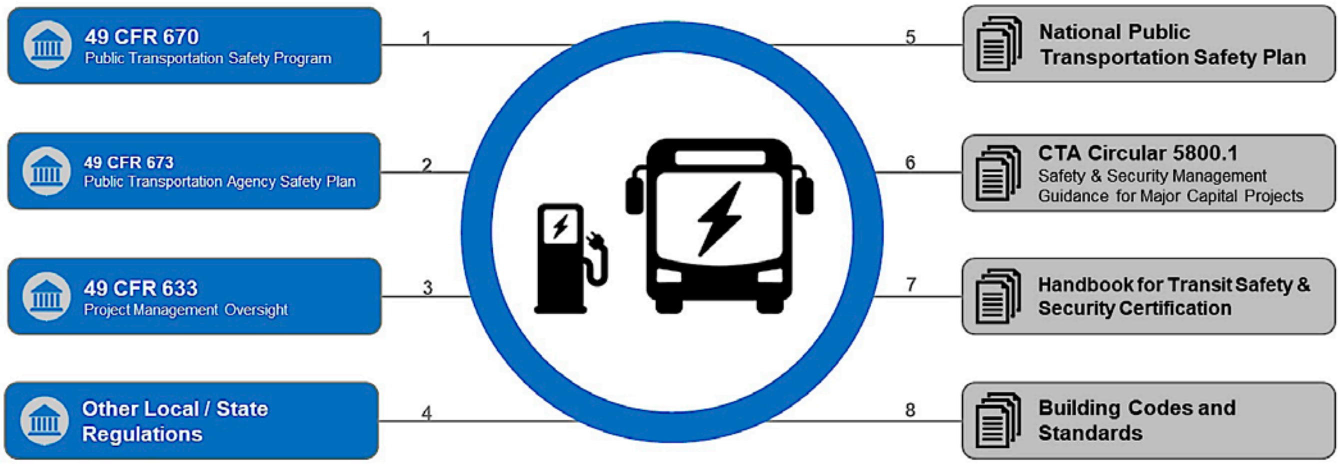

Figure 3-1 *Safety and security requirements for bus transit agencies*

Safety Risk Management

Safety Risk Management (SRM) is the careful examination of real or potential conditions that could cause harm if left uncontrolled. The process is also used in coordination with Safety Assurance (SA) to determine whether sufficient defenses have been implemented or if additional actions are required to prevent harm. Mainly used as a planning activity, SRM offers a perspective into the future to better understand how system interfaces may negatively impact safety performance. SRM supports more efficient resource allocation based on calculated safety risks when appropriately implemented.

SRM is a systematic process built on three subcomponents: hazard identification, risk assessment, and risk mitigation.

Hazard Identification

Agencies should consolidate hazards in one location for easier sorting and analysis to inform the BEB procurement process. Figure 3-2 lists possible sources for BEB hazard identification.

Figure 3-2 *Hazard identification sources*

Risk Assessment

Agencies may use tools like a safety risk matrix to facilitate risk-based prioritization. This approach combines assessed likelihood and severity into one visual, which can help decision-makers understand when actions are necessary to reduce or mitigate safety risks. These tables are most valuable when customized to an agency's unique operating realities and leadership guidance.

Risk Mitigation

Risk mitigation aims to reduce the assessed risk rating to a level acceptable to the agency. While the mitigation process may not eliminate the safety risk entirely, subject matter expert (SME) input emphasizing the mitigation will further reduce the hazard to the lowest practical level. Agencies may consider obtaining input from SMEs from different departments or outside of agencies to ensure that the selected safety risk mitigation is appropriate. Information from multiple sources can help prevent unintended secondary effects, creating new hazards because of the mitigation.

Safety risk mitigation can be accomplished using one or any combination of the following:

- Elimination
- Reducing the occurrence likelihood of the potential consequence(s) of the hazard
- Reducing the severity of the potential consequence(s) of the hazard

Safety Assurance

The Safety Assurance (SA) function helps ensure mitigations manage safety risks and work as intended. Agencies can use their SA processes in the BEB procurement process to ensure systematic actions are taken to assure that the system is delivering as planned and achieves an acceptable level of safety consistently.

Safety and Security Certification

The *Handbook for Transit Safety and Security Certification*[14] defines Safety and Security Certification (SSC) as “The series of processes that collectively verify the safety and security readiness of a project for public use.” Figure 3-3 shows the contents of the *Handbook for Transit Safety and Security Certification.*[15]

Figure 3-3 *Handbook for Transit Safety and Security Certification*

Source: AdobeStock_334231718

[14] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/SSC.pdf
[15] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/SSC.pdf

The Handbook for Transit Safety and Security Certification,[16] published in 2002, defines FTA's recognized SSC 10-step process.

Table 3-1 *FTA's Safety and Security Certification Process*

	Step	Critical SCC Outputs
Step 1	Identify Certifiable Elements	• Certifiable Elements List • Preliminary Hazard Analysis • Threat and Vulnerability Assessment • Certifiable Items List
Step 2	Develop Safety and Security Design Criteria	• None
Step 3	Develop and Complete Design Criteria Conformance Checklists	• Design Criteria Conformance Checklist (DCCC)
Step 4	Perform Construction Specification Conformance	• Construction/Installation Specification Conformance Checklist • Operational Hazard Analysis
Step 5	Identify Additional Safety and Security Test Requirements	• Testing Specification Conformance Checklist (TSCC)
Step 6	Perform Testing and Validation in Support of the SSC Program	• None
Step 7	Manage Integrated Tests for the SSC Program	• None
Step 8	Manage "Open Items" in the SSC Program	• Hazard Tracking Log
Step 9	Verify Operational Readiness	• Operational Readiness Conformance Checklist • Temporary Use Permits
Step 10	Conduct Final Determination of Project Readiness and Issue SSC	• Final Certificates • Safety and Security Certification Verification Report (SSCVR)

Step 1: Identify Certifiable Elements

The first step in the SSC methodology is to identify the elements that must be certified for the project. Safety and security certifiable elements include all elements that can affect the safety and security of transit agency passengers, employees, contractors, emergency responders, or the public. The *Handbook for Transit Safety and Security Certification* defines the elements that should be explicitly considered for BEB certification, as shown in Table 3-2.

[16] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/SSC.pdf

Certifiable elements are composed of numerous certifiable Items. These items comprise the whole of the major element and require individual safety and security verification before the major element is verified as safe and secure for use. Each item must be documented on a Certifiable Items List (CIL). As projects or programs evolve, the related certifiable elements may also change.

Table 3-2 *Certifiable Elements List*

Element	Sub-elements	Items
Charging System	• Chargers • Transformers	• Fail-Safe Design • Impact Protection • Training and Maintenance • Security Considerations • Codes and Standards • BEB and Facility Interfaces
BEB Vehicles	• Battery Modules • Electrical	• Fail-Safe Design • Codes and Standards • Facility and Charging Interfaces
Yards	• Parking/Charging Layout • Physical Security • Fire Life Safety • Drainage • Signage • Damaged Vehicles/Batteries	• Bus Separation Distance • Security Considerations • Fire Suppression • Slope Considerations • Applicable Signage • Isolation Area and Procedures
Facilities	• Parking/Charging Layout • Physical Security • Fire Life Safety • Signage	• Bus Separation Distance • Security Considerations • Fire Suppression • Applicable Signage • Charging Infrastructure Interfaces
Cybersecurity	• Network Security	• Firmware Updates
Communications	• Vehicle – Charger • Battery Management	• Vital Hazard Management
Testing/ Integration	• Charging • Electrical	• Interoperability • Commissioning Tests
Operational Readiness	• BEB Towing • Maintenance • Training • Staffing • Routes • Spare Parts • Public Outreach • First Responders • Emergency Exercise Program • Battery/Bus Disposal • Service Contracts	• Training • Procedures • Operators and Maintenance • Training and Certification • Recharging Considerations • Availability and Delivery Time • Fleet Safety Tips for the Public • Awareness of Unique Hazards • Exercise AARs • Procedures • Warranty and Maintenance

Step 2: Develop Safety and Security Design Criteria

The safety and security requirements of BEBs and their associated systems are addressed during the project design phase by identifying safety and security design criteria for each certifiable element. These criteria are intended to guide the design team in supporting the definition of systems, subsystems, and components, the development of performance requirements, and the final specifications for the system. It is a best practice to include the design criteria and the specifications in the procurement package. Safety and security design criteria can be generated from the following:

- Technical specifications from a previous project
- Existing agency design criteria
- Agency lessons learned
- Bus manufacturer's Failure Mode and Effects Analyses (FMEAs)
- BEB and charging system Operations and Maintenance manuals
- Preliminary/Operating Hazard Analyses (PHA/OHA) and Threat and Vulnerability Assessment (TVA)
- Industry best practices and reports
- Safety and security codes, standards, and regulations defined by federal, state, and local agency standards boards and organizations

Step 3: Develop and Complete Design Criteria Conformance Checklists

During the design of BEB systems, the transit agency should begin identifying criteria requirements for certifiable elements and items. This process involves creating a checklist, referred to as the Design Criteria Conformance Checklist (DCCC), for each certifiable element to record the requirements of the individual items incorporated from safety and security design criteria. In the certification process, contract specifications, design criteria, applicable codes, and industry standards may constitute design conformance for certification verification. For example, some contract specifications requirements may be used as verification, such as maintenance manuals, subsystem hazard analyses, and factory test reports.

While developing the DCCC, safety and security requirements should be identified to assist the project team in performing design reviews, inspections, and testing results. Additionally, during this step, the team will need to determine the process for resolving any "open items" that cannot be verified as compliant with the design requirements, specifications, or safety or security-specific items identified in the PHA and TVA.

Step 4: Perform Construction Specification Conformance

The installation specification conformance process verifies that the as-built facilities and systems incorporate the safety and security-related requirements identified in the specifications and other contract documents, including approved changes since the final design. A Construction/Installation Specification Conformance Checklist (CSCC) should be developed to assist agencies in verifying conformance to installation specifications for BEBs and their associated systems.

The CSCC should be viewed as a component of the DCCC, as it identifies the tests and verification methods necessary to ensure the as-built configuration contains the safety-related requirements in the applicable specifications and other contract documents. The checklist also provides documented verification that the delivered project meets these requirements of the certification process. Ultimately, the CSCC becomes the guiding document of the SSC process.

To further assure safety compliance for the system, an Operating Hazard Analysis (OHA) should be conducted to identify hazardous conditions that can occur during operation and maintenance due to human error. This analysis also provides protective recommendations.

As mentioned in Step 3, the management or resolution of most open items should be resolved upon completing the Construction Specification Conformance Checklist. Safety and security requirements that have not been verified by available documentation or demonstration should continue to be tracked to resolution.

Step 5: Identify Additional Safety and Security Test Requirements

Contractor and integrated testing requirements should be reviewed for safety and security considerations. Like the DCCC and CSCC, these requirements should be documented on a Testing Specification Conformance Checklist (TSCC). Figure 3-4 shows the two types of tests to consider.

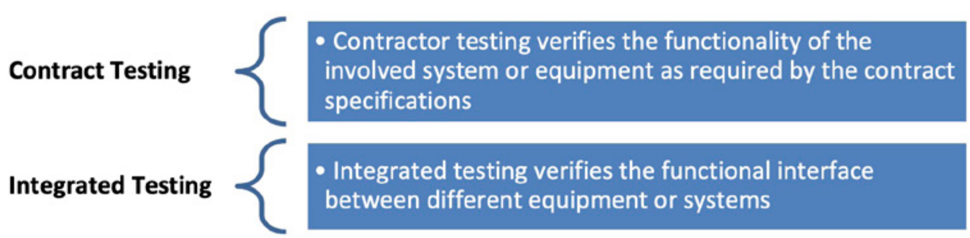

Figure 3-4 *Contractor and integrated testing*

Each component of a BEB system (i.e., vehicles, charging equipment, facilities, etc.) should be tested individually while ensuring that subcomponents interface as expected. Both contractor and integrated testing are subject to certification. As previously mentioned, certification of contractor testing may be verified in the TSCC or combined with integrated testing in a test program certification or by other acceptable means.

Step 6: Perform Testing and Validation in Support of the SSC Program

From the initial stages of the construction development phase, test reports and other documentation will be submitted to the agency to record the results shown in Figure 3-5.

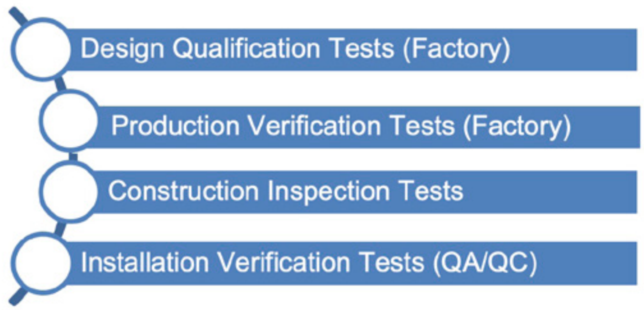

Figure 3-5 *Tests performed to support safety and security certification*

Safety and security-related test results should be documented, as appropriate, in the TSCC.

Step 7: Manage Integrated Tests for the SSC Program

Integrated tests are any tests or series of tests that require the interface of more than one element and are designed to verify the integration and compatibility between system elements. Pre-operations tests require acceptance of all systems and are intended to demonstrate the functional capability and readiness of the system. These tests are not necessarily required by contract specifications but are required as part of the test program plan to ensure that all systems function safely before being placed into operation. Test result reports form the basis for meeting the safety requirements.

Step 8: Manage "Open Items" in the SSC Program

As the certification proceeds, open items will be identified and managed according to the process developed during Step 3. During pre-revenue testing and start-up activities, requests for risk-reduction alternatives and temporary occupancy permits or notices will be made. The SSC program must have the tools available to ensure that the safety and security designed into the system are realized in the delivered, tested, and validated project.

All open hazards or vulnerabilities separate from the PHA, TVA, or OHA can be tracked using a Hazard Tracking Log.

Step 9: Verify Operational Readiness

During the pre-operations phase, procedures and plans are tested for effectiveness under simulated operating conditions for normal, abnormal, and emergencies. Verifying these activities often includes signatures by the appropriate officials or employees on all procedures, rulebooks, and training necessary to support the operation and maintenance of the system. All operating and maintenance procedures and plans are assessed to determine if they meet the agency's operations requirements or if further modifications are required.

Operational readiness is also dependent on the agency's ability to effectively control hazards before introducing the BEB system into revenue service.

Step 10: Conduct Final Determination of Project Readiness and Issue Safety and Security Certification

Before revenue service begins and formal certification is completed, the project team and supporting committees should review all SSC documentation to determine if any outstanding items remain.

Approval of certifiable elements occurs when work has been completed in conformance with criteria and hazards have been reduced to an acceptable level. Any temporary risk-reduction alternatives affecting a certifiable element require initiation of a hazard management plan to analyze the hazard and control the risk to an acceptable level for a defined period. The hazard management plan must include any Category I (Unacceptable) and II (Undesirable) hazards to ensure that they have been resolved or controlled to an acceptable level before entering revenue service.

Once a certifiable element is ready for final certification, the Safety and Security Review Committee, or equivalent, will evaluate the Certifiable Elements List and accompanying verification documentation, along with recommendations and restrictions, and prepare a Certificate of Conformance for that element. Upon issuance of all Project Certifiable Element Certificates of Conformance, a final Project Safety and Security Certificate will be drafted for signature by the Executive Management team for formal approval.

Before or shortly after revenue service begins, the project team will develop a Safety and Security Certification Verification Report (SSCVR) that summarizes the activities performed to assure the project's readiness to enter revenue service. Suggested items for inclusion in this report can be found in FTA's *Handbook for Transit Safety and Security Certification.*

Hazard Identification

The operation, maintenance, and storage of BEB fleets introduces unique hazards that would not typically be considered for conventionally fueled buses.

- The lack of code basis for the design of fire suppression systems to protect BEB fleets
    - Conventional sprinkler systems are largely ineffective in suppressing internal battery pack fires
    - There are no provisions for managing the contamination of suppression water when used to suppress Lithium-Ion battery fires
- Thermal runaway events produce the potential for great loss
- Battery packs damaged in an accident could potentially be susceptible to reignition up to 22 hours after the initial event[17]
- Malfunctioning or damaged battery modules sparking, or off-gassing of toxic vapor clouds, may pose a respiratory system exposure or explosion risk
- Susceptibility to Radio-Frequency Interference (RFI) and Electromagnetic Interference (EMI) can affect BEB functions as well as other transit agency systems[18]
- Storage provisions of damaged, spent, or malfunctioning battery packs or BEBs[19]
- Storage configuration considerations
    - Li-Ion battery fires tend to propagate quickly and may not be controlled with a conventional fire sprinkler design
    - The peak heat release of electric vehicle fires is more intense than fires from conventionally fueled vehicles. The potential impacts on the parking structures from the additional heat loads should be considered.
    - Lack of industry consensus of fire suppression extinguishment of a battery fire

[17] NTSB Safety Report SR 20/01.202

[18] NFPA 855 Standard for The Installation of Stationary Energy Storage Systems requires RFI/EMI assessments.

[19] NFPA, SAE, and most BEB manufacturers recommend that fire damaged buses and battery modules be isolated with a 50-foot radius or a surrounding physical barrier for separation.

Preliminary Hazard Analysis

It is best to systematically verify all BEB components during the certification process, especially during the Preliminary Hazard Analysis (PHA) development. By approaching the PHA in this manner, all hazards associated with BEB interfaces and safety interlocks directly connected to the integrated system can be identified and specific mitigations implemented.

Hazards to Consider

- Typical fire suppression systems are ineffective in suppressing internal battery pack fires.
- Thermal runaway events produce the potential for great loss.
- Damaged battery packs are susceptible to reignition for up to 22 hours.
- Off-gassing of toxic vapor clouds may pose a respiratory system exposure.
- Storage of end-of-life battery packs can be hazardous; storage should consider heat exposure and fire suppression protocol.

PHAs developed for vehicles independent of charging infrastructure or in reverse will likely result in missed hazards and uncontrolled safety risks. As such, the following interfaces should be considered by agencies:

- Vehicle fire sensors interfaced with charging equipment and other Fire Life Safety (FLS) systems
- BEB battery thermal detectors interfaced with building fire alarm systems and battery management systems
- Charging system emergency stops interfaced with BEBs and buildings' fire and life safety systems
- Commissioning and testing of battery and charging safety interlocks onboard the BEB and as part of the charging equipment
- Onboard fire suppression (directly applying extinguishment to the BEB battery modules) systems and thermal management systems to ensure battery modules remain cool

Threat and Vulnerability Assessment

New, unproven technology may incorporate unintentional vulnerabilities in a cyber system, which allow adversaries to exploit specific software vulnerabilities. In the case of one manufacturer, a Software System Analysis (SSA) identified a potential vulnerability in the vehicle's software that could allow hackers to control some of the vehicle functions, such as preventing the vehicle from charging, unlocking doors and windows, starting the vehicle, and disabling the security system.

Agencies must ensure that manufacturers subject their charging software and firmware to the same rigorous cybersecurity testing as other software to mitigate these vulnerabilities and protect against potential threats and attacks. A software quality control plan that includes verification and validation for cybersecurity would benefit agencies. These security vulnerabilities can be assessed through a comprehensive TVA and an SSA.

Operational Hazard Analysis

Hazard mitigation through design and engineering is always preferential to hazard mitigation via procedures and protocols. Developing an Operational Hazard Analysis (OHA) is crucial to providing necessary mitigations to hazards that cannot be fully mitigated through design or engineering.

Caution: An OHA should not be used to forgo hazard mitigation through design. Relying exclusively on operational procedures or personal protective equipment (PPE) to mitigate hazards often places too much of a burden on the agency, and such reliance on the mitigation will likely diminish over time.

If specific hazard analyses are not feasible, such as a fire hazard analysis or proposed engineering mitigations, agencies should consider making the following operational mitigations:

- Fire watch during charging operations, mainly where BEB charging is intended to occur within a building or structure.
- Fleet storage segregation of the BEB fleet from conventionally fueled buses.
- Enhanced training for operator and maintenance personnel to recognize conditions that might lead to a thermal runaway event or BEB fires.
- Inspections, testing, and maintenance programs for BEBs as identified in the National Fire Protection Association (NFPA) 855: Standard for the Installation of Stationary Energy Systems.
- The scope of NFPA 855 would dictate that it does not apply to BEBs; however, application of this standard as it relates to the maintenance of Li-Ion cells would represent a best practice.

Fire Hazard Analysis

The Fire Hazard Analysis (FHA) should be based on the methodologies established in NFPA 551: Guide for the Evaluation of Fire Risk Assessments[20] and the Society of Fire Protection Engineers (SFPE): Performance-Based Fire

[20] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=551

Protection.[21] Furthermore, agencies must ensure that an FHA is signed and sealed by a Registered Fire Protection Professional Engineer (FPE).

The FHA should focus on the vehicle types and configurations used at the agency. The FHA should include, as a minimum, an examination of the peak heat release rate for BEB combustible elements; total heat released; ignition temperatures; radiant heating view factors; and the behavior of BEB components during internal or external fire scenarios.[22]

Computer modeling and material fire testing should assess performance under the potential scenarios. Fire scenarios must consider how Li-Ion batteries contribute to the identified scenario using a typical bus configuration. Fire modeling should include the following fire scenarios, at a minimum:

- BEB starts on fire during charging. All battery systems are the most susceptible to a fire event during charging. It is essential that charging equipment manufacturers and BEB vehicle providers offer a Failure Mode and Effects Analysis (FMEA) to assist in fire modeling.
- BEB starts on fire while stored among other buses with different considerations to indoor and outdoor storage scenarios. This should determine the extent and speed a fire might spread, including the spread between a fleet of densely stored buses as is typical of most agency fleet storage arrangements.
- BEB fire scenarios should be based on BEB fleet storage in an unenclosed parking garage and an open parking lot.
- A fire starts in the parking garage or parking lot as a result of an outside event such as arson, lightning strike, or facility malfunction that then involves a vehicle to ignite.

While computer simulations modeled around these scenarios are effective in most cases, some conditions may require agencies to complete a full-scale fire test. Agencies should be aware that such tests are often costly and can be avoided by computer-generated modules that provide data nearly identical to a full-scale test.

Lastly, the FHA should provide anticipated flammability and smoke emissions typical to buses within the agency's fleet. Flammability and emissions data should be provided according to ASTM E84 for smoke development and fire spread. Data should also be available from the FHA identifying gasses that are a byproduct of fires associated with BEBs. This analysis should include types of gases, expected concentrations as a function of time, and the effects these gasses have on humans.

[21] https://www.sfpe.org/publications/guides/pbfp2nd
[22] If possible, the FHA should use all heat release rate data provided by the NFPA or the designated bus manufacturer for this determination.

Hazard-Based Design Criteria

The agency's design criteria (DC) can be based on the information gathered from the FHA. An agency's DC should consider, at a minimum, sprinkler design, alternative suppression protection, fleet storage configuration with either physical or mechanical separation, and safety interfaces including emergency stop capabilities.

If a performance-based FHA is not feasible and design criteria cannot be based on identified hazards, it may still be possible to mitigate hazards associated with BEBs. However, hazard mitigation will not be as effective as an FHA-based approach to the extent and accuracy of the information a performance-based FHA provides. Possible approaches to non-FHA DC development for fire mitigation include:

1. Overdesigned Sprinkler System

A sprinkler design can be set as an Extra Hazard Group 1 or 2, the highest identified prescriptively in NFPA 13. The challenge to this approach is installing a sprinkler system that may be overdesigned for the hazard at a significant cost to the agency. Most facilities would not have been designed to this level of sprinkler protection, necessitating significant changes to existing sprinkler systems.

2. Onboard Fire Suppression Systems

Onboard BEB suppression systems that can directly apply extinguishment to the battery modules can be assessed as mitigation to the current lack of code to address facility fire protection.

3. Onboard Battery Cooling Systems and Thermal Management Systems

Keeping battery modules cool can reduce the risk of possible thermal runaways. Onboard cooling and thermal management systems can be assessed as mitigation to reduce the possibility of thermal runaway events.

4. Extreme Physical Separation

Instituting fleet storage guidelines with extreme storage distances between BEBs or groups of BEBs minimizes the spread of fire. Physical separation is a simple and effective way to mitigate the potential spread of fire, but it includes the challenge of requiring extra space. For example, if BEB storage typically calls for a 3-foot separation between each bus, calling for an 8-foot separation requires a significant amount of unutilized open space. It is also not possible to accurately identify how much physical separation is adequate. For example, while an 8-foot separation may seem sufficient, this determination cannot be made without an FHA to confirm an adequate distance. Mitigating the associated hazard of fire spread can only be based upon a best-practices approach.

5. Creation of Fire Area

Agencies can also create distinct fire areas with a limited amount of BEBs in each fire area to limit the spread of fire to a lesser number of BEBs. Similar to physical separation, challenges arise with this type of mitigation. Primarily, each fire area will be damaged or destroyed if a fire occurs. Nonetheless, this is a code-recognized way to limit fire loss by containment within a fire area. Fire areas also have higher costs since rated walls and associated openings must be designed to code. These areas still require a suppression system; however, a more typical Ordinary Hazard design likely can be used since the fire area would contain the potential losses.

Operations and Maintenance Considerations

Operational considerations can be reviewed as stop-gap measures to mitigate fire risk while establishing a reasonable basis for fire and life safety design. Operational mitigations for consideration include, but are not limited to:

1. **Fire Watch:** During BEB charging, a qualified fire watch can provide faster initiation of emergency-stop procedures and fire department notification.

2. **Standard Operating Procedures (SOP):** Developing SOPs specific to BEBs and the related charging infrastructure would determine what operators and maintenance personnel should do in a fire involving a vehicle or related BEB system.

3. **Vehicle Health Monitoring System:** During BEB operation, a vehicle health monitoring system enables remote monitoring of bus battery conditions, allowing for early warnings of developing issues prior to a battery fire occurring.

4. **Outside Storage:** Storage adequacy is based on the presumption that fire protection designs of either new or existing facilities are sufficient to protect the infrastructure from the enhanced fire loads of BEBs. Conditions permitting, agencies can consider moving charging and storage operations to an outdoor location at appropriate setbacks from buildings and other vehicles. This is one of the more cost-efficient and effective operational mitigations if fire protection systems are inadequate to manage recognized FLS hazards.

5. **Storage Separation:** Supplemental to item number 3 above, agencies should consider storage separation of at least 10 feet from adjacent buses.

Cybersecurity

Systems, including chargers and buses, could be affected by a successful cyberattack, further illustrating the need for IT departments to assist with the design, specifications, and manual reviews provided by manufacturers. The most likely vulnerabilities occur while updating the equipment firmware. During this time, agencies expose themselves to a potential network breach simply by using the standard methods of utilizing a Wi-Fi or 3G/4G/5G Internet connection to perform the update. Should an attacker gain access and introduce an alternate firmware package to make the bus or charger perform abnormally, the consequences could be severe. The attacker might affect the bus's operation or allow the charger to rapidly charge the bus batteries, leading to a collision or a battery fire. Conversely, an update could render the charger(s) incompatible with some or all buses, preventing them from returning to revenue service. As with other cybersecurity measures, default passwords provided by the manufacturer should be changed immediately and replaced with complex passwords to prevent tampering.

Before purchasing BEBs, each agency should ensure that vendors will supply a list of the Internet-accessible systems and software that comprise the total system to assist with meeting their Safety and Security Certification requirements. Questions for the vendor might include:

- What safeguards and standards are implemented in the BEB system to reduce the potential for cyberattacks?
- Have their buses been involved in a cyber incident? If yes, what was learned, and what was done to prevent it in the future?

Currently, the transit industry has been limited in the availability of this information from manufacturers, with most requests being fulfilled weeks after vehicle delivery. In the interim, an agency's safety and security staff should work collaboratively with their bus operations and maintenance, information technology, and consultants to evaluate the cybersecurity risks associated with equipment and software.

Resources are available for transit agencies to use when drafting cybersecurity vulnerability assessments. APTA SS-CCS-WP-005-19 standard for "Securing Control and Communications Systems in Transit Bus Vehicles and Supporting Infrastructure" offers a starting point for evaluating these vulnerabilities and risks. The Transportation Security Administration (TSA) also offers a Cybersecurity Toolkit that has additional best practice resources.

Summary

Safety and Security Certification of Battery Electric Bus Fleets – Industry Best Practices presents guidelines that are designed to improve a bus transit agency's ability to recognize BEB fleets' unique hazards and vulnerabilities and associated infrastructure, which have been summarized in this section. While the section opened with the applicability of safety risk management and safety assurance in the procurement, operation, and maintenance of BEBs, it focused on SSC, including the 10 steps of an SSC. In addition, hazard identification considerations, preliminary hazard analyses, threat and vulnerability assessments, operational hazard analyses, fire hazard analyses, hazard-based design criteria, and cybersecurity were covered. This section is most beneficial to transit agencies that are initiating their SSC for BEB procurement, or agencies that have procured BEBs prior to performing the necessary SSC as operations and maintenance considerations are identified as well.

Safety Risk Management – Built upon hazard identification, risk assessment, and risk mitigation.

Safety Assurance – Ensures mitigations manage safety risks as intended.

Safety and Security Certification – Series of processes to verify the safety and security readiness which identifies key activities, highlights resources, incorporates and provides tools to promote safety.

Hazard Identification – Fire suppression system effectiveness on electric fires, thermal runaway potential, damaged battery pack reignition potential, off-gassing respiratory hazards, end of life battery storage.

Preliminary Hazard Analysis (PHA) – Interfaces are one aspect of a PHA including fire sensors interfaced with charging equipment and thermal detectors with building fire suppression system.

Threat and Vulnerability Assessment (TVA) – Software system analyses should identify vulnerabilities including any cyber security vulnerabilities.

Operational Hazard Analysis (OHA) – OHAs identify hazards that were not fully mitigated through design or engineering, which may include fire watch during charging and training to recognize warnings of thermal runaway events.

Fire Hazard Analysis (FHA) – FHA should examine peak heat release rate, total heat released, ignition temperatures, radiant heating factors, and behavior during thermal events.

Hazard Based Design Criteria – Minimum design criteria include sprinkler design, alternative suppression protection, fleet storage configurations, and safety interfaces.

Operations and Maintenance Considerations – Minimum considerations include fire watch, SOPs, vehicle health monitoring systems, outside storage, and storage separation.

Cybersecurity – Inquire about safeguards in place to prevent cyberattacks and ensure compliance with the APTA SS-CCS-WP-005-19 standard for “Securing Control and Communications Systems in Transit Bus Vehicles and Supporting Infrastructure and TSA best practices.

Section 4

Guidelines for Maintenance and Operator Training on BEBs and Charging Systems

Consistent operator and mechanic training will increase safety and an agency's transition to BEBs, helping minimize the inevitable learning curve for BEB maintenance and operation. Similarly, the staff involved in bus planning, scheduling, and run cutting should be given BEB training as block scheduling and dispatching may be impacted by the range limitations of certain BEB technologies and other factors. BEB training can also influence operational and economic considerations for an agency since suboptimal BEB operation can affect bus range and charging efficiency. Beyond training, bus tests, charging infrastructure inspection, and emergency preparedness plans are key practices for ensuring safety. The bus original equipment manufacturer (OEM) predominantly provides most operations and maintenance training for the bus and charging infrastructure.

Existing operator and maintenance training associated with BEB systems must be revised from the typical training for conventionally fueled buses. Specific training for both operating and maintenance staff will supplement other FLS and electrical hazard mitigations.

Training provided by the OEM should be clearly outlined in the bus procurement documents and should occur shortly after bus delivery to limit delays in revenue service deployment. Contract specifications should include requirements for training hours, aids, materials, tools, and diagnostic equipment. In advance of the buses arriving at the property, agencies should confirm what direct staff training or "train-the-trainer" instruction will be given by the OEM and ensure that the transit agency has access to the needed tools and materials.

Source: AdobeStock_220511384

Operations Training

The introduction of BEBs will require additional training and retraining of current bus operations personnel. Agencies should provide training for individuals beyond operators, including but not limited to supervisory staff, training personnel, and bus planning, scheduling, and run cutting teams.

Consistent training will increase safety, enhance organizational transitions into BEB operations, and help minimize service disruptions, especially if supporting departments such as planning and schedules are informed of current BEB fleet limitations. This will lead to greater efficiencies and service reliability.

Source: AdobeStock_387162078

Operator training on the differences between BEB operation and conventionally fueled vehicles is essential for safety and efficiency. Training for BEB operators must address proper docking during charging, energy-efficient driving, braking, and shutdown, as well as general BEB operation. Operators need to know how the battery state of charge (SoC) relates to the range and how environmental factors affect the range so sufficient charge can be maintained according to the planned route. Additionally, operators must be familiar with emergency safety protocols.

Training topics agencies should consider include but are not limited to:

- BEB hazards
- On-route charging procedures
- Hazards related to battery chargers
- Regenerative braking
- Noise level
- Emergency procedures

Maintenance Training

Routine BEB maintenance is dissimilar from diesel or hybrid vehicles. While diesel vehicles require knowledge of electrical systems, greater understanding and awareness are required of maintenance staff on the more complex BEB systems. Electrical systems knowledge will also be required to maintain supporting systems such as charging stations, charging monitoring systems, and communication systems.

Agencies must train maintenance personnel at all levels to ensure knowledge and ability with all electrical propulsion and auxiliary systems. Training should also cover onboard diagnostic systems and safe maintenance operations with or around high-voltage systems, including battery handling, storage, and disposal. Additionally, an agency should ensure its Preventative Maintenance Inspection processes are revised and incorporated into the training curriculum. Training topics might include information regarding hazards associated with:

- Battery chargers
- High-voltage cables
- Potential thermal events
- Safe handling and deactivation of high-voltage components, including required personal protective equipment (PPE) for different tasks and capacitor discharge timing
- OSHA compliant lockout/tagout (LOTO) procedures for working on energized components and systems
- Battery-specific issues such as electrocution, arcing, and fires from short circuits
- Locations of emergency cutoff switches and fire response equipment

Transit agencies may consider hiring additional staff with the proper training and accreditations to maximize maintenance efficiencies and manage potential gaps in training proficiencies. Bus OEMs may also support this necessity, especially for maintaining advanced systems related to electric propulsion or charging.

Additionally, the maintenance training program must include scheduled training and retraining for tow truck operators and contractors moving BEBs.

First Responder Training

During the procurement process, agencies should coordinate first responder training with the OEM in advance of revenue service deployment of BEBs. Doing so should ensure proper emergency response procedures will be followed if an incident occurs. Similarly, incident response procedures should be revised and included as part of the training program to discuss assessing high-voltage systems and risks and procedures for isolating risks and preventing further damage and exposure.

At a minimum, agencies should consider the following within their training program:

- How to distinguish electric buses from conventional buses
- How to best approach BEB fires
- How a BEB fire differs from a conventional internal combustion vehicle fire
- Properties of Li-Ion and Lithium-Metal batteries and the distinct fires each produces
- How to isolate high-voltage systems
- Overview of the location of essential components on a BEB
- Location of emergency cutoff switches
- Proper procedures for disconnecting batteries and isolating them from the bus
- How to treat chemical burns and neutralize battery fluid
- Understanding of all hazardous fluids being used and proper storage methods
- Information on any potential explosive or toxic gas hazards that batteries may pose

Training should be followed up with the deployment of a drill or exercise pursuant to Homeland Security Exercise and Evaluation Program methodology. A drills and exercise program could begin with a seminar incorporating the content previously discussed, followed by a tabletop exercise to establish adequate standard operating procedures, which can lead to a full-scale exercise.

The National Fire Protection Association (NFPA) offers first responder training for alternative fuel vehicles in response to the National Transportation Safety Board (NTSB) Safety Report 20/01, *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles.* NFPA first responder training and additional resources are available online at https://www.nfpa.org/EV.

Summary

Consistent operator, mechanic, and first responder training increase safety as an agency transitions their fleet to BEBs, helping minimize the inevitable learning curve for BEB maintenance, operation, and emergency response. Minimum training topics have been highlighted throughout this section to guide agencies on specific considerations as they determine the training appropriate for their agency.

Operations Training – Minimum operations training topics include BEB hazards, on-route charging procedures, hazards related to battery charging, regenerative braking, noise level, and emergency procedures.

Maintenance Training – Minimum maintenance training topics include battery chargers, high-voltage cables, potential thermal events, deactivation of high-voltage components, LOTO procedures, electrocution, arcing, and fires from short circuits, and locations of emergency shutoff switches and fire response equipment.

First Responder Training – Minimum first responder training topics include how to extinguish electric bus fires, how to approach a BEB fire, properties of Li-Ion batteries, how to isolate high-voltage systems, locations of essential BEB components, locations of emergency cutoff switches, procedures to disconnect batteries, how to treat chemical burns, hazardous fluid handling, and potential explosive or gaseous hazards.

Section 5

Challenges Faced and Lessons Learned When Deploying Battery Electric Buses

Survey analysis revealed respondent agencies learned many lessons from the various challenges faced in their BEB procurement and maintenance endeavors. There were challenges determining their desired specifications and requirements of both vehicles and infrastructure in their first procurements. Agencies faced funding issues and time constraints such as longer than anticipated lead times for charging infrastructure and production delays, in addition to infrastructure bids that exceeded initial cost estimates. In terms of range considerations, transit agencies contended with matching infrastructure technology to support all routes and having to modify schedules to accommodate BEB range capabilities. Another power-related concern was the need to perform a power capacity evaluation to ensure the transit facilities could handle the additional power draw of charging a bus fleet, which many times leads to facility improvements. Agencies also reported challenges working with power companies, especially in terms of timing the delivery of the charging infrastructure to precede the delivery of the first BEB to ensure ability to charge it for use. Other power company issues involved the installation time required for wayside depot charging infrastructure, determining on-route charging locations, and integrating with facility power needs to ensure the existing infrastructure footprint could accommodate the agency's increased power needs.

Source: AdobeStock_506311816

Challenges in Procurement Phase

Following is a summary of challenges during the procurement phase shared by survey respondents.

- New vendor challenges
  - Unproven technology
  - Knowledge curve
  - Determining desired specification and requirements
- Costs – funding and time
  - Production delays
  - Infrastructure bids were higher than estimates
  - Lead times for charging infrastructure
- Range considerations
  - Matching infrastructure technology to support all routes
  - Schedule modifications to accommodate range
  - Power capacity evaluation and required improvements
- Working with the power company
  - Timing the charging infrastructure to precede the BEB delivery
  - Installation time for wayside depot charging infrastructure
  - On-route charging locations not on transit property
  - Integration with facility power needs and existing infrastructure footprint

Challenges Faced Throughout BEB Deployment

Respondents were asked what challenges they faced throughout the deployment of their first and subsequent BEB deployment(s). Responses ranged from timing and training to interoperability and connectivity issues. Vendor problems were also mentioned, including unmet expectations and undelivered promises.

- Timing
  - Training
  - Parts delays
  - Route considerations/accommodations
- Cost and space
  - Support
  - Funding
  - Space for charging infrastructure

- Vendor challenges
  - Typical bus configuration
  - Communication
  - Unmet expectations
- Other challenges
  - Software bugs
  - Interoperability issues
  - Connection

Aside from the procurement issues, agencies faced additional challenges as they deployed the BEBs into service. First, they mentioned problems with timing, including timing for training, timing of routes and charging, and timing concerns due to delayed parts. Second, agencies listed issues with cost and space, specifically related to support, and space for charging infrastructure. Next, agencies mentioned vendor challenges over typical bus configurations, communication, and unmet expectations. Finally, agencies shared miscellaneous challenges associated with software bugs, interoperability, and connection. Due to many of these concerns, 44% of the respondent agencies indicated they cannot currently envision a path to full fleet electrification.

Case Study Challenges and Lessons Learned

In addition to the survey data that was collected, 8 case study agencies were selected from the 25 survey respondents, and additional follow-up communication allowed for more details to be collected (Figure 5-1). The case study agencies include AC Transit, Foothill Transit, LYNX, Pinellas Suncoast Transit Authority, Port Authority of Allegheny County, SEPTA, TriMet, and Valley Regional Transit.

Figure 5-1 *Case study agency challenges and lessons learned*

BEB Learning Curve – With BEB technology in the maturation stage, the learning curve remains challenging. For instance, agencies had to determine what PPE should be required and what testing protocol was necessary for the PPE. One agency suggested installing a third-party analytic system on the BEBs and their charging equipment to improve information sharing.

Charging Considerations – Agencies should consider various specification concerns for bus and charging infrastructure, including a diversification of fuel sources for emergency operations, interoperability of various vendors, on-route charging, electrical capacity, and managed charging.

Delays – Delays should be considered in timelines, as they are prominent. Agencies experienced delays with communication, parts, bus delivery, repairs, and charging infrastructure installation.

Planning Ahead – It is suggested that agencies plan for future expansion of their BEB fleet as they are initiating procurement of their first BEB delivery. Especially for the agencies that plan to fully convert their fleets to electric propulsion, there are expansion considerations that should not be overlooked. Agencies also suggested anticipating and planning for reacting to worst-case scenarios, such as a long-term disruption in power.

Partnerships – Several agencies suggested hiring a consultant when procuring BEBs for the first time, in addition to establishing partnerships with the local utility company early in the process. Agencies also mentioned the benefits of partnerships with OEMs to submit feedback.

Quality Issues – A few agencies experienced significant challenges with bus design defects. Agencies should consider and inspect for water intrusion when there is potential for electrical exposure to moisture. One agency experienced significant cracking on the body of the BEBs with no known source or remedy, causing the entire BEB fleet to remain out of service.

Costs – Several agencies mentioned additional costs during BEB implementation that were not initially considered including tooling costs and costs associated with space constraints, which all contribute to the total cost of BEB ownership.

Summary

Throughout the *Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices* and the *Safety and Security Certification of Battery Electric Bus Fleets – Industry Practices* reports there were many challenges identified and lessons learned that transit agencies detailed in survey responses. This section provided a brief synopsis of the challenges faced and the lessons learned related to timing and delays, cost and space challenges, vendor challenges, learning curves, charging considerations, planning ahead, partnerships, and quality issues.

Section 6

Conclusions and Findings

Guidebook for Deploying Battery Electric Buses was developed to support transit agencies as they implement BEB deployments through an SMS implementation process. The guidance and findings presented in this document are not intended to be prescriptive. All transit agencies should develop comprehensive SSC programs tailored to their unique operating environments and characteristics. The combined findings from peer agencies offer insight so agencies can learn from others and avoid or prepare for similar challenges.

Safety and Security Certification is a risk-based process paralleling the project's life cycle and schedule. While the process is often misunderstood, SSC acts in the best interest of the bus agency to ensure all hazards and vulnerabilities are appropriately mitigated, and any calculated risk is reduced to the lowest practical level. As such, the evolving dynamics of the battery electric market demand agencies implement a robust verification process through SSC to identify and mitigate BEB-specific hazards. While some BEB components are similar to the conventional fuel alternatives, there are new considerations that may not have been incorporated into existing or past BEB and associated infrastructure procurement processes.

Managing the recognized gaps in the Safety Risk Management processes of SSC requires agencies to employ several operational strategies to mitigate unwanted risks. The current code does not specify specific BEB fleet fire protection requirements. More specifically, nationally recognized codes such as NFPA and the International Fire Code (IFC) do not provide the direct language typically used to prescriptively design Fire Life Safety systems that would adequately mitigate unacceptable hazardous conditions. This results in inconsequential conditions in past design and installation phases of the procurement's life cycle.

The literature reviews, surveys, data analyses, and reports led to many valuable findings and identified challenges that agencies should consider when transitioning their fleet to BEBs. The overall benefits of this report focus on key challenges agencies should expect as they initiate their transition to battery electric bus fleets. This guidance will be most beneficial to agencies that are planning their next BEB procurement. The literature review revealed common themes that occurred throughout various agency BEB procurements. The recommended practice themes include safety and security certifications, procurement, coordinating with utility providers, facilities, charging infrastructure, parts and batteries, training, and operations.

Safety and Security Certifications

Certifications verify necessary safety – Recipients of federal financial assistance from FTA, with significant capital projects meeting the applicability criteria, defined in the Code of Federal Regulations Title 49 Part 633 – Project Management Oversight, are required to prepare and carry out Safety and Security Management Plan activities for safety certification. SSC is how recipients will verify that the project outputs are safe for passengers, employees, public safety personnel, and the public.

FTA recognizes SSC as a 10-step process:

1) Identify Certifiable Elements
2) Develop Safety and Security Design Criteria
3) Develop and Complete Design Criteria Conformance Checklists
4) Perform Construction Specification Conformance
5) Identify Additional Safety and Security Test Requirements
6) Perform Testing and Validation in Support of the SSC Program
7) Manage Integrated Tests for the SSC Program
8) Manage "Open Items" in the SSC Program
9) Verify Operational Readiness
10) Conduct Final Determination of Project Readiness and Issue SSC

Procurement

Specific procurement language – Transit agencies that have procured BEBs suggested more specific procurement language, more options, and requirements for support and supply chain provisions. Agencies also suggested procurement language that requires sufficient warranties on major BEB components. In future procurements, agencies indicated they would look for BEBs that have a range that exceeds 300 miles, and they will look for bids that explicitly define the charging time capabilities.

Identify and prioritize charging needs – In future procurements of charging infrastructure, agencies suggested their peers have a distinct infrastructure contract that is separate from the vehicle procurement contract. While many agencies recognized a necessary change in their approach to procure charging infrastructure, some specifically identified their need to prioritize overhead pantograph charging to improve depot management, while others recognized the need to develop on-route charging strategies to allow for charging during layovers to increase range and decrease battery capacity needs.

Require interoperability – Agencies also identified some other changes they would include in future BEB procurements such as including specific language to require interoperability of chargers, no matter the manufacturer, which will be especially important as agencies procure additional BEBs. Some agencies suggested procuring BEBs from more than one vendor to be able to compare performance. Agencies suggested their peers develop route profiling prior to procurement to optimize route performance. Finally, agencies suggested including more tooling, more PPE, and more training in future procurements.

Regional or state procurement coordination could leverage economies of scale – Regional or state procurement contracts provide agencies with an opportunity to leverage the benefits of economies of scale, negotiated procurement language, and pooled funding when available.

Utility Providers

Variable utility rates lead to inconsistent charging costs – Agencies may have limited negotiating powers with utility providers; thus, it is important that agencies consider the variations in utility rates by time of day.

Resiliency and backup power source considerations – Fuel diversification and availability of backup power may be beneficial in circumstances where power is unavailable for extended periods of time, such as in hurricane events or other natural disasters, to ensure that an agency can provide the necessary transportation. Other considerations include partnering with utilities to expand grid connections and implementing battery storage and microgrids. Agencies may benefit from States developing backup power plans to assist locally when necessary.

Facilities

Facility upgrades and space are necessary – Whether planning for the first BEB procurement or a BEB fleet expansion, facilities require charging infrastructure installation, lifts that are rated for the weight of a BEB, fire suppression systems, and storage space for batteries and spare parts, all of which accumulate space especially as fleets transition to larger BEB fleets. BEBs that have roof-mounted equipment also require personnel lifts to accommodate top-of-bus maintenance and additional fall protection.

Interoperability challenges will exacerbate space limitations for charging infrastructure – As agencies mix fleets in their second and third BEB procurements, the need for interoperability regardless of the make/manufacturer of the vehicle or charging system will be more pronounced, thus it may be beneficial to require interoperability in the procurement language.

Charging Infrastructure

There are options for owning/maintaining charging equipment – Transit agencies may feel more confident initiating the decarbonization of their bus fleets with the understanding that there are often options to lease charging equipment from utility companies, rather than the agency owning full responsibility for the charging infrastructure.

Charging infrastructure is advancing – Higher power ultra-fast charging systems are entering the market with the promise of reducing dwell time for charging, possibly allowing BEBs to serve longer routes than traditionally thought. Additionally, using smart charging, managed charging, or other charging optimization techniques may lead to greater cost savings, especially as BEB fleet sizes increase.

Parts and Batteries

Parts availability – Agencies should include OEM parts availability expectations in contract negotiations or procurement language. This will increase the likelihood that required parts will be available and therefore reduce vehicle out-of-service time.

Battery warranty – Requesting clear language in the battery warranty that dictates whether the warranty applies to the battery system versus the individual battery packs, cells, and/or battery management systems within the system could reduce ambiguity of the warranty.

Battery disposal – It is beneficial to include battery storage, disposal, and/or recycling details in procurement language to reduce unexpected challenges associated with repurposing or disposal when the battery system or individual battery packs reach the end of their useful life.

Training

Standardized training would be beneficial – Operator training beyond the general vendor-provided training may improve the operator's performance to increase BEB efficiency. Technician training beyond the general vendor-provided training may improve the confidence of technicians who work on BEBs, which may in turn reduce the technician shortages that many agencies are experiencing. Finally, providing first responder familiarization training of BEB designs may reduce unanticipated hazards and challenges when emergencies occur.

Operations

Route design methodology may need to change – Depending upon fleet conversion goals, it may be necessary to redesign routes and/or operating parameters to accommodate the BEB performance capabilities (or to accommodate on-route charging). Additionally, performance capabilities may vary with extreme weather, thus route design methodology may need to vary by season in some geographies.

FTA prepared this guide to support transit agencies in their SMS implementation and supporting processes while they plan for and implement battery electric buses into their fleets. As part of U.S. Department of Transportation (USDOT) efforts to support the transition of the nation's transportation systems to electric vehicles and other zero-carbon technologies', the *Guidebook for Deploying Battery Electric Buses* was developed to offer bus transit agencies leading transit industry practices for planning and implementing battery electric busses into their fleets. The recommended practices presented in this document and emphasized through the background research are not intended to be prescriptive in nature. All public transit agencies should develop battery electric bus procurement processes, which should be tailored to their unique operating environments and the complexity of the operation provided.

Key points, effective practices, and the Appendix were delineated and presented to assist transit agencies in planning for and procuring BEB fleets. Transit agency personnel responsible for procuring, operating, and maintaining battery electric buses and their charging equipment are encouraged to participate in FTA sponsored training events, and remain abreast in these key topic areas:

- Safety and Security Certifications
    - Certifications verify necessary safety
    - Follow 10-step process
- Procurement
    - Identify and prioritize charging needs
    - Require interoperability
    - Regional or state procurement coordination could leverage economies of scale
- Utility Providers
    - Variable utility rates lead to inconsistent charging costs
    - Resiliency and backup power source considerations
- Facilities
    - Facility upgrades and space are necessary
    - Interoperability challenges will exacerbate space limitations for charging infrastructure
- Charging Infrastructure
    - There are options for owning/maintaining charging equipment
    - Charging infrastructure is advancing
- Parts and Batteries
    - Include OEM parts availability expectations in contract negotiations
    - Request clear language in the battery warranty
    - Include battery storage, disposal, and/or recycling details in procurement language

- Training
  - Standardized training would be beneficial for operations, maintenance, and first responders
- Operations
  - Route design methodology may need to change

Appendix A

Recommended Expanded RFP Language for Providing Training for Zero-Emission Buses

The International Transportation Learning Center is a workforce development nonprofit organization that collaborates to develop and support technical training for the front-line workforce. As agencies transition to zero-emission fleets, there is an inherent need to coincidentally train employees on the safe use and maintenance of these fleets. Agency RFPs can be used to set standards for training. While the APTA Bus Procurement Guidelines provide recommended language for bus procurement, this recommended expanded RFP language focuses on training language.[23]

Agency Review of Training Materials

The Contractor shall provide copies of all lesson plans, detailed instructor guides, student workbooks, manuals, publications, videos, PowerPoints, transparencies, and any other training aids used by instructors 90 days prior to the delivery of the first production bus. The Contractor shall identify the instructor and provide the qualifications of the instructor 90 days prior to the delivery of the first production bus. Dates of the training shall be determined by the Agency in coordination with the Contractor. The Contractor shall inform the Agency of any training support equipment (such as DVD player, personal computer with PowerPoint, projector, etc.) and/or supplies required for the training. The training, including materials, schedule, instructors, and course outlines, shall be approved by the Agency prior to their use.

For each separately ordered group of buses, the Contractor shall provide a program of instruction, instructional materials, and training aids targeted for specific groups of operations and fleet maintenance personnel, as described below. This training shall take place at the Agency.

The Contractor shall make clear which of the trainings included in its proposal will be provided by the Contractor, and which trainings will be provided by a third-party organization such as a component vendor. Contact information for each outside training provider shall be provided. For each segment of training provided (e.g., HVAC, brakes, propulsion, etc.), the Contractor shall itemize costs for each, and then provide a total cost for all training offered. The Agency reserves the right to select all, or part of the training offered by the Contractor with costs adjusted accordingly. The Contractor shall indicate the

[23] https://www.transportcenter.org/images/uploads/publications/ITLC_ZEB_Report_Final_2-11-2022.pdf

extent to which interactive and engaging learning techniques shall be applied. The Contractor shall indicate which aspects of the training shall be provided in-person, and which through e-learning and distance-based platforms.

The Contractor shall designate a specific individual as the "Principal Training Contact" for the scheduling and accomplishment of the Contractor and third-party vendor training. The Contractor shall provide a name, complete mailing address, telephone number, and e-mail address for this person to the Agency no later than 90 days after Notice to Proceed.

Operator Training (Phase 1 Training)

For each separately ordered group of buses, the Contractor shall provide a minimum of 6 hours of training to Operations Personnel and Maintenance Personnel as designated by the Agency on driving characteristics of the bus; use of all controls, gauges, warning lamps, and driver's seat controls; CDL pre-trip requirements for safe operation; emergency procedures; use of the wheelchair ramp system; and other operational items as required to safely and efficiently operate the bus.

Maintenance Training Courses

The Contractor shall provide maintenance training utilizing two modules of instruction: General Orientation and Technical Orientation.

- **General Orientation (Phase 1 Training)**
  For each separately ordered group of buses the Contractor shall provide an initial orientation for Maintenance Personnel as designated by the Agency. The General Orientation shall be provided at each facility where the buses ordered could be maintained or repaired and shall be provided for each shift. The General Orientation shall be presented on and around the bus. The General Orientation session shall be, at a minimum, 8 hours in duration. The General Orientation shall include, but not be limited to, the following: fluid types; fluid quantities; fluid level checks; inspection and maintenance of fluid types (manual and electronic); fill ports; basic servicing of bus to include PM schedules and all related safety precautions; procedures for charging buses for quick or slow charge and hazards, safety procedures, and PPE related to both types of charging. The General Orientation shall also cover familiarity of vehicle for safe operation and specific procedures that the Agency could use to train First Responders.

- **Technical Orientation for Each Area of Instruction (Phase 2 Training)**
  The Contractor shall provide a structured program of technical training. The number of times each program is delivered depends on the number of

Maintenance Personnel to be trained. See Table 1. This program shall be delivered at locations to be specified by the Agency.

The training shall consist of specific and identifiable separate areas of instruction, including at least the following (see Table 1):

- Electrical/Multiplex System
- Energy Storage System (ESS)4 and Battery Management System5
- Propulsion System Familiarization/ HV6 Safety
- On-Board and Off-Board Charging System Equipment
- HVAC System
- Brake and Air Systems
- Steering, Suspension and Axle Systems
- Wheelchair Ramp System
- Entrance & Exit Doors
- Electric Propulsion System Overhaul

A detailed class shall be provided for each area of instruction shall include, at a minimum:

1. Component identification and location
2. Diagnosis and repair
3. Safety and warnings
4. Theory of operation
5. Diagnostic software and computer use
6. System maintenance and troubleshooting
7. Agency specific configuration files in digital format
8. PPE and its use specific to BEB systems
9. A list and pricing of all required PPE and special bus-specific tooling

Special Instructional Materials and Training Aids for Each Area of Phase 2 Training

The contractor shall supply the following instructional materials for each separately ordered group of buses 90 days before delivery of the first production bus in each group. The Contractor shall provide two complete sets of:

- electrical and electronic wiring diagrams
- instructor guides and training aids
- overhaul process guide
- videos

- PowerPoint and other presentations
- wall chart training aids
- student guides

Training materials shall be sufficient to allow maintenance personnel to:

- Identify component function and location within system
- Use diagnostic test equipment to perform troubleshooting procedures
- Be certified by the OEM to perform warranty repairs
- Perform preventative maintenance procedures
- Perform equipment repair

The Contractor shall supply the following training aids for each separately ordered group of buses 90 days before the delivery of the first production bus in each group, in addition to training aids necessary for the above listed systems. Pre-production design of each unit shall be subject to the approval by the agency.

- Air Conditioning System Training Module: a stand-alone, fully operational training aid, representative of the vehicle's air conditioning system, constructed using actual bus parts identical to those being used on the vehicles provided under this contract including but not limited to the following: compressor and clutch assembly, service valves, condenser, condenser fans, receiver tank, filter dryer, expansive valve, evaporator pressure regulator (if applicable), evaporator coil, evaporator fans, heater coil, return air filter, minimal ducting. The unit shall demonstrate the operation of the complete air conditioning system. The unit shall also include all switches, electronic controls, sensors, lights, warning devices, and gauges to indicate all system functions. The unit shall be delivered fully charged with the same refrigerant used on the vehicles provided under this contract. The unit shall be powered by a 3-phase AC motor with sufficient voltage and pulley with simulates the rotational horsepower taken from an engine/electric propulsion system.
- Vehicle Multiplex Module: a fully operational multiplex system with the vehicle to be delivered.
- Air Brake Module: a fully operational air brake system with the vehicle to be delivered.

OEM "Train the Trainer" Maintenance Training

The Contractor shall provide a "Train the Trainer" program for each separately ordered group of buses covering all subject areas listed above. The "Train the Trainer" program, intended specifically for Maintenance Instructors, shall be accomplished thorough instruction led by the Contractor, OEM Component Vendor, or third-party as appropriate. This training shall also incorporate the use of instructional training aids and materials described above.

"Train the Trainer" training is preferably held at the manufacturer's factory location. All courses shall include transportation, lodging, and meal per diem for (Add number of Instructors attending). The training shall be provided in two phases pre-delivery and post-delivery of buses. The contractor shall itemize in detail when the training is to be provided by all entities. The "Train the Trainer" program shall accommodate a minimum of (add number of trainers). The "Train the Trainer" program shall include, at a minimum, the subject areas listed above for the technical training.

Electronic Maintenance Information

The Contractor shall supply all software information, including source codes for any programmed module or component. Also, to be supplied is any special hardware necessary to repair or modify any microprocessors and/or software used in the bus. The Contractor shall supply complete schematic drawings containing component identification, and the location of the components on the circuit board; circuit descriptions; and theory of operation for all electronic components. The Contractor shall also supply information on programmed array logic (PAL) and any other preprogrammed device. The Contractor shall identify all data it considers as proprietary.

Table 1: Training Requirements

Note: length of hours for each course has been provided as a minimum. Agencies may need to adjust the hours and insert the number of sessions required to suit their individual needs.

PHASE 1 TRAINING			
Course	**Description**	**Target Audience**	**Length (Hours)**
Class 1: Operator Orientation	Class shall cover driver familiarity, operation of all vehicle systems including the wheelchair ramp, and CDL pre-trip requirements for the safe operation of Battery Electric powered vehicles. This orientation shall also cover familiarity of vehicle for safe operation and specific procedures that the Agency could use to train First Responders.	Maintenance Personnel and Operations Personnel as designated by the Agency	6
Class 2: Maintenance Orientation	Class shall cover fluid types, fluid quantities, fluid level checks inspection and maintenance of fluid types, (manual and electronic), fill ports and basic servicing of bus to include PM schedules and all related safety precautions. procedures for charging buses for quick or slow charge and cover all hazards, safety procedures, and PPE related to both types of charging.	Maintenance Personnel and Operations Personnel as designated by the Agency	8

PHASE 2 TRAINING			
Course	**Description**	**Target Audience**	**Length (Hours)**
Class 3: Electrical and Multiplexing	Class shall cover the non-propulsion electrical system and multiplex system. Class shall cover the inspection, location, troubleshooting/diagnostics, maintenance and repair of over voltage monitor, battery, equalizer, battery maintenance, print reading, multiplex system, ladder logic, wiring color coding, harnesses, connectors, plugs, J1939 communication circuit	Maintenance Personnel as designated by the Agency	24
Class 4: Energy Storage & Management Systems	Class shall cover the inspection, location, troubleshooting/diagnostics, maintenance (preventive and corrective) and repair of the high voltage energy storage system, battery management system, and any related components, controllers, etc. The class shall provide safety procedures for handling and working with a high voltage system, and power down procedures; general construction and principles of operation and troubleshooting; battery thermal management system, pumps/piping diagnostics, lock-out/tag-out, and assembly and disassembly procedures.	Maintenance Personnel as designated by the Agency	12
Class 5: Propulsion System Familiarization/HV Safety	Class shall cover fluid types, fluid quantities, fluid level checks inspection and maintenance of fluid types, (manual and electronic), fill ports and basic servicing of bus to include PM schedules and all related safety precautions. procedures for charging buses for quick or slow charge and cover all hazards, safety procedures, and PPE related to both types of charging.	Maintenance Personnel as designated by the Agency	16

PHASE 2 TRAINING			
Course	**Description**	**Target Audience**	**Length (Hours)**
Class 6: Charging System Equipment	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance (preventive and corrective) and repair of all aspects of the charging equipment including depot and wayside charging equipment.	Maintenance Personnel as designated by the Agency	8
Class 7: HVAC System	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance (preventive and corrective) and repair of the HVAC system for both the vehicle itself and propulsion system to include: compressor, evaporator/ condenser fans, motor drivers, recovery/recycling refrigerants, system operation, diagnostic software, bus interface electrical and mechanical drawings.	Maintenance Personnel as designated by the Agency	12
Class 8: Brake and Air Systems	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance and repair of air lines, valves, compressor, air dryer, tanks, plumbing diagrams, electrical interface, kneeling system and air suspension, inspection, location, troubleshooting, maintenance and troubleshooting, maintenance and repair of regenerative braking and foundation braking.	Maintenance Personnel as designated by the Agency	16
Class 9: Steering, Suspension and Axle Systems	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance and repair of steering, suspension, and axle systems	Maintenance Personnel as designated by the Agency	8
Class 10: Wheelchair Ramp System	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance (preventive and corrective) and repair of the wheelchair ramp system including automatic and manual operation as applicable	Maintenance Personnel as designated by the Agency	4

PHASE 2 TRAINING			
Course	**Description**	**Target Audience**	**Length (Hours)**
Class 11: Entrance & Exit Doors	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance (preventive and corrective) and repair of coach assembly, door adjustments, fasteners, repairs, major repairs, windows, seat adjustments, interiors, doors, under-floor heater boxes, etc.	Maintenance Personnel as designated by the Agency	8
Class 12: Electric Propulsion System Overhaul	Class shall cover the inspection, location, troubleshooting/ diagnostics, maintenance (preventive and corrective) and repair of the electric propulsion system including traction motor(s) and other propulsion components that can be overhauled. Training shall include performance testing, bus interface electrical and mechanical drawings, and diagnostic software, general construction and principles of operation, cooling pumps/ piping diagnostics, and vehicle interface and the electronic control system. Assembly and disassembly procedures shall also be provided by the OEM.	Maintenance Personnel as designated by the Agency	40

Special Tools and Diagnostic Equipment

The Contractor and any OEM component vendors shall provide a list of all required special tooling and diagnostic equipment pertaining to the BEB being procured and related pricing.

The Contractor and any OEM component vendors shall also provide a recommended list of all generic insulated tooling and high-voltage PPE.

Vehicle Maintenance Training – Warranty (Optional)

The Contractor shall provide training to a level whereby the Contractor, following all training delivered, certifies that those trained are fully capable of performing all warranty repairs on the BEBs purchased. If the Contractor will not certify agency employees to perform certain warranty repairs as a result of their training, the Contractor shall list the specific repairs and the reason(s) why Agency employees cannot be certified to perform them.

It is understandable that prior to receiving the full complement of training and resulting certification and in cases where Agency employees cannot be certified, the Contractor or affiliated vendor will need to make certain warranty repairs. In those cases, the Agency shall use the warranty repairs as a training exercise if sufficient staffing is available. Before the warranty repairs begin, the Contractor or Component Vendor shall inform the maintenance department when (date and time) the warranty repair(s) will be made, the cause of the need for repair, and the anticipated repair procedures. If a technician or instructor is available, the Agency will send the appropriate staff representative to oversee the repair. During the repair, the Contractor or Component Vendor shall describe all procedures used to facilitate the repair including any safety considerations and use of special tools or procedures. The Contractor or Component Vendor may have available Agency staff (e.g., technician, instructor, supervisor) assist with the repair as part of the training exercise. A copy of the repair order shall be submitted to the Agency immediately following each warranty repair. This option does not prevent the Agency from having OEMs perform warranty repairs if they choose to.

The table below provides guidance pertaining to insulated tools and PPE typically required for BEBs.

INSULATED TOOLS	
Tool	**Recommended Quantity**
CAT III rated digital multimeter(s) (rated up to 1000 VDC)	1 for each BEB technician
Insulated hand tools that follow ASTM F1505-01 and IEC 900 standards and compliance with OSHA 1910.333 (c)(2) and NFPA 70E standards (as recommended by the BEB OEM)	1 set for each BEB technician that could be working on a BEB at any given time

PERSONAL PROTECTIVE EQUIPMENT		
Tool	**Recommended Quantity**	**Notes**
ASTM Class 0 insulated gloves with red label	1 pair, properly sized for each BEB technician	Insulated gloves need to be tested and replaced at specified intervals.
Leather gloves to be worn over ASTM insulated gloves	1 pair, properly sized for each BEB technician	
Insulated EH Rated Safety Shoes	1 pair, properly sized for each BEB technician	
NRR 33 rated ear plugs	Ample supply for each BEB technician that could be working on a BEB at any given time	
NRR 331 rated (overhead) earmuffs	Ample supply for each BEB technician that could be working on a BEB at any given time	Note: Combining NRR 33 rated ear plugs with NRR 31 earmuffs can provide a NRR protection level of 36.
Arc flash suits	Ample supply for each BEB technician that could be working on a BEB at any given time	
Combination arc flash shield and hardhat	Ample supply for each BEB technician that could be working on a BEB at any given time	
Arc flash hoods	Ample supply for each BEB technician that could be working on a BEB at any given time	Arc flash shield, hardhat and hood may be procured as one integrated item depending on manufacturer and agency preference.
Insulated electrical rescue hook(s) (Sheppard's Hook) sized for use on BEBs	1 set for each BEB technician that could be working on a BEB at any given time (certain HV operations require a second worker to be available to extricate primary worker in an emergency)	

Acronyms and Abbreviations

APTA	American Public Transportation Association
BEB	Battery electric bus
DCCC	Design Criteria Conformance Checklist
FTA	Federal Transit Administration
FLS	Fire Life Safety
LoNo	Low or No Emission Vehicle Deployment Program (through 2015)
LOTO	Lock Out/tag Out
Low-No	Low or No Emissions Vehicle Program (from 2016)
NFPA	National Fire Protection Association
OEM	Original equipment manufacturer
OHA	Operational Hazard Analysis
PHA	Preliminary Hazard Analysis
PPE	Personal protective equipment
SA	Safety Assurance
SAE	Society of Automotive Engineers
SMS	Safety Management System
SoC	State of charge
SRM	Safety Risk Management
SSC	Safety and Security Certification
TSCC	Testing Specification Conformance Checklist
TVA	Threat and Vulnerability Assessment
ZEB	Zero-emission bus

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