FTA Report No. 0253

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Procuring and Maintaining Battery Electric Buses and Charging Systems – Best Practices

PREPARED BY

Center for Urban Transportation Research

AUGUST 2023

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

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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)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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14. ABSTRACT
The primary objective of this project was to identify the best practices for procuring and maintaining battery electric buses (BEB) and charging systems to help in U.S. Department of Transportation efforts to support the transition of the nation's transportation systems to electric vehicles and other zero-carbon technologies. The research outcomes include the identification of areas for voluntary standards development, and the development or modification of existing relevant standards including procurement specifications, other procurement documents, and maintenance standards and guidelines for transit buses powered through electric propulsion and associated charging infrastructure.

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Abstract

The primary objective of this project was to identify the best practices for procuring and maintaining battery electric buses (BEB) and charging systems to help in U.S. Department of Transportation efforts to support the transition of the nation's transportation systems to electric vehicles and other zero-carbon technologies. The research outcomes include the identification of areas for voluntary standards development, and the development or modification of existing relevant standards including procurement specifications, other procurement documents, and maintenance standards and guidelines for transit buses powered through electric propulsion and associated charging infrastructure.

Executive Summary

Introduction

The primary objective of this project was to identify the best practices for procuring and maintaining battery electric buses and charging systems to help in U.S. Department of Transportation efforts to support the transition of the nation's transportation systems to electric vehicles and other zero-carbon technologies. The research outcomes include the identification of areas for voluntary standards development, and the development or modification of existing relevant standards, including procurement specifications, other procurement documents, and maintenance standards and guidelines for transit buses powered through electric propulsion and associated charging infrastructure. This project was performed for FTA's Office of Research, Demonstration and Innovation (TRI).

The overall benefits of the current report focus on key challenges agencies should expect as they initiate their transition to battery electric bus (BEB) fleets. The summarized findings provide insight and considerations that will be most valuable for transit agencies that are not yet mature in their BEB fleet transition. In addition to this report, a holistic guidebook or guidance document will be developed to combine the findings from this report, the findings from the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* report, and the guidance detailed in the International Transportation Learning Center's report *Providing Training for Zero Emission Buses: Recommended Expanded RFP Language*.[1] The future guidance document will be most beneficial to agencies that are planning their next BEB procurement. Additionally, the guidance document will ultimately be provided to the American Public Transportation Association (APTA) for consideration of inclusion by reference in the Battery Electric Bus sections of its *Standard Bus Procurement Guidelines*.

Background

FTA entered into a Cooperative Agreement with the University of South Florida's Center for Urban Transportation Research (CUTR) to explore areas of transit safety risk, identify associated existing standards and recommended practices and training, perform gap analyses, and produce research reports. FTA may utilize the findings from the research reports conducted through the program to document the need for additional standards, guidance, or recommended practices to support and further the decarbonization of the nation's public transportation systems.

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

The current FTA Standards Development Program report was developed as a resource for the industry, providing a summary of industry reports that highlight the challenges and opportunities with BEB deployments and the outcomes of federally sponsored deployments, existing standards from the American Public Transportation Association (APTA) and the Society for 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. The findings serve as tools to identify likely challenges that transit agencies should consider prior to embarking on the journey to transition bus fleets to electrification, such as specific language to include in procurements to reduce issues associated with parts availability and battery warranty ambiguity. The findings, when considered together, provide transit agencies a compilation of best practices in terms of procurement language, training, interoperability, resiliency, and variable charging management approaches. The report also addresses training for technicians assigned to maintain and repair BEB vehicles and support infrastructure.

Methodology

This research was performed by a team of researchers from the Center for Urban Transportation Research (CUTR). In addition to the transit agency representatives who were interviewed, the project team also engaged CUTR's Transit Standards Working Group, industry stakeholders, and APTA, including its Standards Program Battery Electric Bus Subcommittee.

This report includes:

- A literature review summary
- Identification of existing standards, recommended practices, and guidance documents associated with the procurement or maintenance of battery electric buses and charging systems
- Identification of needs and gaps for new voluntary standards, guidance documents, or other resources
- Identification of any existing standards, guidelines, or other industry technical assistance documents that need to be modified or enhanced
- Identification and description of standards development organization (SDO) coordination during report development and in implementation options
- Conclusions and findings

Conclusions and Findings

The literature review revealed common themes that occurred throughout various agencies that have procured BEBs. The literature review led to 12 general preliminary findings that can be broken down into 6 categories: planning, training, cost, space, charger efficiency and interoperability, and challenges accessing parts. Through the extensive literature review followed by a survey of 25 transit agencies that have procured BEBs, case study follow-up interviews with 8 transit agencies, and extensive feedback from the CUTR Transit Standards Working Group, the research team developed several significant findings. These findings comprise the general summary of themes that recurred throughout this research project:

1. **Parts availability remains challenging:** Agencies that include original equipment manufacturer (OEM) parts availability expectations in contract negotiations/procurement language may reduce associated challenges with the unavailability of necessary replacement parts.

2. **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.

3. **Battery warranty ambiguity:** 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 the ambiguity of the warranty.

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

5. **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 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.

6. **Standardized training would be beneficial:**

    - 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, which may in turn reduce the technician shortages that many agencies are experiencing.

- Route planning and control center training to clarify the capabilities and limitations of BEBs for both route planners and control center personnel may align the expectations of the BEB with its performance ability, and may in turn reduce unexpected state of charge challenges.
- First responder training to provide familiarization of BEB designs may reduce unanticipated hazards and challenges when emergencies occur.

7. **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 when transitioning to larger fleets. BEBs that have roof-mounted equipment also require personnel lifts for top-of-bus maintenance and additional fall protection.

8. **Interoperability challenges will exacerbate space limitations for charging infrastructure:** As agencies begin to mix fleets during 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.

9. **Resiliency and backup power source considerations:** Fuel diversification and availability of backup power may be beneficial when power is unavailable for extended periods of time, such as during 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 needed.

10. **Charging infrastructure is advancing:** Higher power ultra-fast charging systems are entering the market with the promise of reducing dwell time or 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.

11. **Variable utility rates lead to inconsistent charging costs:** Agencies may have limited negotiating powers with utility providers and should therefore consider variations in utility rates by time of day.

12. **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 transit agency owning full responsibility for the charging infrastructure.

Section 1

Introduction

The primary objective of this project was to identify the best practices for procuring and maintaining battery electric buses and charging systems to help in U.S. Department of Transportation efforts to support the transition of the nation's transportation systems to electric vehicles and other zero-carbon technologies. The project outcomes include the identification of areas for voluntary standards development, and the development or modification of existing relevant standards, including procurement specifications, other procurement documents, and maintenance standards and guidelines for transit buses powered through electric propulsion and associated charging infrastructure. This project was performed with significant industry stakeholder participation and standards development organizations (SDOs), such as the American Public Transportation Association (APTA). While the scope of work did not include evaluating the processes and procedures associated with battery electric buses, the findings of this examination may support the further review, demonstration, and/or testing of processes, procedures, or technologies that could be implemented to safely accelerate the decarbonization of transit. This project was performed for FTA's Office of Research, Demonstration and Innovation (TRI).

The overall benefits of the current report focus on key challenges agencies should expect as they initiate their transition to battery electric bus (BEB) fleets. The summarized findings provide insight and considerations that will be most valuable for transit agencies that are not yet mature in their BEB fleet transition. In addition to this report, a holistic guidebook or guidance document will be developed to combine the findings from this report, the findings from the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* report, and the guidance detailed in the International Transportation Learning Center's report *Providing Training for Zero Emission Buses: Recommended Expanded RFP Language*.[2] The future guidance document will be most beneficial to agencies that are planning their next BEB procurement. Additionally, the guidance document will ultimately be provided to APTA for consideration of inclusion by reference in the Battery Electric Bus section of its *Standard Bus Procurement Guidelines.*

Background

FTA entered into a Cooperative Agreement with the University of South Florida's Center for Urban Transportation Research (CUTR) to identify associated existing standards and recommended practices including those that fall within safety promotion, such as training; to perform gap analyses; and to produce research reports in the area of battery electric bus procurement and maintenance. FTA may

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

utilize the findings from the research reports conducted through the program to document the need for additional standards, guidance, or recommended practices to support and further safe deployment and operation of BEBs in the nation's public transportation systems.

The current FTA Standards Development Program report was developed as a resource for the industry, providing a summary of industry reports that highlight the challenges and opportunities with BEB deployments and the outcomes of federally sponsored deployments, existing standards from 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. The report also addresses training for technicians assigned to maintain and repair BEB vehicles and support infrastructure.

Methodology

This project was performed by a team of researchers from the Center for Urban Transportation Research (CUTR). The project team engaged CUTR's Transit Standards Working Group, industry stakeholders, and APTA, including its Standards Program Battery Electric Bus Subcommittee.

This report summarizes the project efforts, including:

- A literature review
- Identification of existing standards, recommended practices, and guidance documents associated with the procurement or maintenance of battery electric buses and charging systems
- Identification of needs and gaps for new voluntary standards, guidance documents, or other resources
- Identification of any existing standards, guidelines, or other industry technical assistance documents that need to be modified or enhanced
- Identification and description of SDO coordination during report development and in implementation options
- Research findings and corresponding recommendations

Section 2

Literature Review

The following section details the literature review and background research on procuring and maintaining battery electric buses and charging stations to inform subsequent tasks. These literature review sources included:

- Relevant FTA internal or external strategic research plan/direction documents
- Research reports issued by:
  - FTA Bus Testing and Reports – Altoona Testing and Low-No and LoNo Emission reports
  - Other FTA TRI research reports and program planning documents
  - Transit Research Board (TRB) and its Cooperative Research Programs
  - Other research bodies (including state departments of transportation)
  - Relevant reports issued by Volpe National Transportation Systems Center
- Voluntary consensus standards, guidance documents, and model practices used by or with relevance to the U.S. transit industry, including those developed by APTA as an example. This involved relevant APTA standards and recommended practices in development, such as the Battery Electric Bus elements in APTA's *Best Practices Procurement Manual* and BEB familiarization training.

At a minimum, the background research and examination also included:

- Related Federal transportation laws or regulations (e.g., Title 49, Chapter V, Part 571, Subpart B – Federal Motor Vehicle Safety Standards, No.105)
- Related state transportation laws or regulations
- Other standards issued by SDOs such as SAE and APTA, as examples
- Federal guidance documents issued by the U.S. Department of Transportation and its Modal Administrations, as examples
- Technical and academic papers submitted to various journals and academic sites, including Elsevier and its associated journals, World Transit Research (Monash University), and others
- Other industry best or model practices, guidance documents, and training manuals

FTA TRI Zero-Emission Bus Evaluation Results Reports

FTA has remained involved and invested in research to advance the production and deployment of advanced vehicle technology, including improved understanding of zero-emission bus deployments, and the associated challenges that have been faced throughout the transition to zero-emission fleets. The relevant FTA publications are summarized throughout this section.

FTA TRI Research Reports and Program Planning Documents

Transit Vehicle Innovation Deployment Centers (TVIDC) Advisory Panel Overview and Conclusions

While FTA Report No. 0182, published January 2021, includes vehicle innovation beyond BEB, many of the proposed solutions are associated with BEB and other zero-emission bus (ZEB) industry needs and important considerations.[3] The proposed solutions were formed with input from an advisory panel and categorized into five focus areas:

- Bus testing facilities
- ZEB innovation research
- Transit bus automation
- ZEB workforce development
- Collaboration with electric utilities

The proposed solutions related to bus testing include recommendations to eliminate the cost share requirements for the Low and No-Emission Component Assessment Program (LoNo-CAP) to incentivize voluntary component testing; establish clear roles and responsibilities of each designated testing facility to reduce redundancy and lead on standards development; and to inform bus testing priorities through an industry working group that could also serve as a channel for comparison and discussion of public testing results.

The proposed solutions related to innovation research contain recommendations to prioritize at-scale ZEB demonstrations (more than 50 buses) to fully understand the technical and operational challenges associated with full fleet transitions; focus research on efficiency improvements to improve overall vehicle energy efficiency; explore resiliency and disaster mitigation strategies to allow BEB use as generators; and develop a repository for lessons learned to inform industries, policy makers, and the general public.

In terms of transit bus automation solutions related to BEB, the panel proposed a reassessment of FTA goals for transit bus automation with an emphasis on advanced driver assistance systems that may improve safety and yard capabilities for automated BEB charging and parking.

The proposed solutions related to ZEB workforce development recommend dedicating a program for ZEB training and workforce development; expanding the National Transit Institute (NTI) program to incorporate ZEB related

[3] https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-01/FTA-Report-No-0182.pdf

workforce development that focuses on areas such as high-voltage systems training, diagnostics, operations, procurement, charge management and telematics, and executive level and capital planning; and incentivizing the use of workforce development centers.

Finally, in terms of collaboration with electric utilities, the panel recommended that FTA designate or sponsor a cross-industry working group to provide education, outreach, discussion opportunities, and expand on collaborative efforts, and develop an infrastructure deployment planning guidebook to improve transit agencies' understanding of electric utility operations, rate-setting, and how utilities can support infrastructure deployment and electricity provisions for BEB operations.

FTA Annual Report on Public Transportation Innovation Research Projects for Fiscal Year 2020

The FTA mission to improve public transportation for America's communities is served in part through FTA's overarching research goals focused on safety, mobility innovation, and infrastructure.[4] Through a four-phase research-to-practice pipeline process, research leads to innovative development, followed by demonstration and development, and finally evaluation and implementation.

FTA has been investing in reducing transit greenhouse gas and energy dating back to the Transit Investments for Greenhouse Gas and Energy Reduction (TIGER) grant program, which funded eight rounds of projects between 2009 and 2017.[5] The Low or No Emission Vehicle Deployment Program (LoNo) was a research program established under the Moving Ahead for Progress in the 21st Century Act (MAP-21) that funded low-no projects until 2015.[6] Projects funded after 2016 receive funds under the 5339(c) Low or No Emission Vehicle Program (Low-No).[7] While the programs are similar, they are not interchangeable due to the differing reporting requirements.

Several of the early projects have now completed their final reports, offering details and insight into their alternatively fueled vehicle deployments. Table 2-1 displays the transit agencies whose final reports on battery electric bus deployments were examined for this literature review.

[4] https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-01/FTA-Report-No-0181.pdf
[5] https://www.transit.dot.gov/funding/grants/better-utilizing-investments-leverage-development-build-transportation-grants-program
[6] https://www.transit.dot.gov/research-innovation/fiscal-year-2015-low-and-no-emission-vehicle deployment-program-projects; https://www.transportation.gov/briefing-room/us-department-transportation-announces-225-million-put-more-low-and-no-emission
[7] https://www.transit.dot.gov/lowno

Table 2-1 *LoNo Emission Vehicle Deployment or Low-No Emission Vehicle Program Deployments Highlighted*

Project	Transit Agency	City and State
15 BEBs	Foothill Transit	Greater Los Angeles, CA
5 BEBs	Alameda-Contra Costa Transit District Commission	Oakland, CA
10 BEBs	Long Beach Transit	Long Beach, CA
8 BEBs	King County Metro	Seattle, WA

Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses

In 2010, King County Metro was awarded a grant to fund the addition of three 40-foot fast-charge, composite BEBs to its fleet.[8] The National Renewable Energy Laboratory (NREL) performed an in-service evaluation of King County Metro's BEB fleet in the greater Seattle metropolitan area. The BEBs were compared to 40-foot model year (MY) 2015 bus models, including a GILLIG standard diesel bus, New Flyer's Xcelsior diesel-hybrid bus, and New Flyer's Xcelsior electric trolley bus. The data was collected from April 2016 to March 2017.

The BEBs performed 83,128 miles in the data collection period for an average of 27,709 miles per bus. The BEBs' overall efficiency averaged 2.36-kilowatt hours (kWh), which is comparable to a fuel economy of 15.9 miles per diesel gallon equivalent (mpdge). During the data collection year, the cost of electricity for the BEBs averaged $0.20/kWh and $1.60/gal for diesel fuel. KC Metro acquired demand charges when the charging rates surpassed 50 kW, which comprised a substantial percentage of the monthly utility bills (between 34% and 54%). NREL also evaluated the reliability of bus performance using miles between road calls (MBRC) as the measure. The BEB performed better (below 3,500 MBRC) compared to the diesel (17,332 MBRC) and hybrid bus fleet (7,641 MRBC). Maintenance costs (both scheduled and unscheduled) were tracked; the average per-mile maintenance cost for the data collection period was $0.26/mile for BEBs compared to $0.32/mile for the hybrid fleet, $0.46/mile for diesel buses, and $0.46/mile for trolley buses. NREL found that the most expensive maintenance costs for both the battery electric and conventional diesel buses were due to (1) parts and accessories, (2) propulsion system, and (3) preventative maintenance inspections.

[8] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf

Table 2-2 *King County Metro BEB Detail*[9]

Data Item	Battery	Hybrid	Diesel	Trolley
Number of buses	3	10	3	10
Total mileage (in data period)	83,128	435,552	69,329	180,554
Average monthly mileage per bus	2,309	3,630	1,926	1,505
Availability (85% is target)	80.6	90.5	86.4	84.9
Fuel economy (kWh/mile)	2.36	—	—	2.57
Fuel economy (miles/dge)	15.9	6.3	5.3	14.7
Average speed, including stops (mph)	14.8	15.2	14.6	9.0
Miles between roadcalls (MBRC) – bus	2,771	7,641	17,332	1,641
MBRC – propulsion system only	80.6	90.5	86.4	84.9
Total maintenance cost ($/mile)	0.26	0.32	0.46	0.46
Maintenance – propulsion system only ($/mile)	0.05	0.12	0.13	0.17

NREL identified a number of lessons learned from the King Metro BEB demonstration to support both agencies and the industry in future BEB deployments.

- *Reducing demand charges*. NREL found that the monthly demand plug-in charges incurred by King Metro to support the BEB fleet was inversely proportional to the monthly operation of the battery electric buses; demand charges decreased as the mileage increased due to the fast charger being employed more often. Charger utilization will increase as the BEB fleet grows or if the existing battery bus fleet runs more often.
- *Availability of on-route fast chargers.* The on-route chargers are essential for supporting the operations of a fast charge BEB fleet.
- *Operator training*. BEBs require additional operator training on the charger docking procedure and ensuring that the BEBs are fully charged prior to returning to the base facility. If a fast charger is deployed at the base facility, this negates the need to return BEBs fully charged. These are key considerations for transit agencies deploying electric buses to integrate into training programs.
- *Operations planning*. Fast charge BEBs operate differently compared to conventional diesel buses. BEB range requires them to run on select routes and to regularly access charging stations. Service needs to be limited to select routes until charger capacity is sufficient to meet charging demand. Planned layover time for a BEB requires time to charge the bus; changes

[9] *ibid.*

made to the layover length of time could impact the ability of a bus to fully recharge.

- *Parts availability*. Parts availability can be problematic with BEBs. While King Metro did not experience delays with parts from their bus vendor, it may be necessary to stock parts to minimize repair delays.

Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses

In 2011, Long Beach Transit (LBT) was awarded a grant to fund a BEB pilot project including 10 40-foot BEBs.[10] LBT then evaluated the performance of the BEBs in comparison to baseline buses in similar service.

In addition to the 10 BEBs, LBT also dedicated 10 parking spaces along a wall of a facility with individual chargers installed at the head of each space. The BEBs charged at the end of the day after 10:00 pm when the rate of electricity was the lowest.

The majority of the BEBs operated one route that travels around a waterfront area with service every day of the week at an average speed of 8.1 mph. The fuel economy for the BEB fleet varied seasonally, as interior heating and cooling loads had a significant impact on the overall bus efficiency.

Through the demonstration and evaluation, LBT identified four key lessons learned to assist the industry in future BEB deployments. LBT recommended assembling an effective project team, expecting delays due to extenuating circumstances outside of the agency's control, planning for sufficient training for staff, and beginning the infrastructure planning early in the project. In addition to the lessons learned, LBT also identified four key technical challenges including battery issues, durability issues, deployment issues, and data collection and monitoring technology issues.

- The batteries developed balancing and degradation issues due to insufficient initial commissioning, in addition to conservative use, which did not allow the batteries to discharge below an optimal state of charge (SOC) and increased battery degradation. BYD, the bus manufacturer, replaced the original batteries under warranty with a newer generation of batteries, which were performing well at the time the report was written.
- LBT experienced issues with the durability of the bushings in the sway bar system and the hub reduction units in the axles. The issue with the bushings was solved through a component upgrade, while the issues with the hub reduction units in the axle had to be sent to the manufacturing plant for permanent repairs.

[10] https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-05/FTA-Report-No.-0163.pdf

- Through the initial deployment, LBT experienced issues with wheelchair lifts and doors, which were not related to the advanced technology components but still led to downtime due to required repairs.
- The Health Alert Monitoring System intended to monitor and collect data for analysis, though the technology was not fully functional when the deployment began, led to data availability challenges in the data evaluation phase of the deployment. Wireless receivers also led to reliability issues with the data collection. Findings from these challenges highlight the importance of validating data collection systems with each new installation.

Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses

In February 2017, County Connection, formally known as Central Contra Costa Transit Authority, in Concord, California, began operating a fleet of four BEBs in its service area.[11] As a part of the funding provided through FTA, an analysis of the four-vehicle fleet was conducted from June 2017 through May 2018. As part of FTA's Clean Fuels Grant Program in 2012, a grant was provided for the purchase of four GILLIG buses and two electric vehicle charging stations, while the 2016 Low-No Program[12] provided a grant that enabled the addition of four electric buses to the County Connection fleet.

The charging infrastructure consisted of two plug-in chargers at the facility and a WAVE inductive charging pad at one stop for wireless charging during scheduled layovers. The average time for the plug-in charger was 126 minutes, which occurred an average of less than once per day. The average charging time for the inductive charger was 6.9 minutes and each battery charged an average of 12 times per day.

In the first four months of evaluation, the BEB fleet experienced some charging issues and issues with the battery management system for high-voltage batteries, which were solved with software updates.

Downtime due to charging was found to significantly affect availability, particularly when reliant on a single on-route charger. The downtime was a result of issues related to the ancillary equipment used for cooling being damaged by an apparent lightning strike. The issues related to the damage were resolved by working with WAVE and average availability increased to nearly 85% for the last eight months of the evaluation.

[11] https://www.nrel.gov/docs/fy19osti/72864.pdf
[12] https://www.transit.dot.gov/funding/grants/fiscal-year-2016-low-or-no-emission-low-no-bus-program-projects

In recognition of the degradation of batteries over time, the agency planned the buses operation to keep the battery state of charge (SOC) above 60%. The average BEB route speed was 6 mph. The average efficiency, in terms of miles per diesel gallon equivalent (mpdge), varied with sensitivity to variation in ambient air temperature, with the lowest fuel economy for when temperatures exceeded 80˚F. The overall fuel economy averaged 13.3 mpdge, which was 3.8 times higher efficiency than the diesel trolley buses operated on the same route. During June 2017 to May 2018, County Connection accumulated more than 51,500 miles on BEBs in revenue service. Throughout that mileage accumulation, a summary of five challenges offers an opportunity for lessons learned.

Charger availability, charger efficiency, added operating costs, maintenance costs, and maintenance skill set were the five areas identified for lessons learned. County Connection determined that an on-route charger is critical for fleet availability. Charger efficiency settings can vary depending on preference of reliability or efficiency, specifically related to the design of the cooling system. There is a potential for added operating costs associated with BEB fleets that exceed the number of available installed chargers, as staff are needed to move buses to ensure that each bus is fully charged before parking overnight. County Connection recognized that this type of configuration will become increasingly challenging as the BEB fleet increases. While the maintenance costs for this analysis timeframe were covered under warranty, County Connection warned other agencies to carefully consider the variation from early reported costs to long-term, post-warranty potential maintenance costs. Finally, it was necessary to train the current staff the skillset necessary to maintain the BEBs. In addition, the maintenance challenges were exacerbated by a shortage of technicians. County Connection reported that the industry is addressing the technician shortage through partnerships with community colleges and technical schools to add the required courses for BEB technicians and provide specific BEB qualified technician certification.

Foothill Transit Battery Electric Bus Demonstration Results

In October 2010, Foothill Transit began a demonstration of 3 Proterra BEBs, followed by an additional 12 BEBs in 2014, which were funded through an FTA Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program grant.[13] The California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) also provided funding to offset the incremental costs of the BEB procurement.[14] The analysis period for these findings corresponds to operations from April 2015 through July 2015. The BEB demonstration initiated with a goal to fully electrify one route and investigate the feasibility of transitioning to BEBs on other routes.

[13] https://afdc.energy.gov/files/u/publication/foothill_transit_beb_demo_results.pdf
[14] https://www.californiahvip.org/

The California Air Resources Board (CARB) adopted the Fleet Rule for Transit Agencies in 2000, focused on reducing diesel particulate matter and emissions from urban buses by requiring agencies with 200 or more buses to include 15% of new bus purchases as zero-emission buses and schedule a path for the alternative fuel fleet transition.[15] Through subsequent resolutions, the implementation requirements were suspended in 2009 in favor of the research and development of commercial-readiness metrics to use as criteria for transitioning to zero-emission buses.

Foothill Transit contracts the operation and maintenance of its fleet, with two Proterra on-site technicians who handle all warranty work on the BEBs.[16] The agency installed an overhead blade fast charger system at a transit center that was conveniently located to charge the buses prior to returning to the depot. Foothill contracted an agreement with the City of Pomona to lease the space for the charging station at no cost for 40 years. A slow charger was also installed at the maintenance facility for additional charging when needed.

Foothill Transit ultimately identified challenges and lessons learned from the BEB demonstration, including demand charges and time of use charges that affect electricity costs, and training operators and maintenance staff in the differences between BEBs and conventionally propelled buses. The agency also determined that more investigation was needed before the agency could transition a greater share of its fleet to BEB.

The availability of charging is essential for the operation of BEB fleets, and Foothill Transit faced some challenges when the original equipment manufacturer (OEM) removed the chargers from its offerings. Two Eaton 500 kW chargers and additional necessary upgrades to the charger controls, cables, and wireless communications substituted for what the OEM was unable to produce. This substitution did lead to increased costs and had the potential to disrupt BEB service. The charging station has two separate chargers that operate on either side of the same facility. A common communication network serves both units with sensors to detect approaching buses and appropriate overhead docking. A full charge is typically complete in under 10 minutes.

The variable charging costs that change with demand, time, and use levels, and difficulties with negotiating reasonable rates with utility providers make the transition of fleets to BEB more costly and difficult to predict.

Operator training was challenging due to the BEB docking procedure, which differs from a conventional bus because the operator must apply the accelerator

[15] https://ww2.arb.ca.gov/news/arb-cuts-emissions-transit-buses
[16] https://afdc.energy.gov/files/u/publication/foothill_transit_beb_demo_results.pdf

rather than the brake as the bus approaches the docking station. Foothill Transit noted that training should be ongoing rather than a one-time event.

Unnecessary emergency stop button activation proved to be another challenge in the initial stages of the project, which was mitigated by installing an added cover to the button and signage indicating the area was under surveillance. Additionally, Foothill Transit found it beneficial to modify the reactivation process from manual to remote, reducing the downtime associated with an unnecessary activation.

The low-voltage starter batteries developed issues that required them to be replaced after operators failed to shut the bus down at the end of a shift, likely due to the lack of sound when the bus was on. This was mitigated from future occurrences through training.

Other issues that were experienced with the BEBs included a faulty connection between the local battery monitoring unit and the battery module, which was solved by replacing the wires and connections, as well as other issues not related to the buses power source.

Additional lessons learned from the Foothill Transit BEB deployment include recommendations to plan ahead to determine who to engage from the start of the implementation, such as utilities, local city officials, first responders, and the general public; reviewing routes to consider the best ones that fit BEB operations; and adjusting route schedules, and possibly route starting points, to accommodate BEB charging times and charger location(s).

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 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 tests to be performed at the bus testing facility.[17] The Altoona Bus Testing Center has had facilities for testing and repairing vehicles that use battery-power electricity in place since 1997.[18] 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 vehicle as it is operated on a chassis dynamometer over three driving cycles representative of typical transit operation.[19]

[17] https://www.transit.dot.gov/research-innovation/program-history
[18] https://www.altoonabustest.psu.edu/
[19] https://www.altoonabustest.psu.edu/bus-tests/Fuel-Economy.aspx

Bus Maintenance and Bus Testing Program Peer-to-Peer Exchange: Summary Report

On October 10, 2019, FTA hosted a peer exchange to provide an opportunity for public transit industry representatives to discuss bus maintenance worker training and best practices for training the next generation of transit vehicle technicians. FTA Report No. 0160 details major takeaways from the session, and includes recommendations from transit agency participants, vehicle and equipment manufacturers, trainers, researchers, and employee representatives. The major takeaways and lessons learned concerning BEBs are summarized below.[20]

- Standardized courses on newer technologies, including BEBs, would assist agencies with their workforce training.
- Technicians must now be trained to work on various propulsion and engine types. There is a need to develop the most streamlined ways to provide training that covers a variety of fuels and engines, including natural gas, hybrid, and BEBs.
- Working with utility providers is important for assessments of infrastructure and power needs when converting to BEBs.
- Workforce training should be included as part of procurement, especially with newer bus technologies. Training can be a component of the transaction cost of procuring new buses rather than a separate budget item.
- Shreveport Area Transit System (SporTran) in Louisiana partnered with a local community college to train student technicians to work on alternative fuel buses, including natural gas and BEBs, given that management did not plan ahead for training when the agency first integrated compressed natural gas (CNG) buses in 2010.
- Pinellas Suncoast Transit Authority (PSTA) in St. Petersburg, Florida, operates a large fleet of hybrid-electric buses and has also begun adopting battery electric buses. PSTA combines OEM trainers and in-house staff to train technicians in small groups in order to develop a workforce that is skilled in working on various propulsion types and technologies.
- Southeastern Pennsylvania Transportation Authority (SEPTA) in Philadelphia began adopting hybrid buses in 2000 and estimates that by 2021, 96% of their buses will be hybrids. The agency also has 25 BEBs. Training is included in bus procurements, and frontline employees are asked to submit their concerns and needs to the OEMs, who develop the training. The agency uses a web-based interface to conduct training through online webinars, which are also made available to other transit agencies.

[20] https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-05/FTA-Report-No.-0160.pdf

- Los Angeles County Transportation Authority (LA Metro) has 140 BEBs on order. The agency is preparing for these buses by providing high-voltage training through a contract with OEMs, which LA Metro also offers to other transit agencies. Online training works well for younger technicians, and the agency found the cost of proper training is less than the cost of an undiagnosed or misdiagnosed problem and parts replacement for the bus.

APTA Standards Guidelines, Reports, and Resources

Standard Bus Procurement Guidelines Request for Proposals APTA BTS-BPG-GL-001-12 (Rev.2.1.)

In April 2021, the APTA *Standard Bus Procurement Guidelines* was updated to include a battery electric bus option that uses depot-based charging and/or on-route charging.[21] The guidelines in this document are designed to provide direction to agencies for decision-making on procurement of battery electric buses, noting that there is not a one-size-fits-all model particularly as this technology continues to evolve. The BEB related sections are highlighted below, while the full 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. At extreme low SoC or extreme battery temperatures the regenerative brake performance may be reduced. However, any reductions should be smooth and predicable. Additionally, the system should be programable 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 defined range. The agency should define minimum operating range and time between charges as the default recommended practice, and the OEM-provided solution for range and time between charges as the alternative.
- *Section TS 8.2. Agency Operating Profile (Battery Electric Bus)*. Range specifications should be determined based on charging and operating solutions, given range requirements can be met with different bus and charging types. Buses may use on-route/opportunity charging to extend

[21] https://www.apta.com/wp-content/uploads/APTA-BTS-BPG-GL-001-13_R2_1.docx

range, compared to buses with larger battery packs, which may meet range needs with depot charging. Variables impacting range include average speed, route grades, driver behavior, climate/temperature, HVAC and heating use, passenger loads, and battery state of charge.

- *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 2344 to the greatest extent practical. 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 so 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 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 shall comply with similar applicable standards. The contractor should 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*.[22]
- *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*

[22] https://www.apta.com/wp-content/uploads/APTA-BTS-BPG-GL-001-13_R2_1.docx

Preparing to Plug In Your Bus Fleet

Prepared as a guide to working with local electric companies, this report was released through APTA in late 2019 and provided 10 key considerations for transit agencies looking to electrify their bus fleets.[23]

1. Engage with your electric company early and often.
2. Minimizing fuel costs is the key to success.
3. Electricity is delivered in real time and charging management strategies may be necessary.
4. Electric costs depend on charging management strategies.
5. Work with your electric company to ensure facilities are ready for charging.
6. Plan charging strategies prior to purchasing an electric bus.
7. Choose charging solutions for your needs.
8. Cooperation will be necessary across multiple agency departments.
9. Electricity as a fuel changes typical fuel availability considerations.
10. Transit agencies have many options to manage costs.

The appendix of the guide contains a service evaluation template for electric fleets to help transit agencies that are embarking on a fleet electrification project and are ready to begin evaluating their electricity needs. It includes basic questions related to location information, vehicle and operating profiles, and charging infrastructure. Additional questions on 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.

Public Transit Leading in Transition to Clean Technology

APTA estimated that the share of hybrid-electric or fully electric bus fleets increased 17% between 2009 and 2018. Furthermore, maintenance savings can be realized with BEBs due to the lack of oil changes, no transmissions, and longer-lasting brakes, resulting in a BEB's ability to travel more than twice the distance of natural gas buses between routine services. While hybrid-electric buses represented 21% of the fleet in 2018, the goal for transit agencies has focused toward zero-emission buses, such as BEBs. This APTA report concluded noting that strong partnerships and clear targets are essential as agencies transition their fleets.[24]

[23] https://www.apta.com/wp-content/uploads/PreparingToPlugInYourBusFleet_FINAL_2019.pdf
[24] https://www.apta.com/wp-content/uploads/Public_Transit_Leading_In_Transition_To_Clean_Technology.pdf

Best Practices for Implementing Battery Electric Buses into Your Fleet

This 2019 presentation from APTA Emerging Leaders presents best practices for agencies considering adoption of BEBs. BEB demand is increasing, particularly since costs per unit are set to decrease as manufacturing and technology improves. As BEB technology continues to evolve, several factors are anticipated to continue driving the BEB market including faster charge times, wireless/inductive charging systems, battery and range improvements, solid state batteries, and fuel cell range extenders. Below is a summary of the best practices identified by practitioners in the report.[25]

- 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 that 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, are 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 help to 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.

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

- Develop programs that track efficient driving behaviors to maximize BEB efficiency.

APTA Emerging Leaders – Resiliency for Battery Electric Buses: Best Practices & Future Strategies

When planning to integrate BEBs into a fleet, agencies need to consider the resiliency of electricity as a primary fuel source. BEBs depend on the reliability and availability of the power grid, unlike gaseous fuel propulsion systems such as diesel or CNG. 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.

This document from APTA identifies key considerations with regards to BEB resiliency.[26]

- 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 a power outage and disruption of BEB operation.
- Backup power sources should also be available at facilities, including diesel or CNG-powered generators.
- Working with utilities to set up multiple connections to the grid allows bus chargers to 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 deliver back-up power in the event of a power outage.

TRB Cooperative Research Program Reports

The Transportation Research Board's Transit Cooperative Research Program (TCRP) is an applied research program that produces solutions to problems identified by public transportation industry stakeholders.

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

Battery Electric Buses – State of the Practice

This 2018 synthesis report from the Transit Cooperative Research Program summarizes BEB market growth and outlines major challenges for the transit sector in deploying BEBs.[27] Major challenges related to scaling up charging infrastructure, such as space constraints, grid impacts, fleet staging, labor, maintenance requirements, and backup power availability, present obstacles to transit agencies seeking to advance their BEB programs. This report identified the need for agencies to properly evaluate life cycle costs to inform procurement. Interoperability is also cited as a major barrier and underscores the need for charging infrastructure standards as developed through cooperative efforts between bus OEMs, charging equipment providers, industry, nonprofits, and transit associations.

Guidebook for Deploying Zero-Emission Transit Buses

This guidebook produced by TCRP in 2021 contains best practices for ZEB (BEB and fuel cell electric bus) deployments and lessons learned from deployments, practitioners, and the industry.[28] The publication offers a framework for transit agencies to navigate the complex decision-making and planning processes for integrating ZEBs into their fleet, including establishing relationships with technology vendors, utilities, fuel suppliers, and contractors. The 10 phases detailed in the guidebook assist users with understanding the key steps, stakeholders, and decision-making processes to maximize BEB deployment. The guidebook emphasizes that BEB deployment requires careful planning and long-term strategies. There will be factors unique to each agency's services, requirements, resources, and organizational goals and objectives. Below is a summary of the best practices developed.

- *Needs assessment*. Establish short- and long-term goals based on input from key staff and start with small-scale BEB deployment. Identify relevant regulations and grant opportunities that may impact this deployment. Work with stakeholders to ensure deployment is coordinated and needs are addressed.
- *Fleetwide assessment and master plan.* Fleet assessments should account for deployment objectives and challenges, as well as the agency's bus replacement schedule. Route and bus modeling are two tools that can produce specific information on BEB performance in an agency's service area. BEBs may not be a 1:1 replacement for diesel or gasoline buses due to range restrictions. The master plan, updated every two years, should inform BEB deployment, infrastructure requirements, facility upgrades, and training needs.

[27] https://nap.nationalacademies.org/catalog/25061/battery-electric-buses-state-of-the-practice
[28] http://www.trb.org/Publications/Blurbs/180811.aspx

- *Technology selection and specification*. Choose the optimal BEB technology based on performance evaluation utilizing both modeling and deployment data. Create technical specification and performance requirements for vehicles and infrastructure that address the agency's particular needs. Confirm BEB procurement documents address inspections, acceptance testing, and warranties.
- *Successful modeling and simulation.* Conduct initial block screening and assess estimated energy requirements to understand the impacts of drivetrain and auxiliary systems energy requirements. Gather data from routes that model the service area as inputs for the model. Collect data over multiple days and identify routes that represent the service area. Model multiple bus efficiencies ("nominal" and "strenuous") to gauge how efficiency and range may be impacted. Consider creating decision-support tools that allow dispatch to better understand expected range based on unique conditions.

BEB Charging Infrastructure

The TCRP guidebook also identifies three general BEB charging technology options available in the industry: plug-in charging, overhead conductive charging, and wireless inductive charging. When charging occurs at the bus depot, plug-in charging is common, while overhead conductive and wireless inductive charging infrastructure are typically used for on-route charging. The guidebook identifies installation characteristics, advantages, and disadvantages for each type of BEB charging infrastructure, highlighting that while the plug-in charging units have a lower unit cost, they can typically only serve one or two buses per unit; meanwhile, the overhead conductive and wireless inductive charging infrastructure cost more per unit, but each unit can serve many buses. The time to charge is another key difference between the three types of charging infrastructure alternatives. Plug-in charging typically takes a few hours, while overhead conductive charging may only take 5 to 20 minutes per charge.

Industry Reports

Steep Climb Ahead: How Fleet Managers Can Prepare for the Coming Wave of Electrified Vehicles

As fleet managers consider strategies to decarbonize fleet operations, electrification is increasingly being considered as a strategy for helping to achieve emission reduction goals. This report from the Rocky Mountain Institute (RMI) summarizes major findings from a survey of fleet managers on their perspectives of electric vehicles, electric vehicle charging equipment, and requirements to scale up EV adoption. The major findings and lessons learned are summarized below.[29]

[29] https://rmi.org/wp-content/uploads/dlm_uploads/2021/01/steep_climb_ahead_fleets_survey_2021.pdf

- *Scaling up charging infrastructure*. As fleet EV procurement expands, scaling up charging infrastructure is a key consideration to support higher charging demand. This may present organizational challenges with procuring more expensive chargers that require more intricate installations.
- *Working with utilities.* Fleet managers should establish good working relationships with their utilities early in the process. Projects that entail charging infrastructure at large fleet depots, truck stops, and fleet yards with medium- and heavy-duty trucks that may have extensive power requirements necessitate involvement from utilities during the early planning process.
- *Ensuring adequate charging levels.* Public charging infrastructure is limited and cannot be relied upon for adequate charging to support operation demands. To scale for a growing BEB fleet, Level 2 charging may not be sufficient and fleet managers may need to deploy direct current fast charging (DCFC), which is more expensive to install and operate.
- *Managing charging for operational requirements.* Managing conventional vehicle duty cycles can be a complex task. Fleet managers need to devote resources and time to planning for charging infrastructure and maintenance of that infrastructure. Another option is to contract with a "charging-as-a-service" vendor.
- *Planning for backup power.* Grid power disruptions present challenges for maintaining BEB operations and fleet managers must prepare to ensure service continuity during disruptions. Backup power capacity may be considerable to support fleet BEBs.

Procurement Strategies for Reducing Capital Costs of Zero-Emission Buses

This report from the Center for Transportation and the Environment (CTE) considers the effectiveness of joint procurement strategies for decreasing capital costs of zero-emission buses.[30] Joint procurement has been implemented to reduce vehicle costs.

- The complexity of the procurement process may require agencies to adhere to local and state procurement regulations, which may vary by state and locality. Many transit agencies develop their vehicle specifications based on APTA bus procurement guidelines; however, at the time of this report, APTA does not have guidelines for zero-emission buses although they are under development. Standardization regarding bus design and aesthetics may also present challenges with procurement partnerships across multiple fleets.

[30] https://cte.tv/wp-content/uploads/2020/12/Joint-Procurement-and-ZEBs_FINAL.pdf

- Cost factors, technology changes, warranties, and training requirements all impact ZEB purchase price.
- Funding availability during procurement cycles is important for ZEB procurement, given that ZEBs continue to be about twice as expensive in terms of upfront costs compared to diesel buses. Funding from federal, state, and local agencies have helped to offset some of these costs. However, grant application timelines vary and may conflict with procurement scheduling.
- Joint procurements can help to increase sales volumes of ZEBs by combining purchases from multiple agencies, which may help to reduce costs and secure better pricing for agencies. Standardization of vehicle configurations and specifications (for example, preferences on propulsion systems, battery systems, and other components) may vary between agencies. A regional joint procurement arrangement may be helpful given that regions may share similar operational characteristics.
- Membership-based cooperative purchasing presents alternative purchasing strategies. Cooperative purchasing organizations, such as Sourcewell, work with OEM suppliers to secure contracts for vehicles and equipment (with various configurations).
- State purchasing contracts can help to increase sales volume and reduce barriers to ZEB procurement. Given that States may be better positioned to understand the unique needs of their urban and rural transit agencies, they can work to develop vehicle and equipment specifications that address these needs.
- Public-private partnerships may provide an opportunity to address barriers to ZEB procurement, such as the high capital costs of ZEBs. Agencies may be able to use operational savings to pay back a private entity for an initial investment.

SAE International Standards

SAE J1772 Plug-in Charging

This SAE standard includes the physical, electrical, functional, and performance requirements to perform conductive charging of battery electric and plug-in hybrid electric vehicles. Transit vehicles use SAE J1772 with a Combined or "Combo" Charging System (CCS) Type 1 and Type 2 five-pin connector for plug-in charging. There is also a seven-pin Combo Coupler that has both a five-pin J1772 connector and a CCS two-pin connector that support DC fast charging. This is the North American standard for electrical connectors, which covers the conductive charging system architecture, operational requirements, and functional and dimensional requirements for the inlet and connector.[31]

[31] https://www.jstor.org/stable/26559569

SAE J3105 Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices – Recommended Practices

This guidance document from SAE International addresses the physical, electrical, functional, testing, and performance requirements for conductive power transfer used primarily for transit buses using an overhead charger to transfer direct current (DC) power. On-route charging uses SAE J3105 with a power transfer system. This power transfer system utilizes an overhead pantograph system on an overhead gantry, which is lowered to the roof of the bus once the operator initiates it. This charging system provides for power up to 600 kW.[32]

SAE J2954/2 Wireless Power Transfer and Alignment for Heavy-Duty Applications

SAE J2954/2, which is currently a work in progress, will designate industry-wide specification guidelines to define criteria for the interoperability, electromagnetic compatibility, minimum performance, safety, and testing of wireless power transfer for high-power wireless charging of battery electric and plug-in hybrid electric vehicles for heavy-duty, off-road, and equipment.[33]

DOT/Volpe Reports

Electrifying Transit: A Guidebook for Implementing Battery Electric Buses

This 2021 guidebook from the National Renewable Energy Laboratory (NREL) and the U.S. Agency for International Development (USAID) provides an overview of key planning and preparation considerations for transit agencies considering BEB deployment.[34]

- Identifying short- and long-range goals, developing key performance indicators, facilitating stakeholder involvement, and securing funding sources are critical steps for designing a BEB program.
- When planning for BEBs, evaluating the available bus and charging technologies is important for designing goals and objectives. The three key components of a BEB are the bus configuration, battery system, and charging infrastructure.
- Charging methods include depot charging, on-route charging, and battery swapping. Power demand from the grid to charge BEBs requires consideration of the electric utility's rate structure, since varying BEB charging strategies may incur additional costs depending on energy

[32] https://www.sae.org/standards/content/j3105_202001/
[33] https://www.sae.org/standards/content/j2954/2/
[34] https://www.nrel.gov/docs/fy21osti/76932.pdf

charges, demand charges, and time-of-use charges. Upgrades to transmission lines and electricity distribution may be necessary if existing infrastructure is not adequate to meet increased load from demand, underscoring the need to engage electric utilities early in the BEB planning process.

- Variables that may affect BEB and charging choices include bus route (length, start/stop frequencies, road grade, road dimension, and traffic patterns) and bus operation (bus speeds, passenger capacity/bus ridership, bus size and weight, operation schedules, deadhead, and vulnerability to route disruptions). Factors that may impact the choice of charging infrastructure include layovers, electrical grid access and interconnection, overlap with routes, and space constraints.
- Other considerations involve the need to factor in training, bus testing, charging station maintenance, and emergency preparedness plans.

Transit Agency Reports

Zero Emission Transit Bus Technology Analysis

This report from AC Transit in 2021 summarizes the agency's analysis of zero-emission bus technologies, including battery electric and fuel cell electric buses, as compared to conventional diesel and hybrid-electric propulsion systems. AC Transit has a long history with ZEBs and the current program involves on-site hydrogen production and fueling as well as electric charging. Lessons learned, best practices, and key considerations were identified from AC Transit's experience with deploying zero-emission technologies. Highlights from the report are detailed below.[35]

- During the testing performance period (July 2020 – December 2020), the BEBs ran fewer miles compared to the other buses in the analysis due to downtime and low availability. BEB availability was substantially lower during the study period compared to the diesel, hybrid, and fuel cell buses.
- The BEBs, at 18.56 M/DGE, had the highest equivalent efficiency compared to the diesel, hybrid, and fuel cell buses.
- When factoring for maintenance and energy costs, the BEBs performed better than diesel and fuel cell electric buses. During the study period (July–December 2020), BEB maintenance costs were $58,338 compared to diesel costs of $60,014 and fuel cell costs of $62,516; BEB energy costs totaled $31,295 compared to diesel at $43,017 and fuel cell at $107,137.
- In terms of road calls by system, BEBs performed better (10 road calls) than the hybrid (24 road calls) and fuel cell buses (16 road calls).
- AC Transit provided operational training for bus operators, mechanics, and support staff utilizing both classroom and real-world-operation training,

[35] https://www.actransit.org/sites/default/files/2021-06/0604-20%20Report-ZEB%20Perf_FNL_062321.pdf

including high-voltage, dash controls, indicator lights, start-up and shut-down procedures, and defensive driving strategies. Vendor-supplied training for the BEBs covered material on orientation, service/maintenance, safety/familiarization, bus components, and battery systems.

- AC Transit is developing innovative workforce training programs such as synchronous learning, which integrates interactive online courses covering various ZEB training topics.
- The agency is also combining data integration and management systems to streamline data-driven decision-making by using various data platforms.

Simplifying Zero-Emission Transit Bus Procurement: Lessons from Statewide Contracts

Four states have zero-emission statewide contracts: California, Georgia, Virginia, and Washington. The *Simplifying Zero-Emission Transit Bus Procurement* report shares perspectives, successes, and lessons learned that were gathered trough their statewide contract development. The report noted benefits of a centralized procurement at the state level including the reduced potential for purchasing bias or favoritism, also noting that transit agencies and state DOTs outside of Georgia and Virginia can purchase from their statewide contracts if the purchases are conducted in accordance with federal requirements.[36] Representatives from Georgia, Virginia, and Washington outlined eight key findings from their struggles and successes:

1. FTA can help with contract framework and brainstorming.
2. The state contracting department should be responsible for the contract, not the DOT.
3. Thoroughly read the most current FTA guidelines.
4. Incorporate options, negotiate prices, and involve transit agencies.
5. Hire a consultant to help in contract development.
6. Identify efficiencies and values gained in the solicitation.
7. Incorporate the best experts you can find.
8. Include utility companies in the discussion early.

Other Reviewed Laws, Regulations, Standards, and Guidance Documents

Federal Transportation Laws

Title 49, Chapter V, Part 571, Subpart B – Federal Motor Vehicle Safety Standards § 571.105 specifies performance requirements for hydraulic and

[36] https://www.cleantransitnetwork.org/site/wp-content/uploads/2020/04/Statewide-Bus-Procurement-Best-Practices-V2-Final-4-13-2020.pdf

electric brake systems. Section 571.105.S6.2 *Electric vehicles and electric brakes* describes that the state of charge determination must be made in accordance with SAE Recommended Practice J227a applicable sections. This section applies to buses with a gross vehicle weight rating greater than 3,500 kilograms (7,716 pounds) that are equipped with hydraulic or electric brake systems. Sections S6.2.2 and S6.2.3 describe the burnish procedures of the effectiveness test and the performance test procedures. Section S6.2.4 describes the different considerations that are necessary when testing if the BEB is equipped with a regenerative braking system.

Bipartisan Infrastructure Law – On November 15, 2021, the Bipartisan Infrastructure Bill was enacted as the Infrastructure Investment and Jobs Act. This law makes funding available between 2022 and 2026 "to replace, rehabilitate, and purchase buses and related equipment and to construct bus-related facilities including technological changes or innovations to modify low- or no-emission vehicles or facilities."[37] Grants that compete for the low- or no-emission funding may include partnerships with other entities, and applicants must "submit a zero-emission fleet transition plan with their applications for both Grants for Buses and Bus Facilities and Low or No Emissions Grants competitive programs for projects related to zero-emission buses."[38]

Related State Transportation Laws or Regulations

In California, the Innovative Clean Transit Regulation was adopted in December 2018 requiring all transit agencies in the state of California to transition to a zero-emission bus fleet by 2040. To accomplish this goal, California transit agencies must gradually transition the share of purchased buses to be zero-emission buses, with 100% of all buses procured in 2029 or later being zero-emission buses.[39]

The Colorado Department of Public Health and Environment's Air Quality Control Commission Regulation Number 20 – Colorado Low Emission Automobile Regulation outlines general provisions for requirements of passenger cars, light-duty trucks, medium-duty passenger vehicles, and medium-duty vehicles model year 2022 or subsequent. However, this is not directly applicable to transit buses.

While not a law, a memorandum of understanding (MOU) was signed by California, Colorado, Connecticut, District of Columbia, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington to support the deployment of medium- and heavy-duty ZEVs through involvement in a Multi-State ZEV Task Force (Task Force).[40] The MOU establishes that each state will

[37] https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-12/Fact-Sheet-Buses-and-Bus-Facilities.pdf
[38] *ibid.*
[39] https://ww2.arb.ca.gov/sites/default/files/2019-07/ICTreg_factsheet.pdf
[40] https://afdc.energy.gov/laws/all?state=ME#Laws%20and%20Regulations

work together to foster a self-sustaining market for zero-emission vehicles, and will develop a multi-state action plan to identify barriers and propose solutions to support widespread electrification of vehicles.[41]

International Transportation Learning Center (ITLC)

Providing Training for Zero Emission Buses: Recommended RFP Language[42] provides examples of sample training language for agencies to consider including in their procurement language. Specifically, the training language addresses nine categories with specific procurement language examples for each category:

- Agency review of training materials – requires training material be provided by the contractor and describes how the training will be scheduled and conducted
- Operator training
- Maintenance training courses
- Special instructional materials and training aids for each area of phase two training
- OEM train-the-trainer maintenance training
- Electronic maintenance information
- Training requirements
- Special tools and diagnostic equipment
- Vehicle maintenance training – warranty

The ITLC report encourages agencies to note that failure to respond to technical specifications for training will result in a proposal being deemed non-responsive, and to offer bonus points on the RFP to proposals that are responsive to training specifications.

[41] https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf
[42] https://www.transportcenter.org/images/uploads/publications/ITLC_ZEB_Report_Final_2-11-2022.pdf

Section 3 Survey and Analysis

To gain a more holistic understanding of the state of the practice in the industry, and to understand many of the challenges that agencies face as they transition their fleets from traditionally fueled to battery electric propulsion systems, a survey was developed and disseminated to transit agencies. The survey aimed to gather agencies perspectives on various aspects of the procurement and maintenance of battery electric bus (BEB) fleets. The survey includes the following sections:

- Contact information
- Procurements undertaken
- Procurement terms
- Partnerships outside the OEM
- Planning
- Type of vehicles and support infrastructure
- Operating environment
- Training
- Lessons learned

Once the draft survey was developed, the research team distributed it to the CUTR Transit Safety Standards Working Group members, who provided feedback to make the survey more straightforward and user friendly. Upon incorporation of the suggested improvements, the final survey was sent directly to 40 transit agencies and was posted in the National Rural Transit Assistance Program (RTAP) eNews, Facebook, and Twitter accounts and in the Community Transportation Association of America (CTAA) Fast Mail Newsletter. The dissemination efforts resulted in 25 completed responses representing transit agencies from 16 different states in the United States. Using the 2019 unlinked passenger trips (UPTs) for motor bus, the transit agencies were categorized as small, medium, or large, as shown in Figure 3-1, with small agencies providing up to 25 million UPTs, medium agencies between 25 million and 125 million UPTs, and large agencies providing more than 125 million UPTs. Given those categorizations, the responses represent 12 small agencies, 5 medium agencies, and 8 large agencies, as shown in Table 3-1.

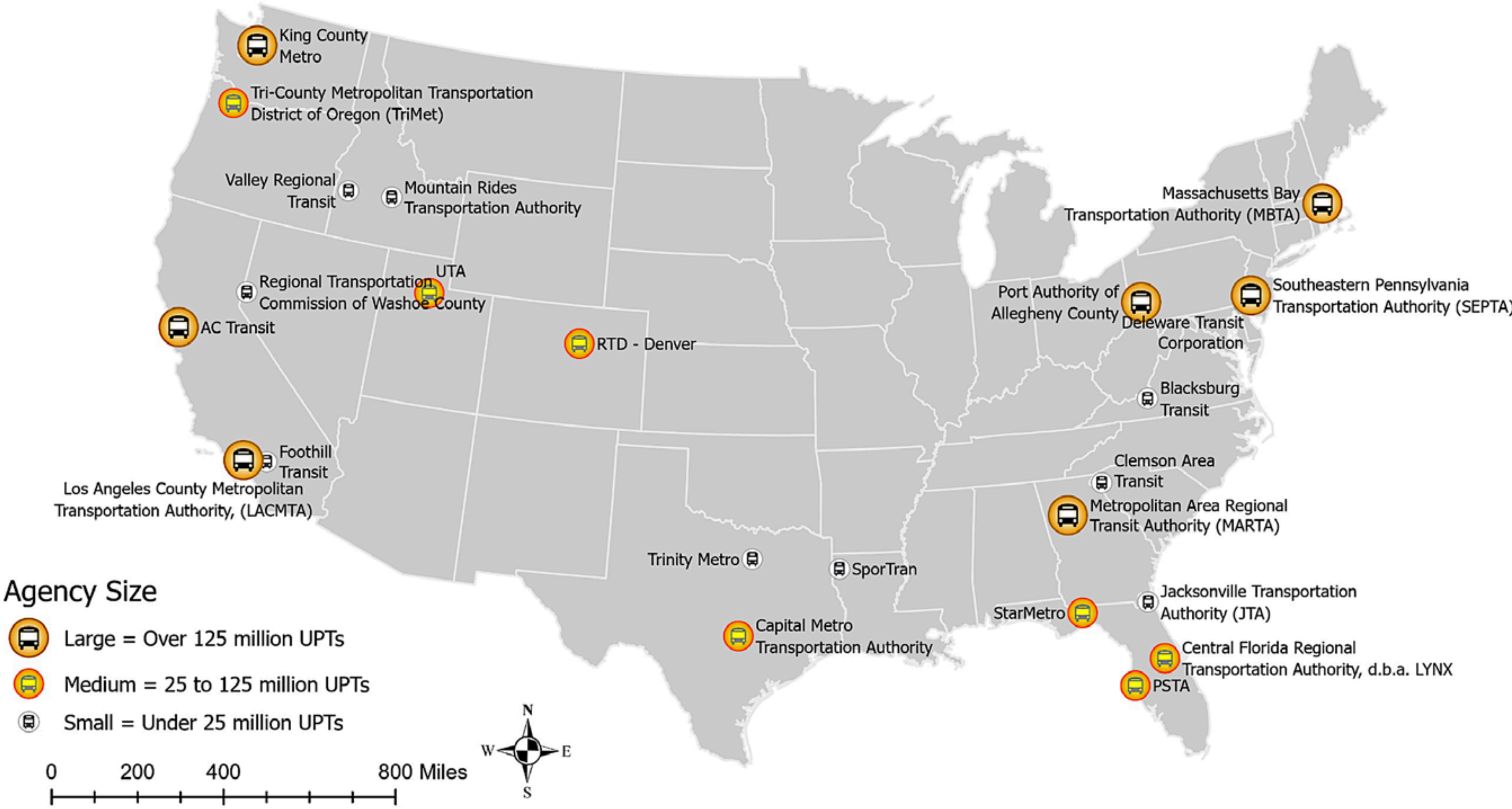


Figure 3-1 *Respondent transit agencies map*

Table 3-1 *Respondent Transit Agencies*

	AGENCY NAME	AGENCY SIZE*	CITY	STATE
1	AC Transit	Large	Oakland	CA
2	Blacksburg Transit	Small	Blacksburg	VA
3	Capital Area Transit System	Small	Baton Rouge	LA
4	Capital Metropolitan Transportation Authority	Medium	Austin	TX
5	Central Florida Regional Transportation Authority (LYNX)	Medium	Orlando	FL
6	Clemson Area Transit	Medium	Clemson	SC
7	Delaware Transit Corporation	Small	Wilmington	DE
8	Foothill Transit	Small	West Covina	CA
9	Jacksonville Transportation Authority	Small	Jacksonville	FL
10	King County Metro Transit	Large	Seattle	WA
11	LA Metro	Large	Los Angeles	CA
12	MARTA	Large	Atlanta	GA
13	Massachusetts Bay Transportation Authority (MBTA)	Large	Boston	MA
14	Mountain Rides Transportation Authority	Small	Ketchum	ID
15	Pinellas Suncoast Transit Authority	Medium	St. Petersburg	FL
16	Port Authority of Allegheny County	Medium	Pittsburgh	PA
17	Regional Transportation Commission of Washoe County	Small	Reno	NV
18	Regional Transportation District - Denver	Medium	Denver	CO
19	SEPTA	Large	Philadelphia	PA
20	SporTran	Small	Shreveport	LA
21	StarMetro - City of Tallahassee	Medium	Tallahassee	FL
22	TriMet	Medium	Portland	OR
23	Trinity Metro	Small	Fort Worth	TX
24	Utah Transit Authority	Medium	Salt Lake City	UT
25	Valley Regional Transit	Small	Meridian	ID

**Agency size legend (2019 UPT): Large – over 125 million UPTs; Medium – 25–125 million UPTs; Small – under 25 million UPTs.*

Procurements Undertaken

The first question in the procurements undertaken section asked how many BEBs are in the current active fleet. More than half the respondent agencies reported having less than 5 BEBs in their current active fleet, while 24% reported having between 6 and 14 BEBs, and 24% reported having more than 15 BEBs in their active fleet, as shown in Figure 3-2.

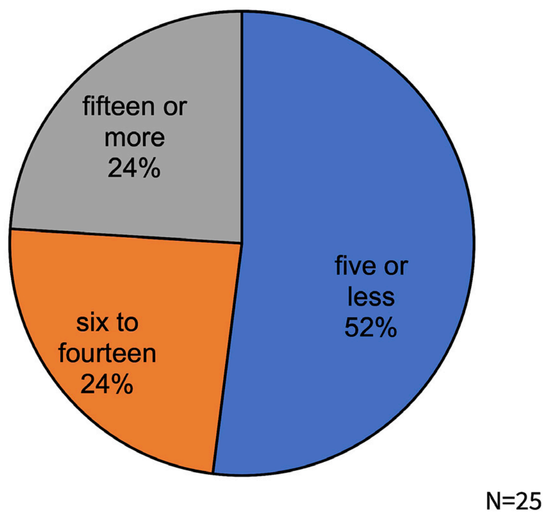


Figure 3-2 *Number of BEBs in current active fleet*

The next question asked when the first BEB was delivered, in hopes of gaining an understanding of the number of years each respondent has been maintaining their BEB fleet. While the majority of respondents received their first BEB in the past three years, there were 11 agencies that received their first BEB between 2010 and 2018, as shown in Figure 3-3.

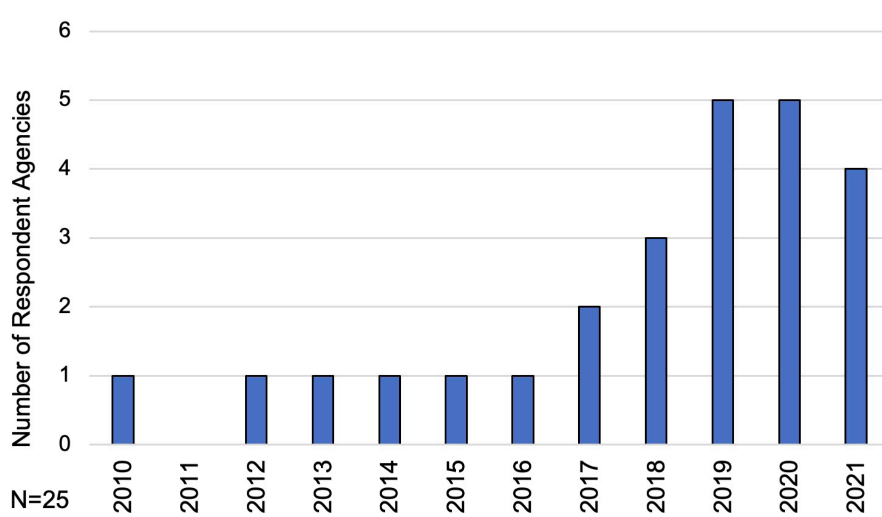


Figure 3-3 *Year first BEB was delivered*

Aside from asking how many BEBs the agency currently has, the survey also asked how many BEBs were included in their first procurement. Most of the respondent agencies, 7 out of 25, procured five BEBs in their first procurement, followed by 5 agencies that procured four BEBs in their first procurement, and 4 agencies procured three BEBs in their first procurement, as shown in Figure 3-4. There were two agencies that procured 25 or more BEBs in their first procurement.

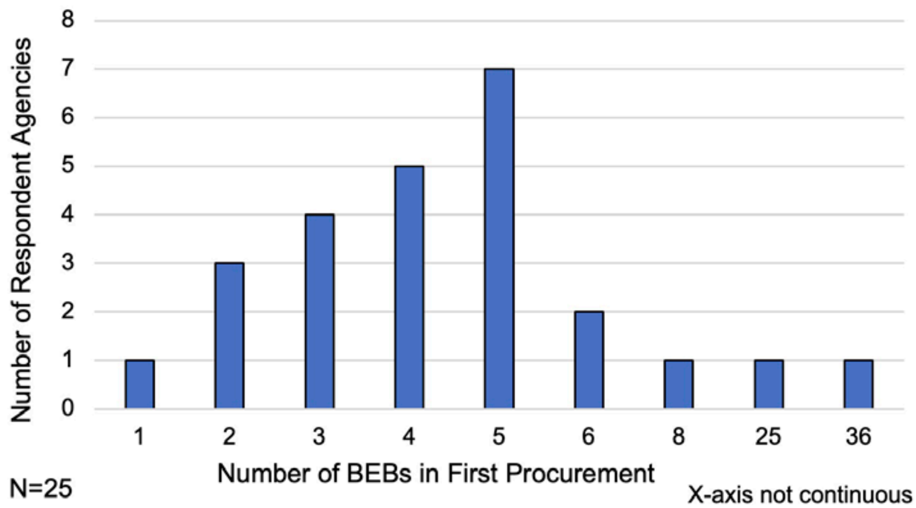


Figure 3-4 *Number of BEBs in first procurement*

Agencies were asked what ratio of charging units per bus were included in their initial procurements and most respondents, 13 of 25, indicated a one-to-one ratio as shown in Figure 3-5.

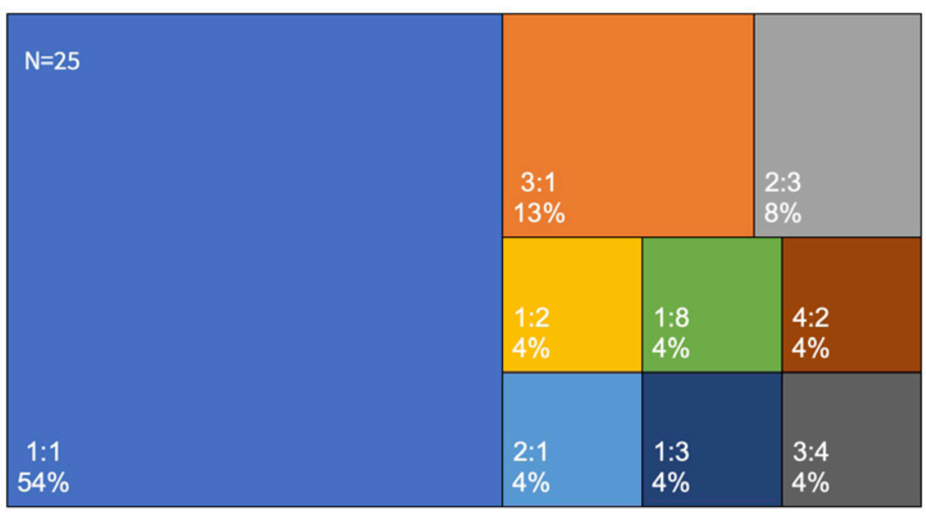


Figure 3-5 *Charger to BEB ratio*

Researchers also asked respondents if they had procured any additional BEBs and/or charging units since their initial procurement, with 68% investing in additional BEBs and 64% investing in additional charging units.

To gain an understanding of the fleet composition of the respondent agencies, the survey asked what percent of their total fleet are currently BEBs. Almost one out of every three respondents indicated that their BEBs account for less than one percent of their total fleet size, as shown in Figure 3-6. However, on the contrary, about one in four respondents indicated that BEBs account for more than 10% of their total fleet.

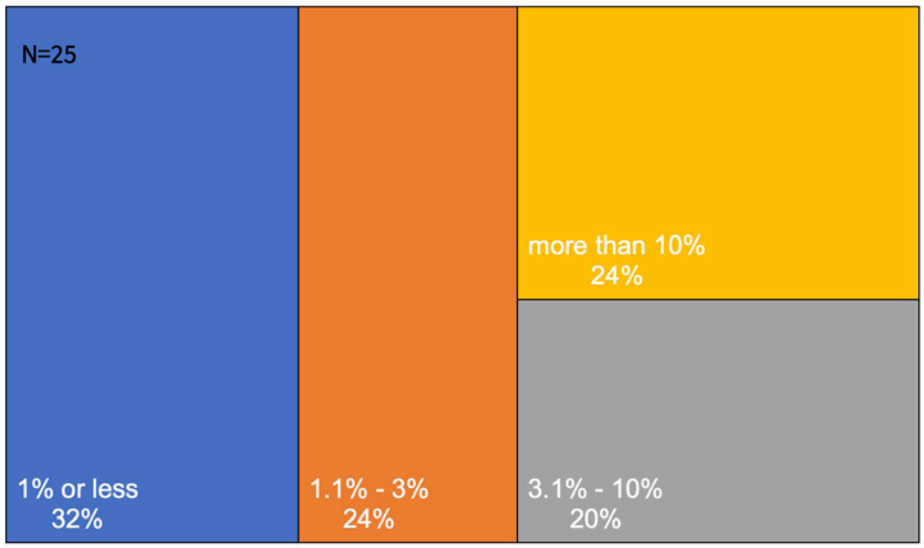


Figure 3-6 *Percent of total fleet that are currently BEBs*

In addition to the current fleet share, agencies were asked about their intentional fleet shares. Of the respondent agencies, 11 out of 25 (44%) plan to transition their entire fleet to BEB propulsion, with full electrification goal years ranging between 2028 and 2050. At the same time, 9 of 25 respondents (36%) do not have a defined electrification goal in place at their agency, while 20% have set goals that are less than 100% of their fleet, as shown in Figure 3-7. Some agencies reported that there are certain routes that cannot be serviced by an electrified fleet, thus prohibiting full fleet electrification. More details about these challenges are highlighted in the case study section of this report.

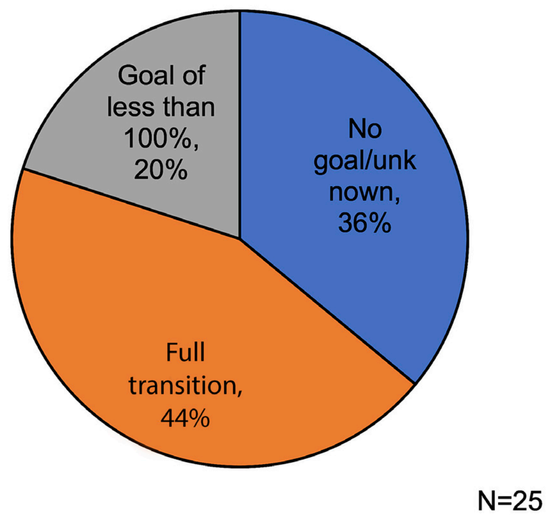


Figure 3-7 *BEB fleet transition goals*

One of the biggest challenges of procuring BEBs and their associated necessary infrastructure is funding. With that in mind, researchers asked respondents to indicate which funding sources they used to purchase BEBs and charging equipment. The FTA Low or No Emission Vehicle Program[43] funding was used by 17 of the 25 respondents, as shown in Figure 3-8.

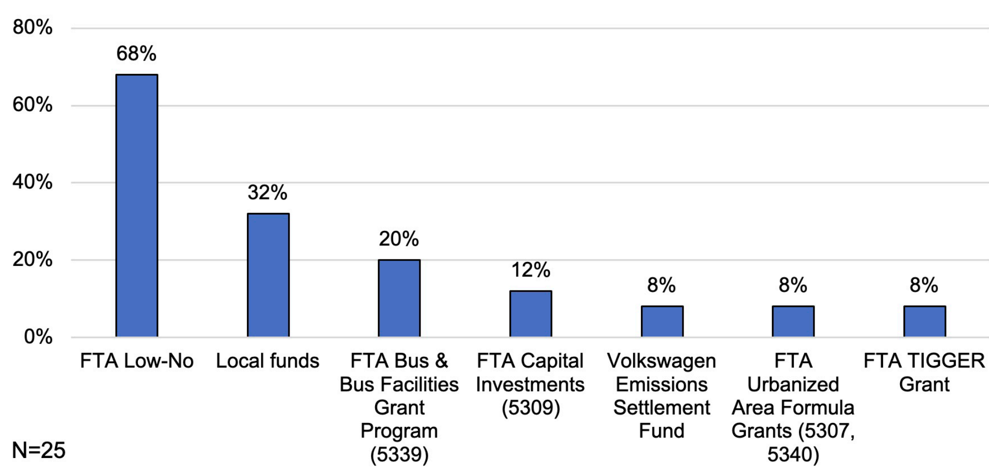


Figure 3-8 *Funding sources used*

Next, agencies were asked if the Buy America requirements introduced any additional challenges with vendors throughout the procurement process. Nearly two of every three respondents (64%) indicated they had no challenges

[43] https://www.transit.dot.gov/lowno

with meeting the Buy America requirements, as displayed in Figure 3-9. However, for the 36% of respondents that did indicate challenges, the challenges faced were related to charging infrastructure compliance and not BEB compliance.

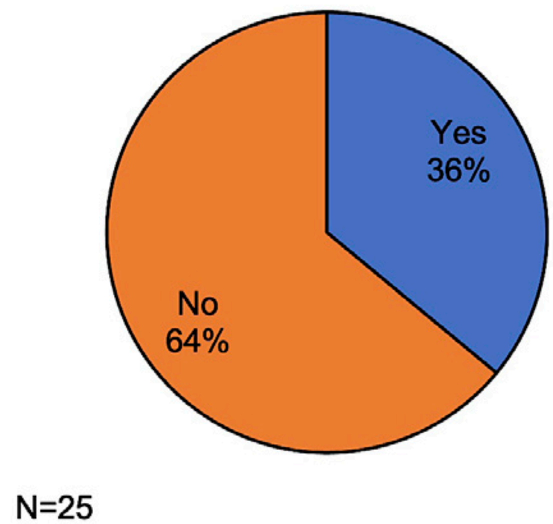


Figure 3-9 *Challenges with the vendors meeting Buy America requirements*

Agencies were asked what type of procurement they used to acquire their BEBs and associated infrastructure. Some respondents indicated using more than one type of procurement, therefore the sum of the totals equate to more than 100%, as displayed in Figure 3-10. Federal Low-No grant partnerships were the most common procurement type, followed by RFPs.

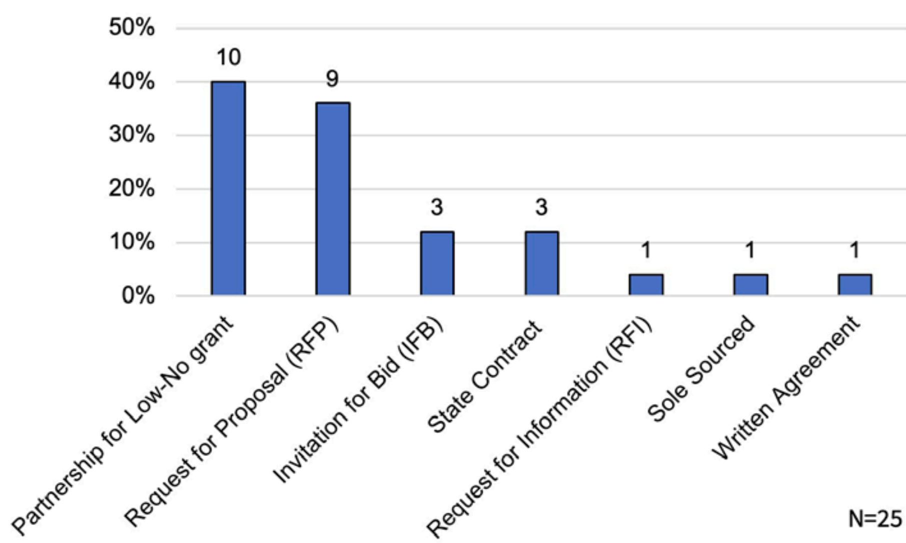


Figure 3-10 *Procurement type*

When asked if they included any diagnostic or other equipment in their bid/RFP, about 76% of respondents indicated they included various equipment, as shown in Figure 3-11. Some agencies included more than one of the items listed, thus the sum of the percentages equates to more than 76%. The most common inclusion in the bid/RFP was diagnostic software, equipment, and laptops, which was included in 16 out of 25 respondent agencies bids/RFPs.

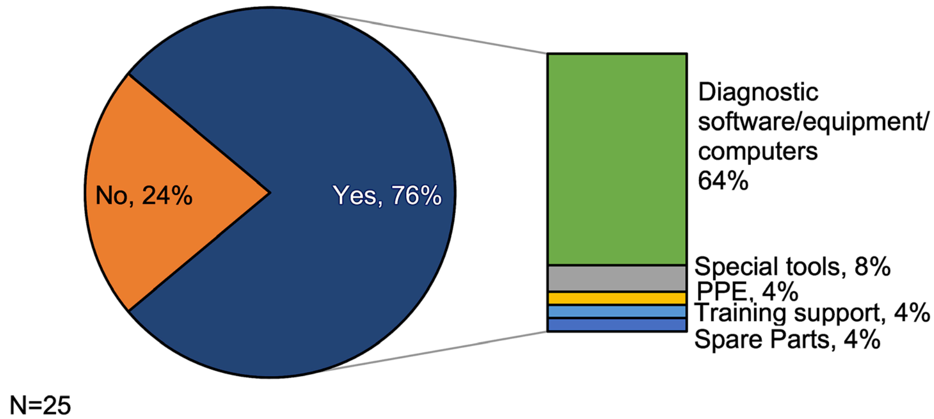


Figure 3-11 *Inclusion of diagnostic equipment in the bid/RFP/other*

When asked if infrastructure was included in the bid/RFP specifications, 60% of respondents indicated that they did include charging infrastructure in their procurements, as displayed in Figure 3-12. Many of the agencies that did not include the charging infrastructure in their bids relied upon their electric providers to acquire the charging infrastructure. Additionally, 24% of respondents included retrofits to their existing maintenance facilities to allow for BEB maintenance, and 68% included a delivery date range in their bid/RFP.

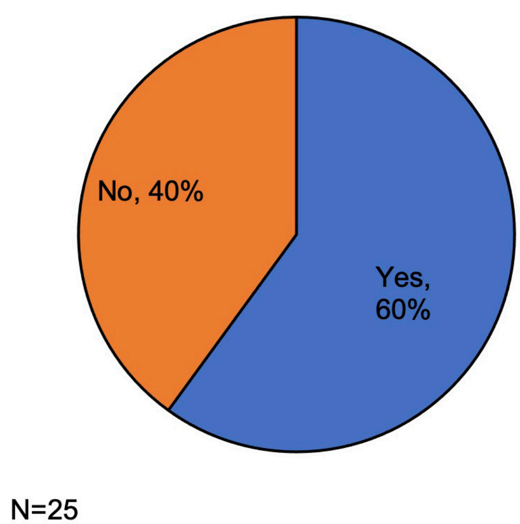


Figure 3-12 *Inclusion of required infrastructure in bid/RFP specifications*

Agencies were asked what the timeframe was between their contract award and receipt of their first BEB, and the responses are displayed in Figure 3-13. Most respondents indicated it took between 7 and 24 months before they received their first BEB.

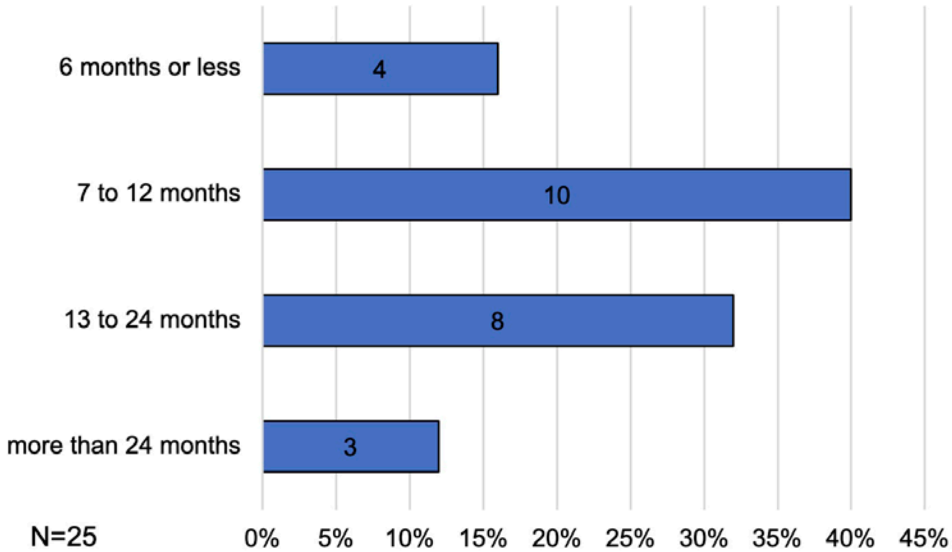


Figure 3-13 *Timeframe between contract award and receipt of first BEB*

Procurement Terms

Following the questions related to what procurements were undertaken, the survey included questions about procurement terms, concerning topics such as support, warranties, and expectations.

Agencies were asked if they conducted a total cost of ownership analysis prior to their proposal and contract execution, and half of the respondent agencies (12 of 24) indicated that a total cost of ownership analysis was conducted prior to contract execution.

The survey included a question about what type of product support the vendor was contracted to provide. Training was required in 71% of respondent contracts and technical support was included in 59% of respondent contracts. Some of the less common inclusions were software and service delivery support, tools and equipment, and parts availability guarantees. More information is shown in Figure 3-14.

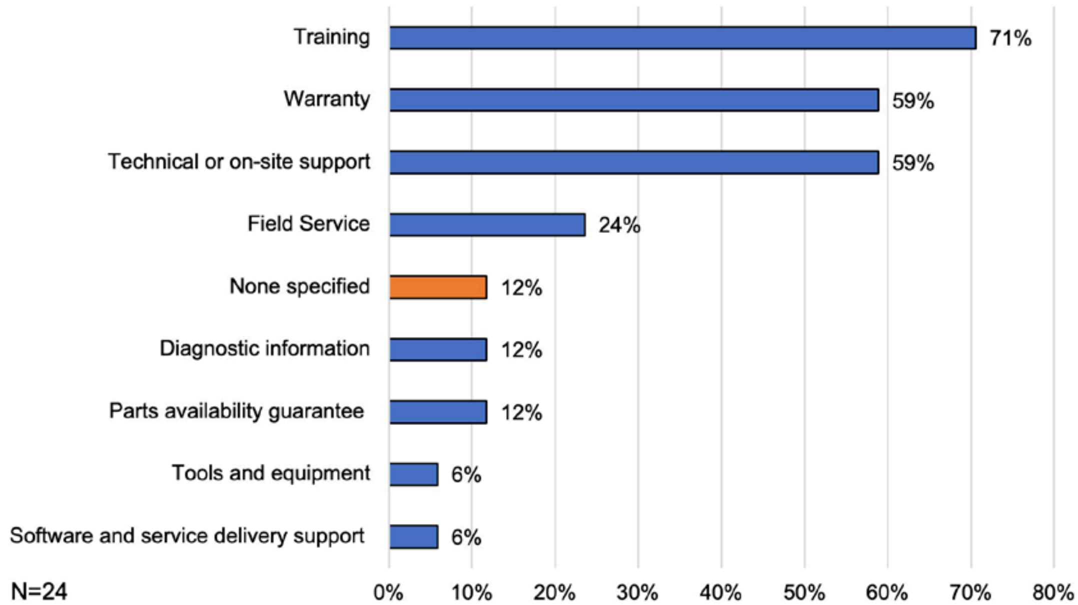


Figure 3-14 *Product vendor support required through the contract terms of BEB procurement*

Recognizing that warranty information would be valuable to understand, the survey asked what the warranty length was for the whole bus, for the batteries, and for the charging equipment. Figure 3-15 shows that 43% of respondents indicated they received a 1-year warranty on the entire bus, and 31% received a 12-year warranty on the battery.

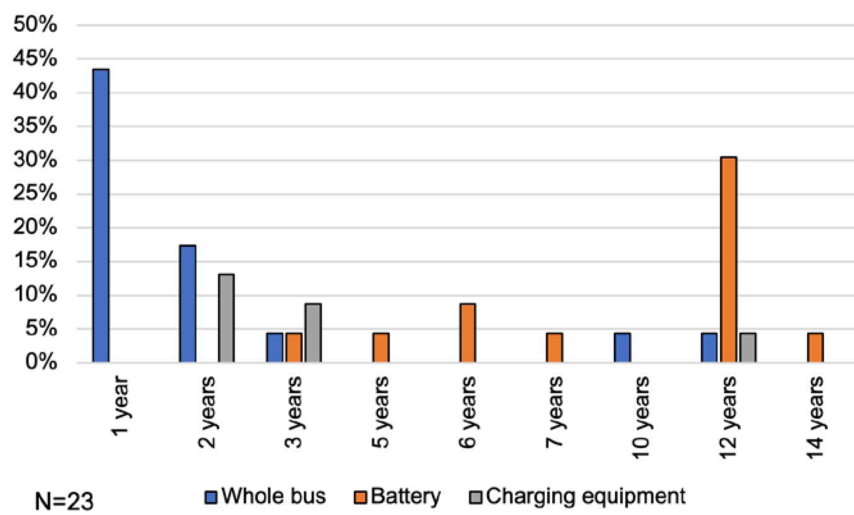


Figure 3-15 *Warranty length for BEBs and other components*

Aside from how long the warranty will last, it is also valuable to understand how the warranty process works. Forty percent of respondents indicated that the OEM sends technicians to the agency to make repairs, 36% indicated that the OEM maintenance technicians are on-site, and 24% make repairs themselves with vendor support, as shown in Figure 3-16.

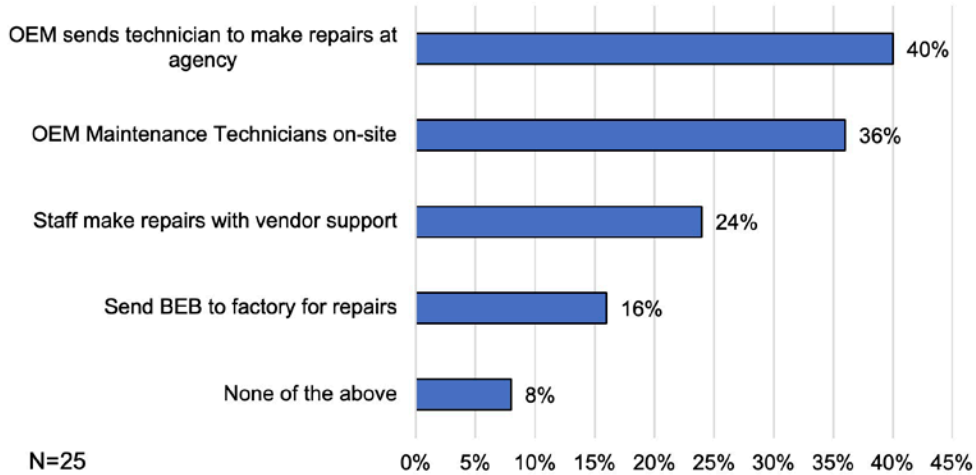


Figure 3-16 *Warranty process for BEBs and the charging infrastructure*

Agencies were asked if the vendor defined the life expectancy of the charging stations and about a quarter of respondents were not involved with the procurement of the charging infrastructure, leaving that responsibility with the utility company instead. Additionally, 42% of respondents indicated that the vendor did not define a life expectancy for the charging infrastructure. Meanwhile, of the 38% that did define a life expectancy, the life cycle range was from 10 to 15 years, as shown in Figure 3-17.

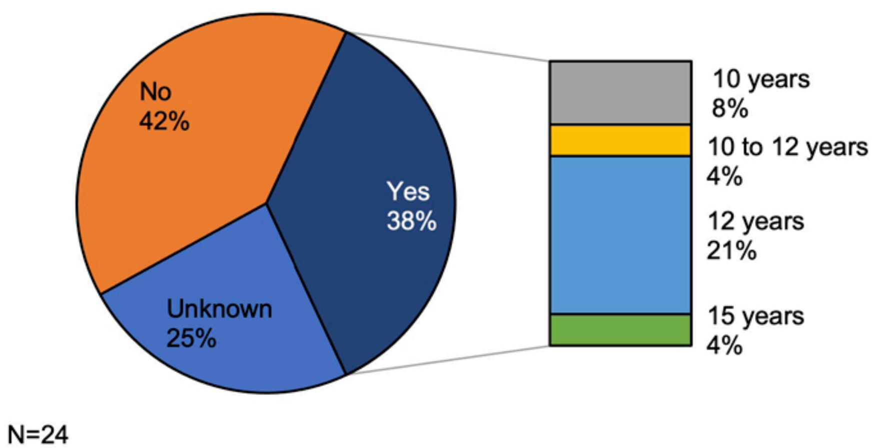


Figure 3-17 *Vendor-defined life expectancy of the charging stations*

Figure 3-18 shows that a much larger share of agencies knew the vendor-defined life expectancy for the BEBs (84%), with the majority of BEBs expected to perform for 12 years or more.

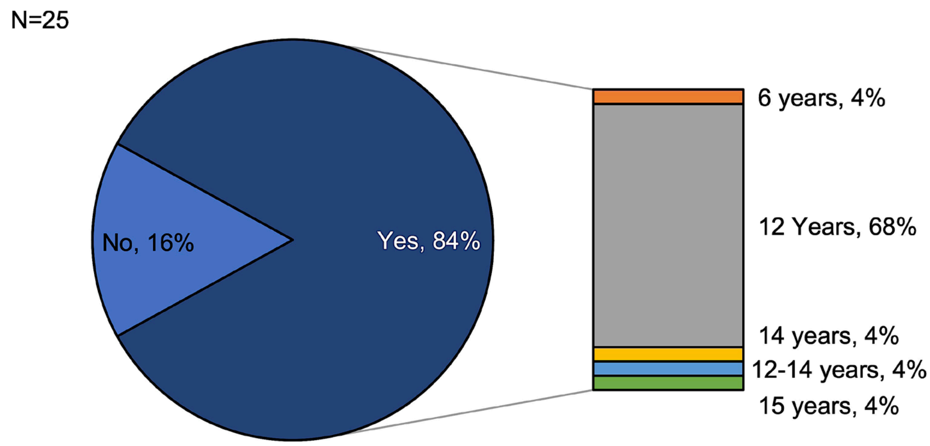


Figure 3-18 *Vendor-included life expectancy for the BEBs*

The next question in the survey asked agencies if there is a midlife overhaul for BEBs, and responses were split with 36% indicating there is not, 32% indicating there is, and 32% of respondents unsure, as displayed in Figure 3-19.

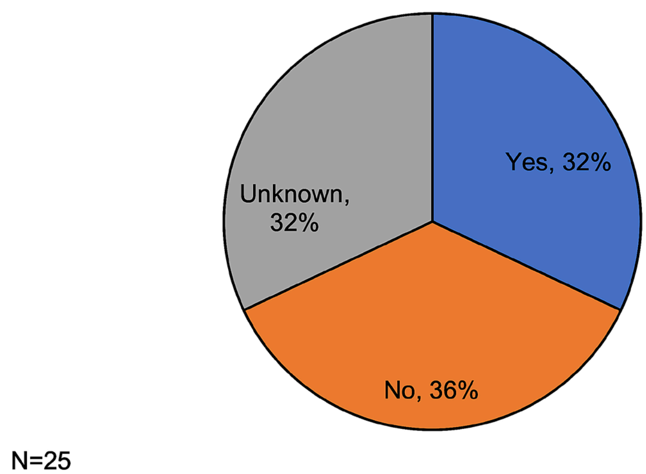


Figure 3-19 *Midlife overhaul for the BEBs*

With much less variation, 96% of agencies indicated that they did not include a midlife overhaul in their BEB bid/proposal, which is displayed in Figure 3-20.

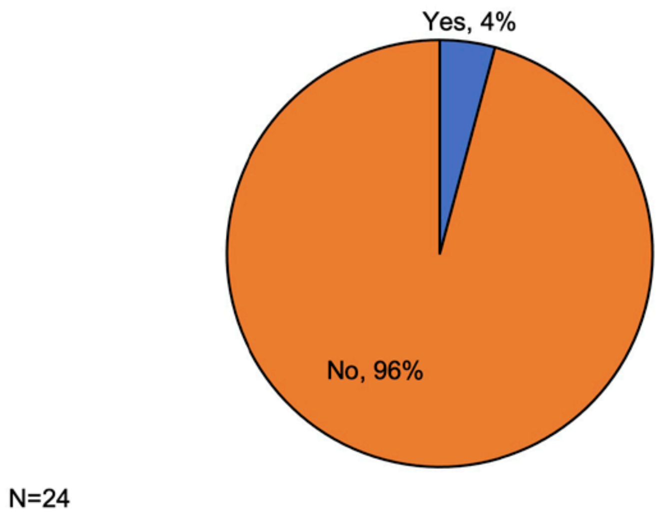


Figure 3-20 *Midlife overhaul included in bid/proposal/other*

The last question in the procurement terms section of the survey asked specifically about battery disposal. Fifty-five percent of respondents indicated that they have not figured out what their battery disposal process will be, mostly because they have not had to dispose of any batteries yet. Figure 3-21 shows some of the other disposal processes in place including recycling, battery lease programs, and others.

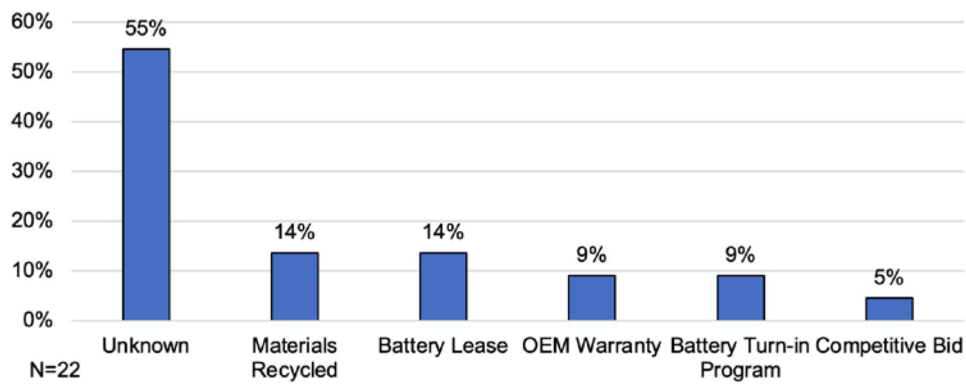


Figure 3-21 *Disposal process for batteries*

With the conclusion of those two sections of the survey, the question topics moved from procurement to questions focused on partnerships, planning, and operation.

Partnerships outside the OEM

Successful partnerships can be extremely beneficial, especially when implementing BEBs. As such, 72% of respondents indicated that they partnered with their local utilities to develop their charging infrastructure specifications, as shown in Figure 3-22.

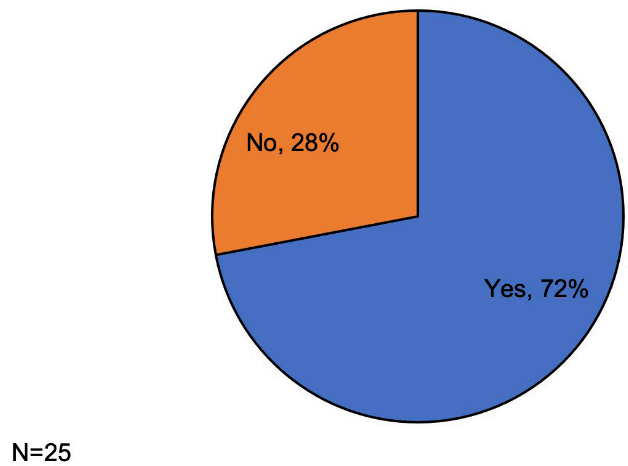


Figure 3-22 *Partner with local utilities in developing charging infrastructure specifications*

In an interest to understand the various motivations behind the transition to BEB fleets, agencies were asked if there are any local or state ordinances that require a transition to zero-emission fleets. Of the survey respondents, 40% live in an area where a state or local ordinance requires a transition to zero-emission vehicles in a certain timeframe, as shown in Figure 3-23.

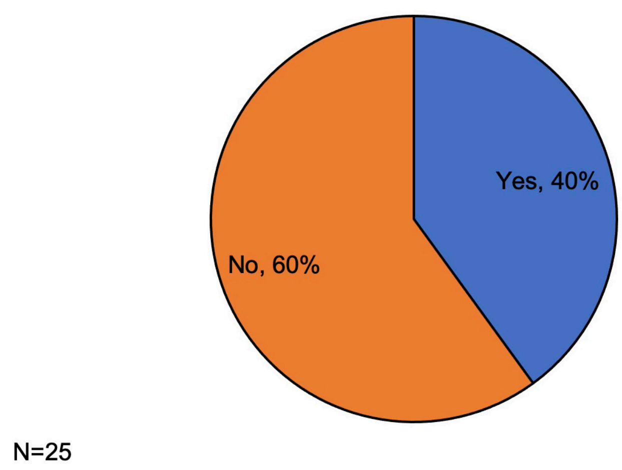


Figure 3-23 *State or local visions or ordinances that require a transition to zero-emission vehicles*

In addition to local visions or state ordinances, there are financial incentives in place that some agencies have leveraged to transition their fleet to electrified zero-emission propulsion. As displayed in Figure 3-24, while 52% of respondents did not have any incentives for purchasing their BEBs, 16% did have state incentives and 12% had incentives from their utility company.

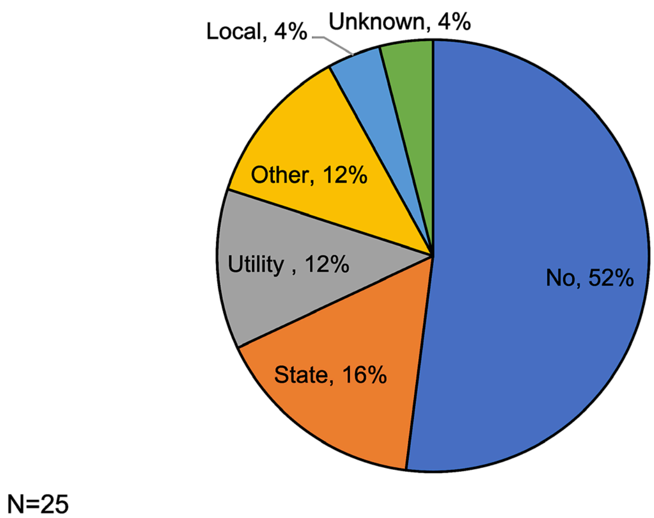


Figure 3-24 *Incentives for purchasing BEBs*

Planning

Beyond procurements and partnerships, there is also a great deal of planning needed when transitioning a fleet to BEB. Understanding that the number of departments included in this planning will vary by many characteristics such as agency size and governance, the survey asked agencies to identify all departments that were included when planning their first BEB procurement. Figure 3-25 shows that agencies were asked to select all departments involved, therefore the sum of the departments listed is more than 100%. The most common departments included were maintenance, operations, planning, and grants.

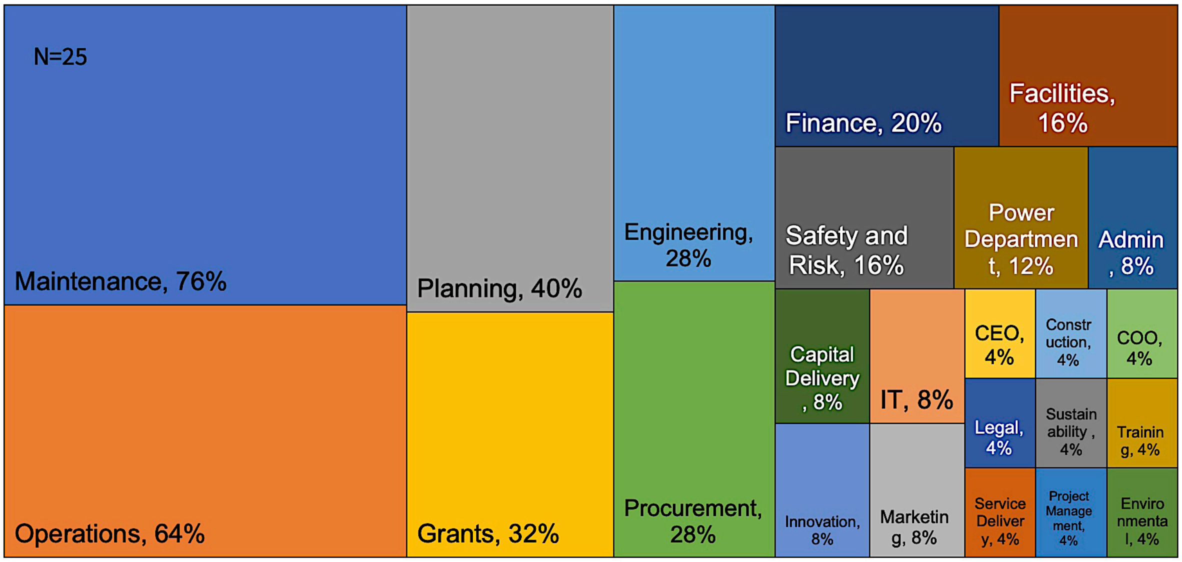


Figure 3-25 *Internal departments involved in the planning and specification development process*

In addition to internal stakeholders, 68% of the 25 respondent agencies included external stakeholders in their BEB planning, as shown in Figure 3-26.

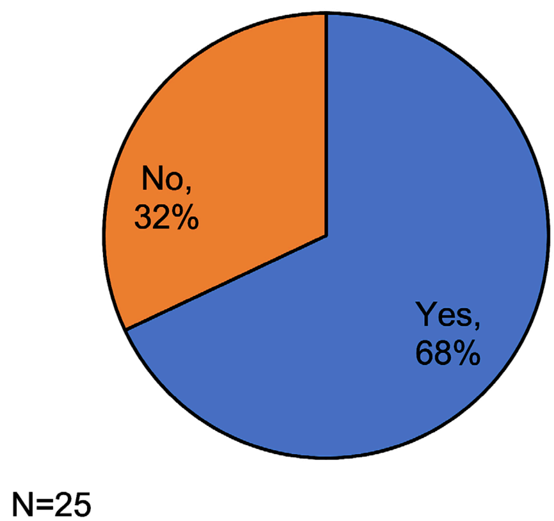


Figure 3-26 *External stakeholder groups in the planning and specification development process*

Agencies were also asked if they would include different or additional stakeholders in the planning process. The majority of respondents (76%) felt they included the right stakeholders, with only about one in four respondents (24%) indicating they would plan differently for BEBs if given the opportunity, as shown in Figure 3-27.

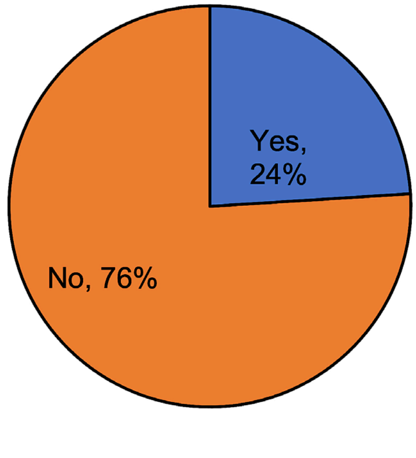


Figure 3-27 *Suggested involvement of different or additional internal or external groups in the planning process*

Also related to planning for BEBs, the survey asked if agencies have any specific routes that cannot be accommodated by BEBs. Figure 3-28 displays the responses, showing that while 36% of respondents do not have any routes that are unable to be served by BEBs, 64% have at least one route that will prevent complete BEB fleet transition. Within that same question was a request about what made the route unable to accommodate BEBs. Agencies were able to mark more than one option, therefore the sum of the percentages is greater than 64%. The most common hinderance, mentioned by 56% of respondents, is the route length. Additionally, 16% of respondent agencies noted that charger location availability limits route accommodation.

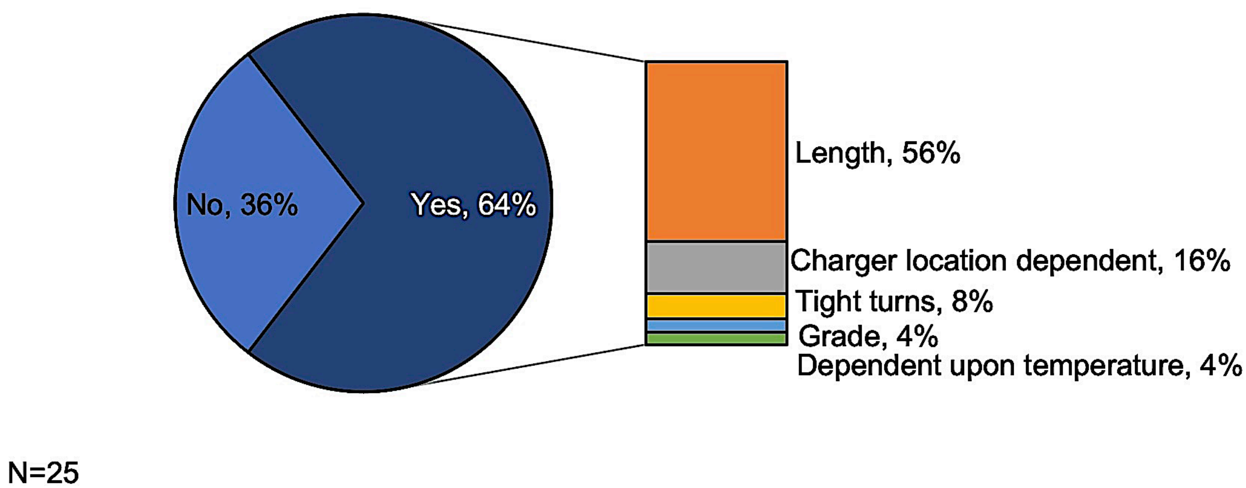
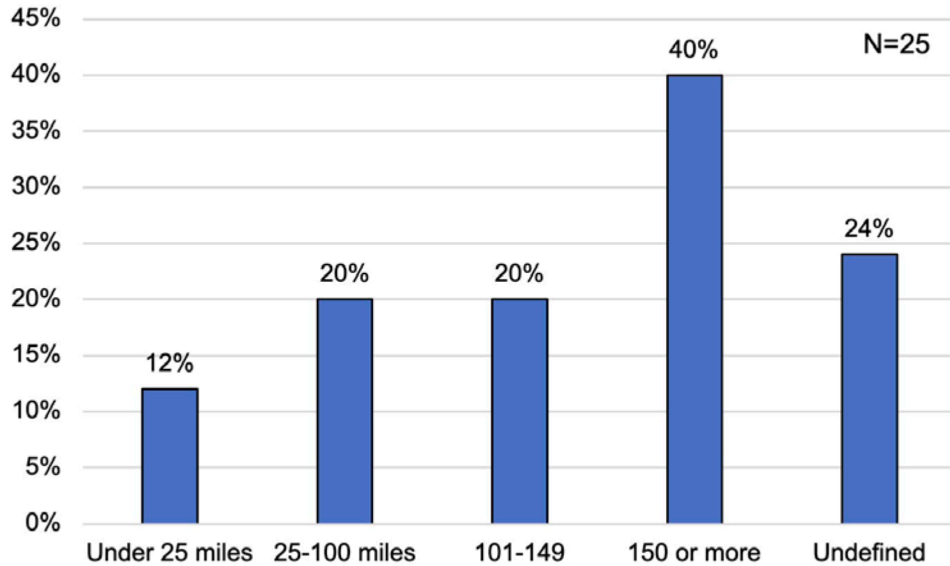


Figure 3-28 *Specific routes that cannot accommodate BEBs and common hindrances*

The mileage range of agency BEBs varies from under 25 miles to over 150 miles. It is important to consider the different types of charging infrastructure in operation, as on-route charging allows for more frequent charges, resulting in shorter mileage limits between charges. Additionally, 24% of respondents have not yet defined their range limit, as shown in Figure 3-29. Some agencies provided ranges that included upper and lower bounds, which fell in more than one of the categories shown in the figure, in which case both values were included.



** If range was provided, both lower and upper bounds were included.*

Figure 3-29 *Limit on miles traveled per vehicle between charges*

Similarly, agencies were asked how often their BEBs are charged. Figure 3-30 shows that the majority (40%) of respondents charge their BEBs daily, while 24% indicated they specifically charge their BEBs overnight. Additionally, 20% charge their BEBs at every pull-in and 20% charge their BEBs hourly. When analyzing the data, it is important to understand that agencies were able to indicate more than one charging frequency and that some agencies have more than one type of BEB. Therefore, one agency may have buses that use inductive charging at every pull-in as well as long-range BEBs that charge overnight.

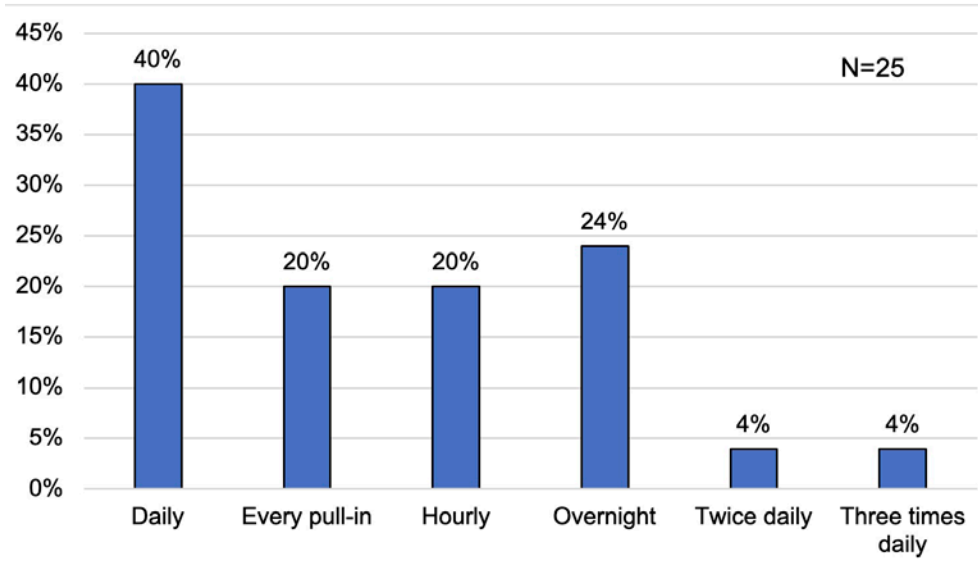


Figure 3-30 *BEB charging frequency*

Figure 3-31 displays the share of respondent agencies that use charging management procedures, such as charging only at certain hours to avoid high energy costs, to optimize the charging schedule for their BEBs. While 48% of respondents indicated they currently follow some type of charging management procedure, the other 52% indicated they either have not had their BEBs long enough or they do not have enough BEBs in their fleet to warrant charging management strategies yet. As the number of BEBs increases, and since the cost of electricity varies by time of day, it may be beneficial for agencies to consider the benefits of charging management procedures to optimize cost savings.

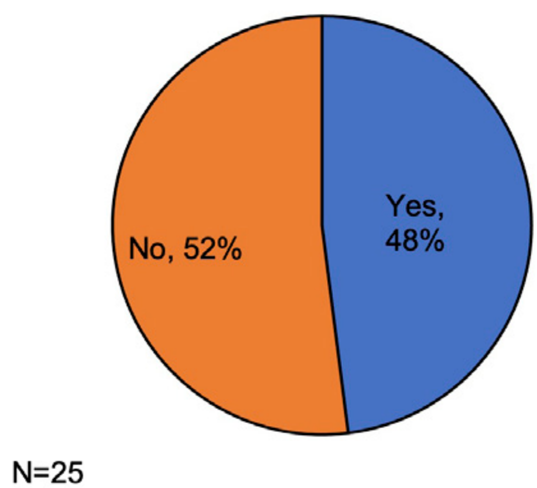


Figure 3-31 *Charging management procedures for BEBs*

Type of Vehicles and Support Infrastructure

Once the survey had adequately captured details related to the procurements, partnerships, and planning of BEBs, the next portion of the survey focused on the types of BEBs and support infrastructure that were procured.

First, agencies were asked which vendor they procured their BEBs through. New Flyer and Proterra were each the vendor of choice for 48% of the respondent agencies, respectively, followed by BYD at 16% and GILLIG and Alexander Dennis at 4% of respondents each, as shown in Figure 3-32. The sum of the shares shown in the figure equals more than 100% because some agencies have more than one type of BEB.

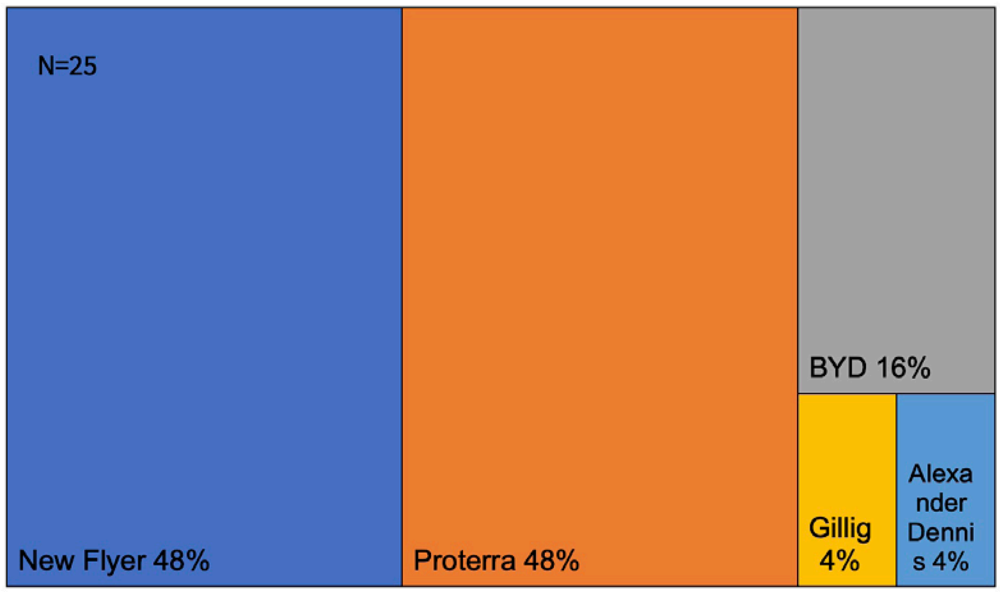


Figure 3-32 *BEB vendor*

The majority of respondents (60%) indicated they have 40-foot BEBs, while 40% indicated they operate 35-foot BEBs, 20% operate 60-foot BEBs, and only 4% operate 45-foot BEBs, as shown in Figure 3-33.

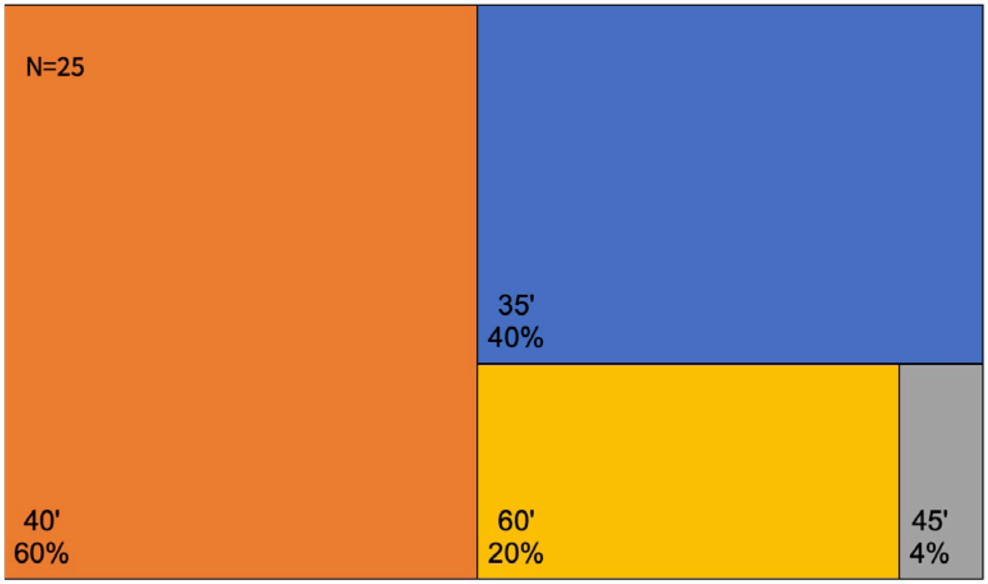


Figure 3-33 *BEB length*

Figure 3-34 displays the responses concerning what type of charging infrastructure accompanies the BEB bus procurement. Every respondent included plug-in charging infrastructure in their BEB procurement. About one in every four (24%) included pantograph charging, 16% included overhead blade charging systems, and only 4% included wireless inductive charging.

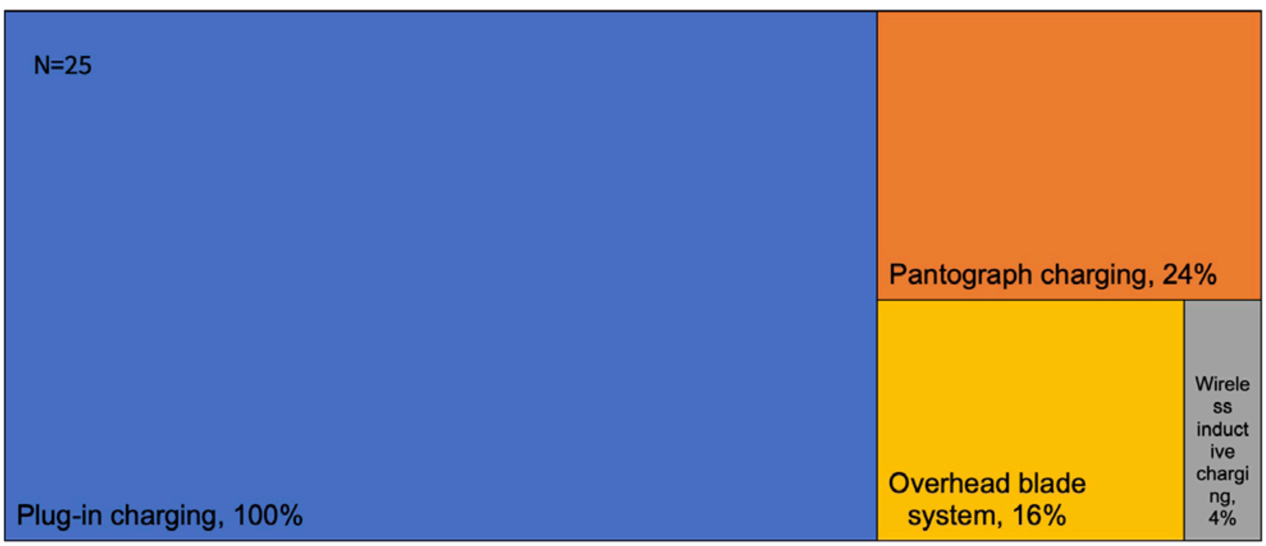


Figure 3-34 *Charging infrastructure that accompanied BEB procurement*

Considering many of the BEBs have batteries and other components located on the top of the bus, agencies were asked if they have fall protection infrastructure in place within their bus maintenance facilities. Figure 3-35 shows that 76% of respondents do have fall protection in their maintenance facilities while 16% do not, and 8% indicated that their buses do not require battery access from the top of the bus.

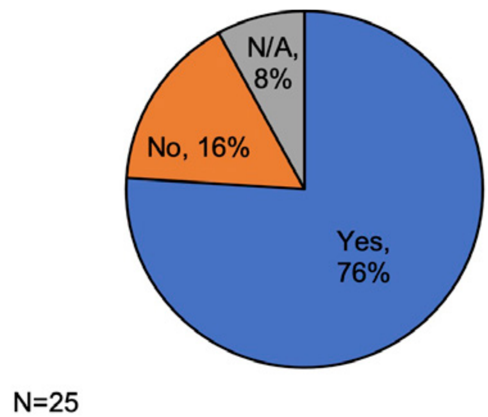


Figure 3-35 *Fall protection infrastructure in bus maintenance facilities to access batteries located at the top of buses*

As shown in Figure 3-36, the vast majority of the survey respondents (96%) indicated they have charging units located in their bus depot, while 44% have charging infrastructure on-route and 8% have charging units in their maintenance facility. As mentioned previously, all BEBs have some plug-in charging capabilities, so even the BEBs that are charged inductively or overhead while on route still require charging units at a depot.

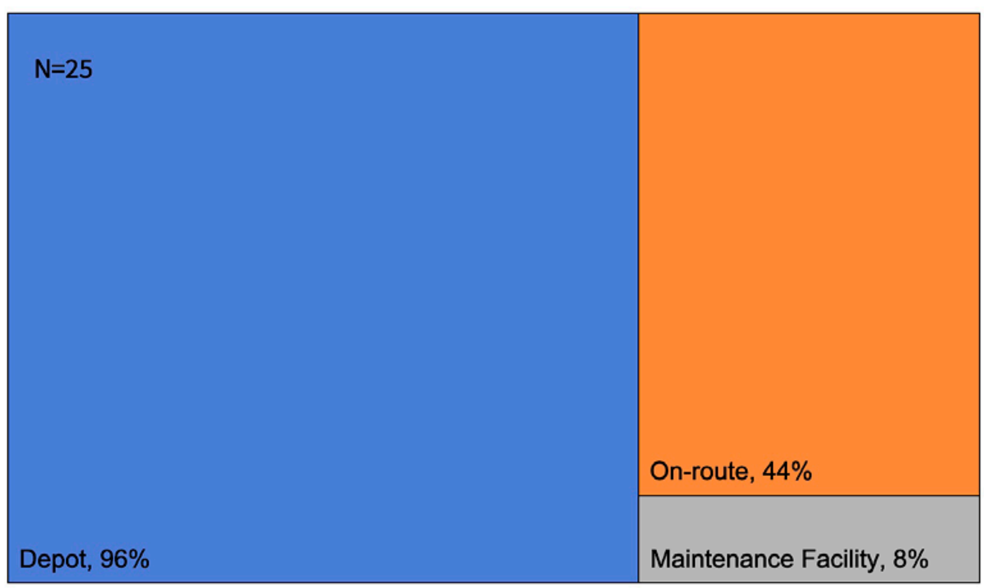


Figure 3-36 *Charging units location*

Understanding that BEBs are still a relatively new technology in the transit world, challenges are to be expected. As such, the survey asked agencies if they encountered any challenges in obtaining buses and parts that were procured, of which 44% indicated they indeed experienced challenges and delays, as shown in Figure 3-37.

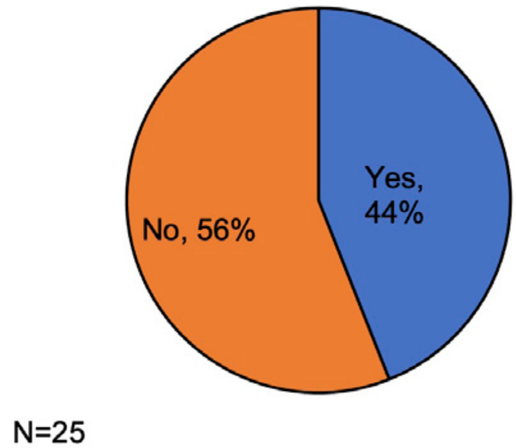


Figure 3-37 *Challenges encountered in obtaining the buses and parts*

When asked specifically about delays, 56% of respondents indicated that they encountered some type of delay. Figure 3-38 shows that of those 14 respondents that experienced delays, 50% (7 agencies) experienced bus delivery delays, 29% experienced delays related to part availability, 14% had delays due to support issues, 14% had delays due to quality issues, and 7% had charging equipment delays.

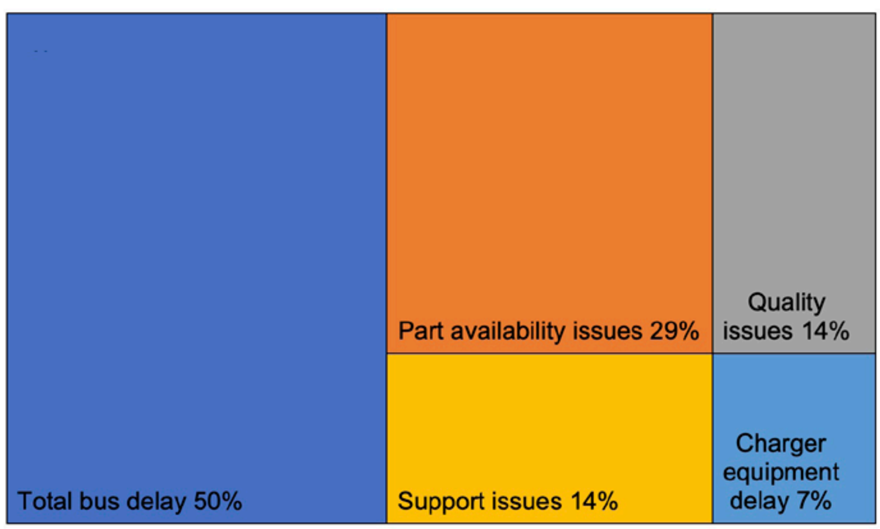


Figure 3-38 *Issues/delays experienced when challenges were encountered*

The survey also asked agencies about challenges they may have faced with interoperability. Interoperability may refer to the lack of compatibility of BEBs manufactured by more than one vendor being able to charge on the same charging infrastructure. Interoperability may also be related to incorporating all the various additional technologies, such as driver monitoring systems, inward and outward facing cameras, or other analytic data gathering onboard technology. Figure 3-39 shows that most respondent agencies (79%) did not experience interoperability challenges.

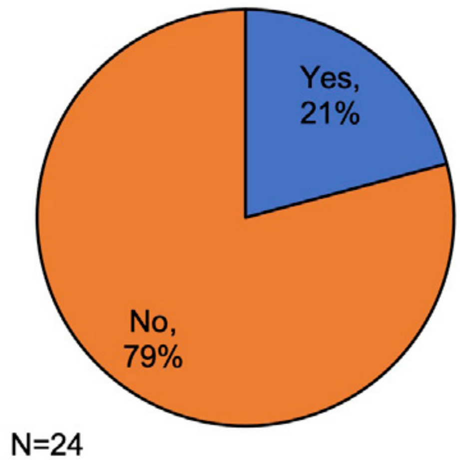


Figure 3-39 *Interoperability challenges when incorporating various BEB technologies*

Operating Environment

The first survey question related to operating environments asked agencies about their typical terrain, and they were asked to select all answers that applied. If they operate on both flat and rolling terrain, respondents were able to select both, resulting in the sum of the responses in Figure 3-40 greater than 100%. While 72% operate on flat terrain, about 40% operate on rolling terrain and more than 30% operate on steep inclines/declines.

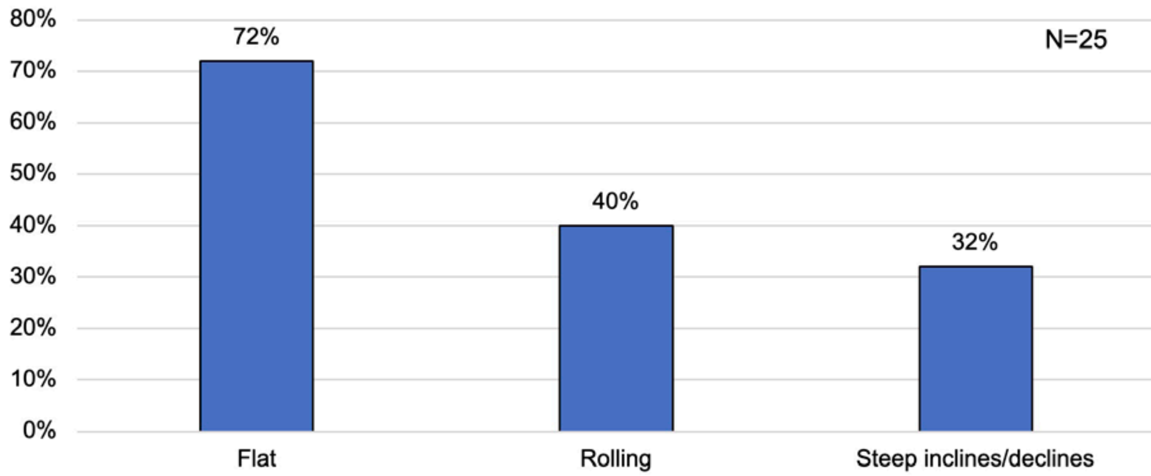


Figure 3-40 *Terrain on which BEB fleets operate*

The majority of respondents (88%) indicated they operate their BEBs on a fixed route service, while the remaining 12% operate their BEBs on circulator routes, as shown in Figure 3-41. Circulator routes can be especially conducive to BEBs that use on-route charging infrastructure.

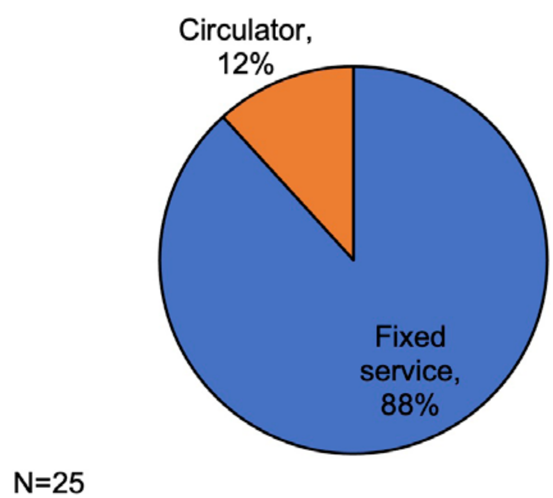


Figure 3-41 *BEB fleet route type*

Agencies were also asked if they have noticed any changes in the BEB operation performance or in the charging patterns associated with changes in seasons. Figure 3-42 displays the results. While more than half of respondents (56%) have noticed changes in charging patterns and BEB operation due to seasonal changes, 16% have not and 28% noted they have not had their BEBs in operation long enough to make that determination.

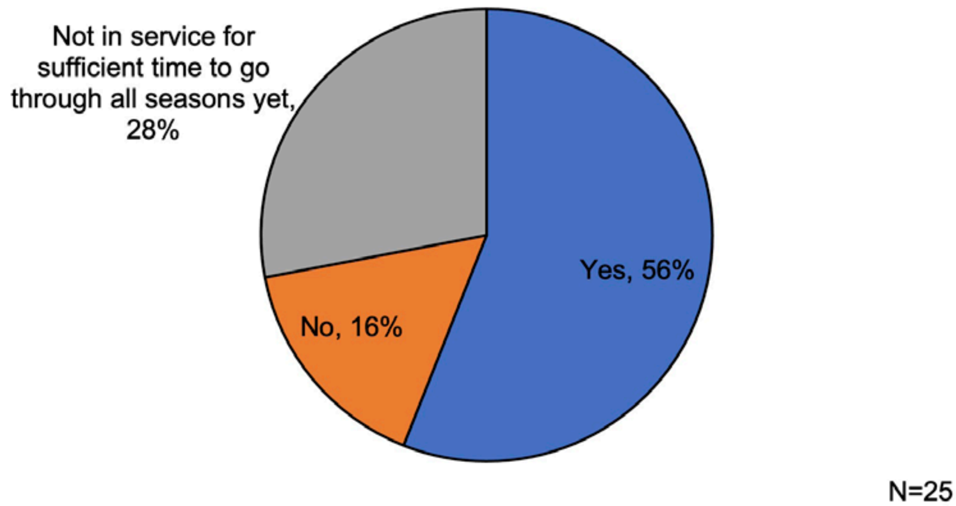


Figure 3-42 *Changes in BEB operation and/or charging patterns associated with changes in seasons*

In a similar question, agencies were asked if they experience extreme weather and whether that effects BEB operations or charging patterns. While 36% of respondents indicated they do not experience extreme weather conditions, about 44% indicated that extreme weather does affect their BEB operations and charging patterns, as displayed in Figure 3-43. Of the remaining respondents, 4% noted that although extreme weather occurs, it does not affect BEB operations or charging and 16% noted this has yet to be determined.

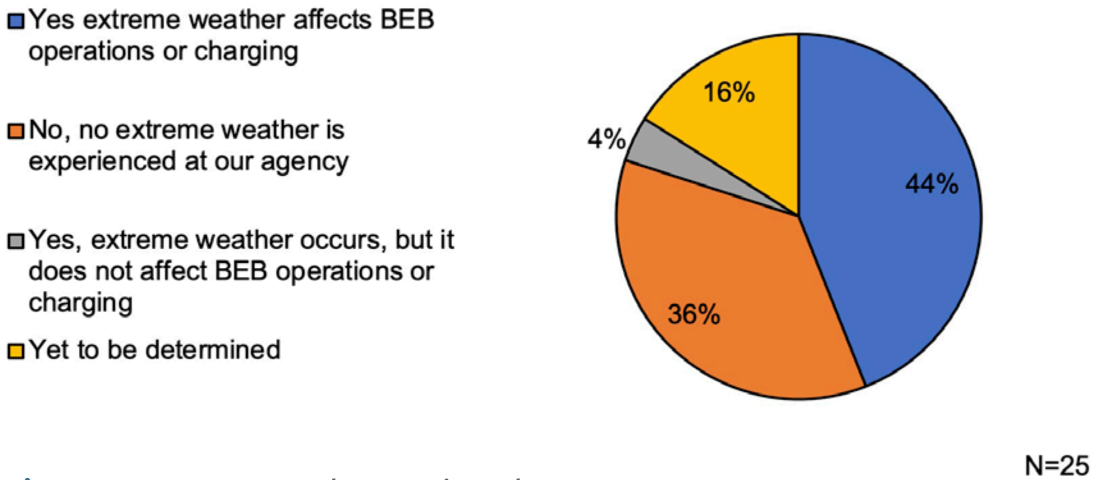


Figure 3-43 *Extreme weather experienced*

The last question about the operating environment focused on the major factors influencing BEB efficiency and performance. Figure 3-44 shows that climate, outdoor temperature, and operator experience are the greatest factors in BEB energy use, followed by the number of bus stops, passenger load, topography, traffic, and average speed.

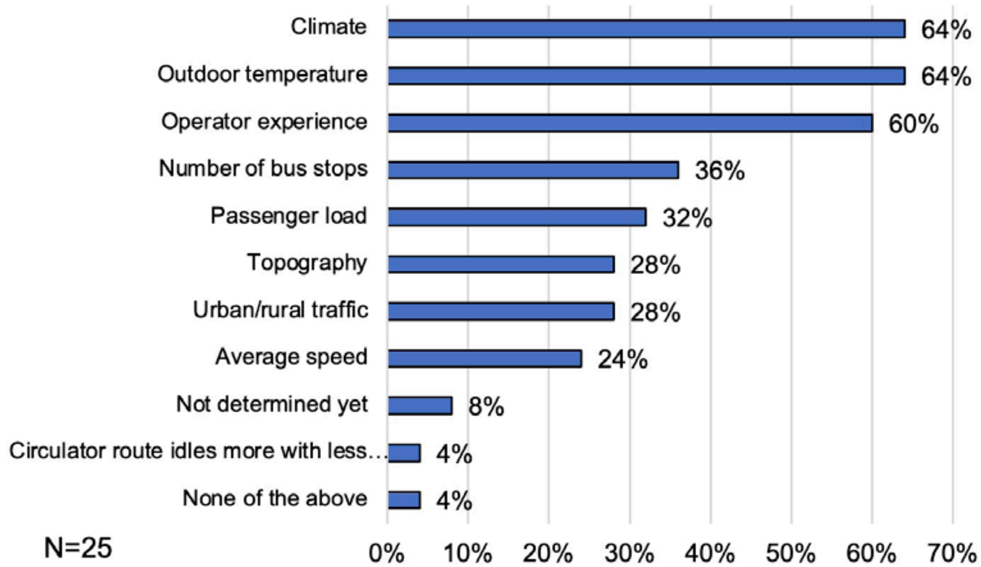


Figure 3-44 *Major influencing factors on BEB energy use*

Training

Training is important to every endeavor in the transit industry and implementing a BEB fleet is no exception. Researchers asked a series of questions in this section of the survey to gain an understanding of the types of BEB training currently provided and the areas where more training may be beneficial. Figure 3-45 displays the responses from agencies detailing who is responsible for initiating BEB charging. Technicians are the most common at 48%, followed by operators at 26% and fueling/service/cleaning employees at 22%.

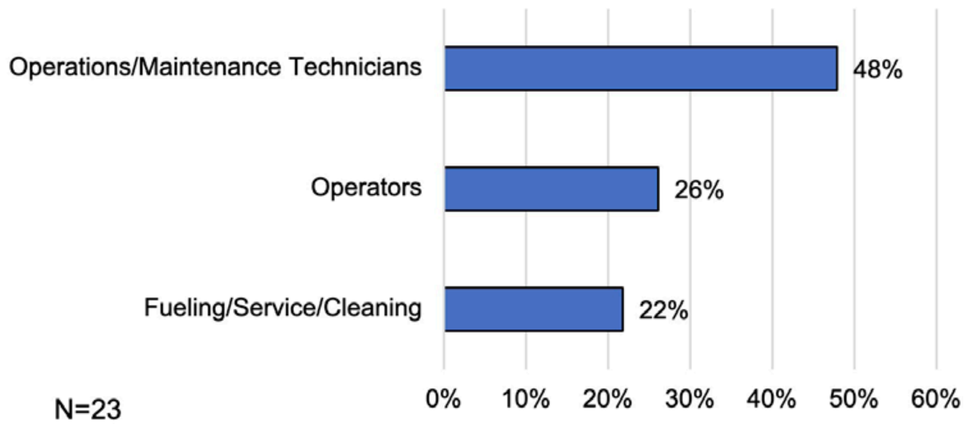


Figure 3-45 *BEB charging initiation responsibility*

Agencies were also asked what type of training was required for those responsible for initiating the BEB charging. Figure 3-46 shows that 48% of respondents provided minimum orientation training, 39% provided vendor-specific training, and a few others included safety and familiarization training (4%), routine training (4%), and theory of operations training (4%) as well.

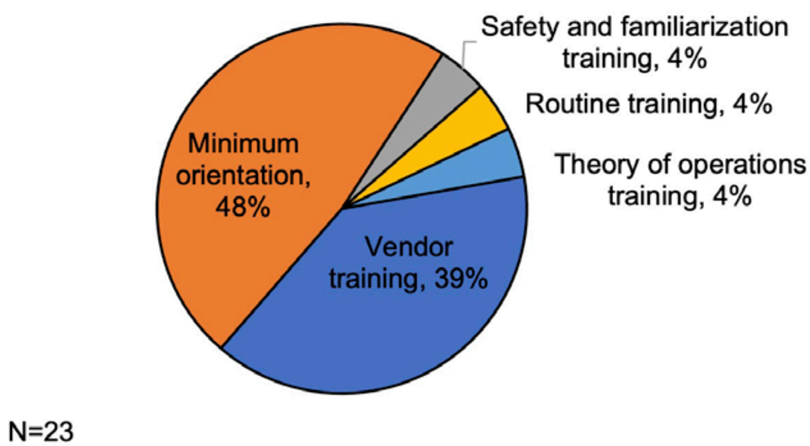


Figure 3-46 *Training required*

The survey also asked specifically about training by agency position for operators, maintenance technicians responsible for maintaining the BEBs, maintenance technicians responsible for maintaining the charging equipment, and first responders. All agencies offer some type of training to operators and maintenance technicians responsible for maintaining the BEBs.

The details covered in the operator training and the robustness of the training varies, from vendor-provided familiarization training all the way to optimization training to teach operators about regenerative braking and other key characteristics such as the quietness of the bus and dashboard differences.

The type of training for maintenance technicians varies by agency. Some respondents indicated maintenance technicians received limited training at new bus delivery from the manufacturer, along with some train-the-trainer materials provided by the vendor. Others offer multi-day trainings that are extensive and comprehensive. Some of the specific types of training topics include:

- ABS brake
- Battery inspection
- Bus defueling procedures
- Electric drive
- Electronic controls and subsystems
- Electronic cooling system
- Emergency vehicle shut-off
- Energy storage system
- Engine/propulsion training
- High voltage
- HVAC
- Lockout/tagout (LOTO) training
- Passenger door and wheelchair ramp system
- Pneumatic system
- Propulsion cooling system
- Safety
- Special equipment
- Steering and suspension
- Use of diagnostic tools
- Vehicle orientation

As Figure 3-47 shows, the share of agencies that provide training to maintenance technicians who are responsible for maintaining charging units was not as ubiquitous, at 79% of respondents. Those that provide training include topics such as:

- Commissioning
- Diagnostics and troubleshooting
- Inspection
- Preventative maintenance
- Software use
- Theory of operations

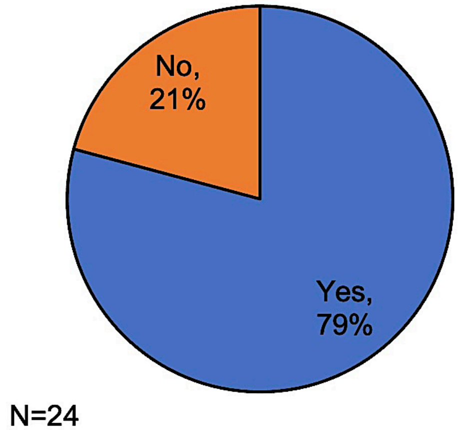


Figure 3-47 *BEB vendor-provided maintenance technician training for those responsible for maintaining the charging units*

In addition to training internal operations and maintenance technicians, it is beneficial to initiate emergency response training with local first responders to ensure at a minimum their response will not increase the severity of a situation they are mitigating. Figure 3-48 shows that 60% of respondents indicated they do coordinate some type of vendor-provided training to familiarize local first responders with BEBs.

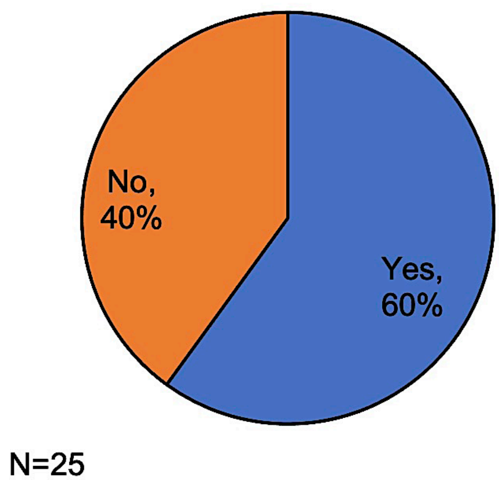


Figure 3-48 *Coordination between the transit agency and/or BEB vendor and local first responders to provide first responder training*

Most respondents (80%) do not contract out any of their BEB and associated charging infrastructure maintenance, as shown in Figure 3-49.

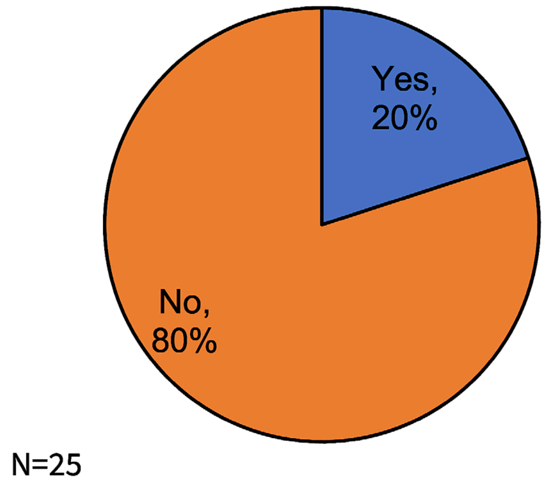


Figure 3-49 *Contract out any BEB and associated charging maintenance*

Concerning what type of technician was trained to maintain and repair agency BEBs, Figure 3-50 shows that 56% of respondents have automotive technicians trained for maintenance and repairs, while 27% reported electricians and 17% reported maintenance technicians were trained to perform those duties.

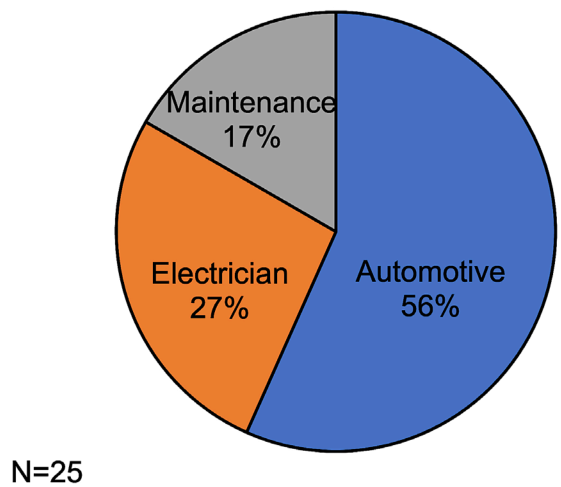


Figure 3-50 *Type of technician trained for BEB maintenance and repairs*

When asked what type of technician was trained to maintain and repair the charging infrastructure, about half (52%) of respondent agencies indicated that electricians are trained to maintain and repair their BEB charging infrastructure, while 20% trained maintenance technicians, 19% trained automotive technicians, and 9% were other types including OEM, contracted, and intelligent transportation system (ITS) staff, as shown in Figure 3-51.

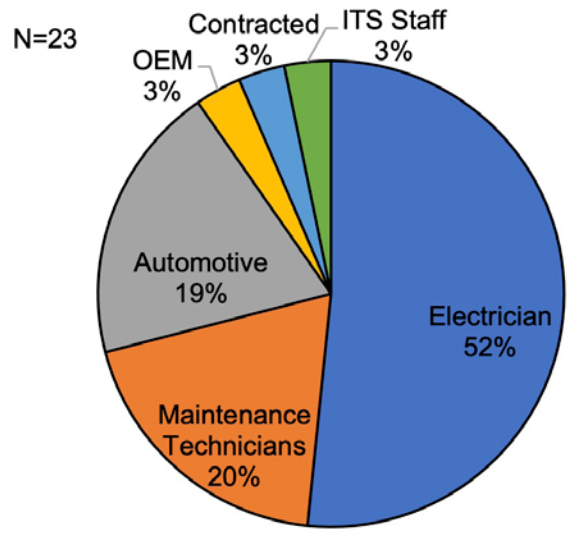


Figure 3-51 *Type of technician trained for maintenance and repairs of the charging infrastructure*

With hopes of gaining insight into what agencies might have changed, researchers asked what type of technician they feel is best suited for providing BEB maintenance and repairs. Figure 3-52 shows that 46% feel automotive technicians are best suited, 23% feel electricians are best suited, and 16% think electromechanics would be best suited for the job. The remaining 15% simply noted other.

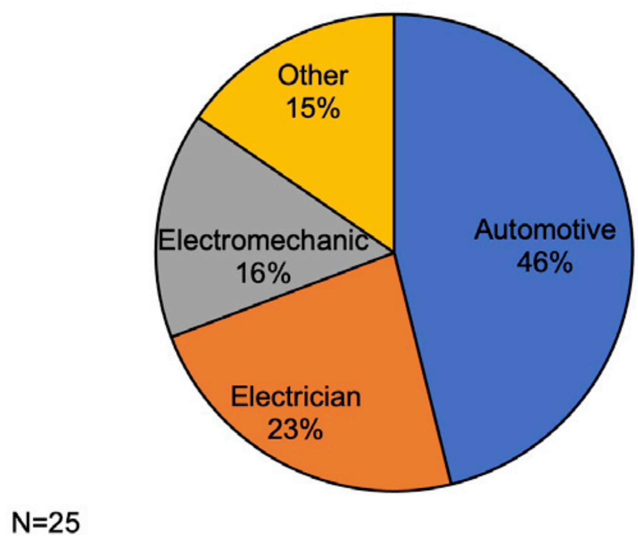


Figure 3-52 *Type of technician best suited for BEB maintenance and repairs*

Similar to the previous question, agencies were also asked which type of technician is best suited to maintain and repair charging infrastructure. Figure 3-53 shows that electricians are favored at 76% of the respondent agencies.

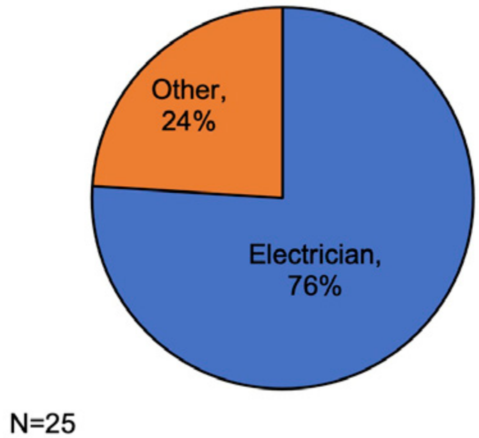


Figure 3-53 *Type of technician best suited for the maintenance and repairs of the charging infrastructure*

Lessons Learned

The last section of the survey focused on the lessons learned that agencies generally share with their peer agencies.

Table 3-2 *Performance Metrics Identified and Measured to Evaluate the Operation and Maintenance of the BEBs and Charging Infrastructure*

Reliability	Cost/Efficiency	Utilization
Availability	**Cost of ownership**	**Mileage**
Charger uptime	Cost of operation	Average daily miles
On time service	Cost per mile	Monthly mileage
Vehicle availability	**Power consumption/efficiency**	Cumulative fleet miles
Road failure intervals	Average monthly fleet efficiency	**Range**
Mean distance between failures (MDBF)	Energy consumption versus charger energy delivered	Average speed
Mean time to failure (MTTF)	Fuel efficiency versus external temperatures	Average regeneration rate
Road calls	Grid energy used	Charge capacity
	kWh/mile	Impact of HVAC on energy use
	mi/diesel gallon equivalent	Rate of charge
	Route specific efficiency analyses	SOC used

While 36% of respondents indicated they did not experience any specific challenges, the agencies that did experience challenges in the procurement phase indicated issues that ranged from new vendor challenges typical for unproven technology to timing challenges, charging location challenges, coordination with power companies, and scheduling challenges as the most problematic, as shown in Figure 3-54.

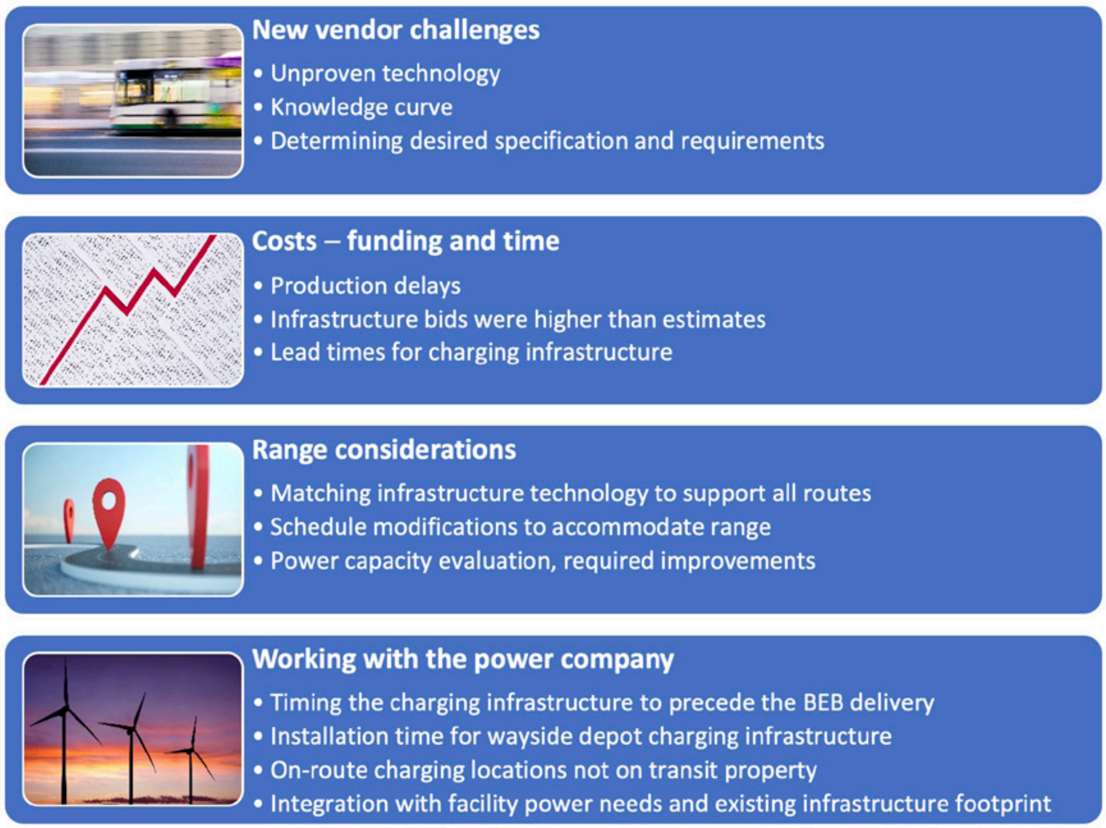


Figure 3-54 *Specific challenges encountered in the procurement phase of the BEB and associated infrastructure*

Based on their first BEB procurements, agencies were asked what changes they would include in their next procurement specifications. While about 12% of respondents would not change any of their language, and another 12% of respondents were not yet sure what changes they would make, 76% indicated they would make various changes ranging from language to range requirements, to charging infrastructure, and more.

Figure 3-55 shows suggested changes by agencies. Some of the language changes would include industry standard language and expectations spelled out explicitly in the procurement language, and more specific and concise language with better provisions, delivery of the vehicles with a full state of battery charge, and longer lasting warranty components. Other respondents indicated the importance of including more mileage, longer ranges, and improved capabilities in the next procurement. In terms of the charging infrastructure changes, one agency would include a distinct infrastructure contract that is separate from the BEB vehicle procurement contract. Others mentioned how important charging management will be as the BEB fleet grows, and there is a need for interoperability of various chargers and buses.

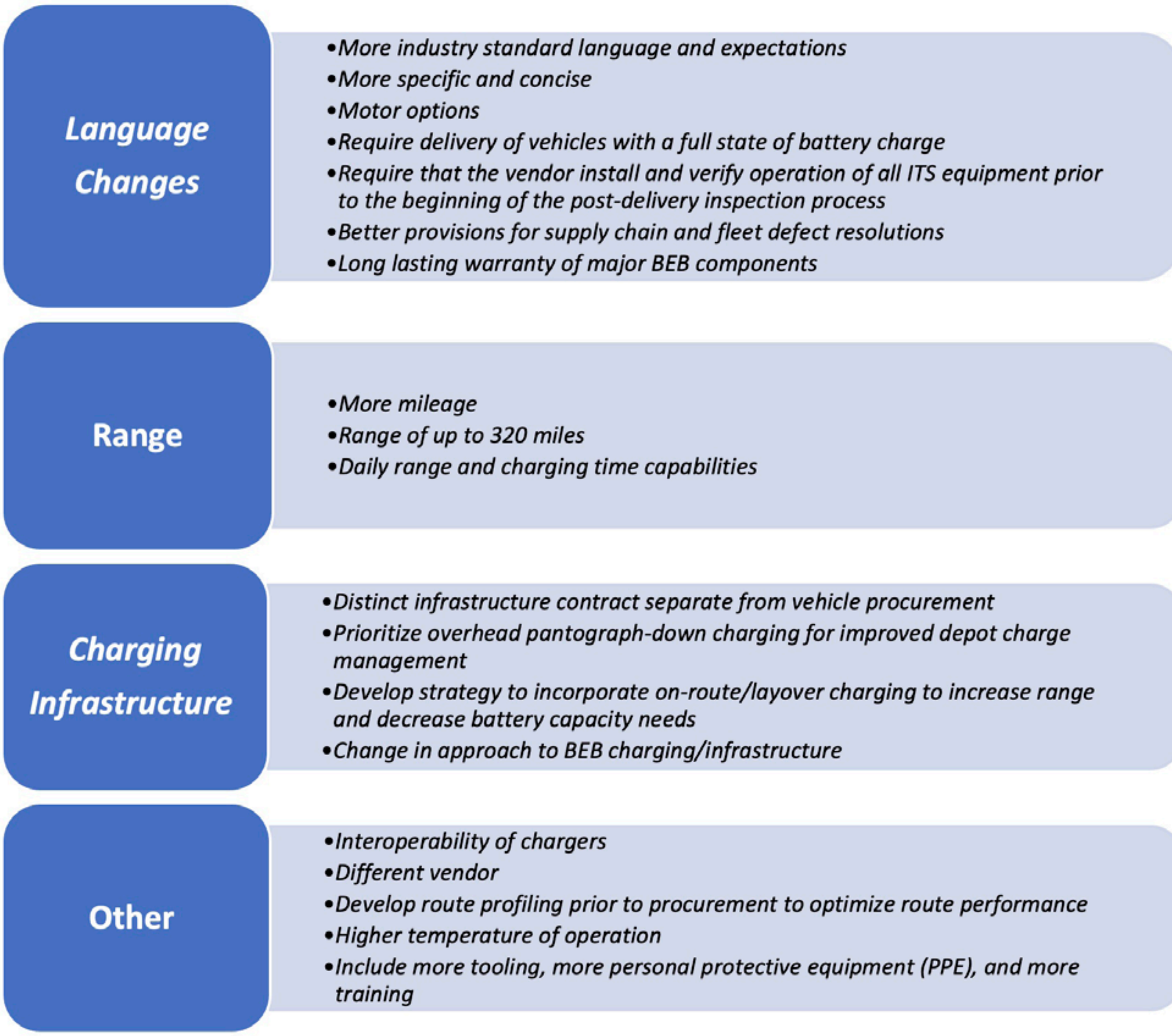


Figure 3-55 *Suggested changes to include in future BEB procurements*

Agencies were asked what challenges they faced throughout the deployment of their first and subsequent BEB deployment(s). Responses ranged from timing and training challenges to interoperability and connectivity challenges. Vendor challenges with unmet expectations and undelivered promises were also mentioned. All the challenges are summarized in Figure 3-56. Anticipated challenges for BEB fleet expansion are listed in Figures 3-57 and 3-58.

Figure 3-56 *Challenges faced throughout the BEB deployment*

Physical Needs	•Long-range bus weight exceeds bridge weight capacity •Updated maintenance facilities •Battery storage, maintenance, and disposal •Real estate limitations for charging infrastructure •Maintenance training •Designated safe tooling, PPE
Dependability	•Dependability and reliability issues related to technology maturity •Infrastructure troubleshooting •Loose connections and software challenges •Range challenges – maximizing usable energy onboard
Charging	•Charger capabilities, power availability •Charger OEM delays in providing SIM cards delayed charger operation by significant period of time •Charging infrastructure regularly had faults that impacted charging •Increased complexity of vehicle assignments •Developing a charging strategy
Cost	•Funding •Parts cost more •Diesel replacement ratio average 1.5 to 1 •Spare ratio requirements are inconspicuous – do charging buses count as spares?
Data	•Controller area netork (CAN) library to support single source for CAN analysis and data extrapolation

Figure 3-57 *Challenges faced with any BEB expansion, or challenges anticipated with the transition of a larger percentage of bus fleet from traditional diesel to electric vehicles*

Figure 3-58 *Challenges anticipated to convert half of a bus fleet to BEB*

At an average, the respondent agencies felt about 40% of their fleets could be electrified based on current existing technological constraints. The individual shares ranged from 0 to 100%, as shown in Figure 3-59.

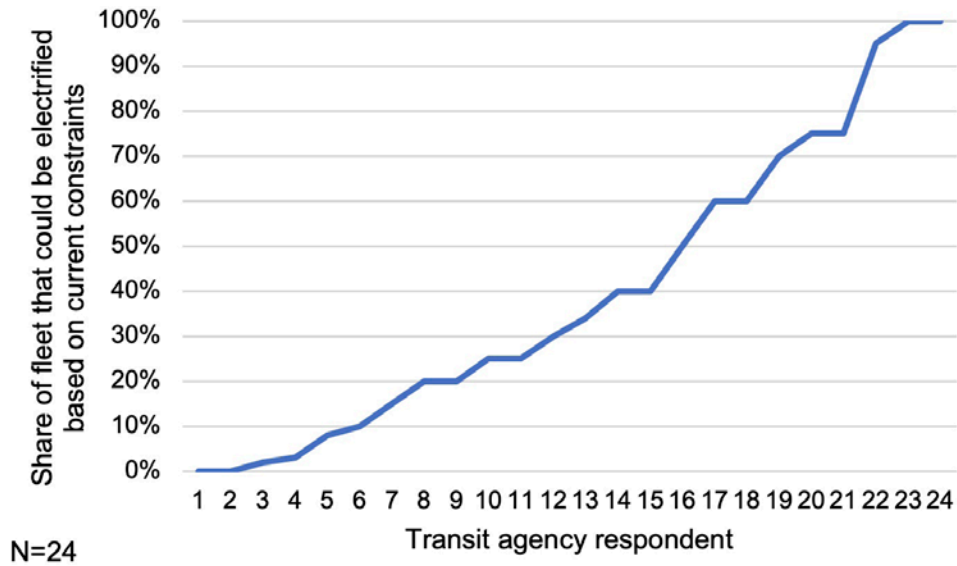


Figure 3-59 *Percentage of fleet believed to possibly be electrified based on existing technological constraints*

Respondent agencies learned many lessons from the various challenges faced in their BEB procurement and maintenance endeavors, ranging from dealing with new vendors on unproven technology to the knowledge curve associate with that unproven technology. There were also challenges determining the desired specifications and requirements in their first procurements. Agencies faced challenges associated with funding and time constraints such as longer than anticipated lead times for charging infrastructure and production delays, in addition to infrastructure bids that exceed the estimates. In terms of range considerations, transit agencies faced challenges with matching infrastructure technology to support all routes and having to modify schedules to accommodate the range capabilities of the bus. Another power-related challenge was associated with the need to perform a power capacity evaluation to ensure that the transit facilities could handle the additional power draw of charging a bus fleet, which many times leads to having to improve the facilities. Agencies also reported facing challenges working with their power companies, especially in terms of timing the delivery of the charging infrastructure to precede the delivery of the first BEB to ensure the ability to charge the BEB for use. Other power company challenges included 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 would accommodate the increased power needs of the agency.

When agencies were asked what changes they would make in future procurements, many responses focused on changes in procurement language, such as more specific language, more options, and requirements for support and supply chain provisions. Agencies also suggested that procurement language requires sufficient warranties on major BEB components, and requires the vendor verify the operation of all ITS equipment on the BEB prior to beginning the post-delivery inspection. In future procurements, agencies indicated they would be looking for BEBs that have a range exceeding 300 miles and they would be looking for bids that explicitly define the charging time capabilities.

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 the need to prioritize overhead pantograph charging to improve depot management, while others recognized the need to develop on-route charging strategies to allow charging during layovers, increase range, and decrease battery capacity needs.

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

Aside from the procurement challenges, agencies faced additional challenges as they deployed the BEBs into service. First, agencies mentioned challenges with timing, including timing for training, timing of routes and charging, and timing challenges associated with delayed parts. Second, agencies mentioned challenges with cost and space, specifically related to support, and space for charging infrastructure. Third, agencies mentioned vendor challenges including those with typical bus configurations, communication challenges, and unmet expectations. Finally, agencies mentioned some miscellaneous challenges associated with software bugs, interoperability challenges, and connection challenges. Many of these challenges have led to 44% of the respondent agencies indicating they cannot currently envision a path to full fleet electrification, as shown in Figure 3-60.

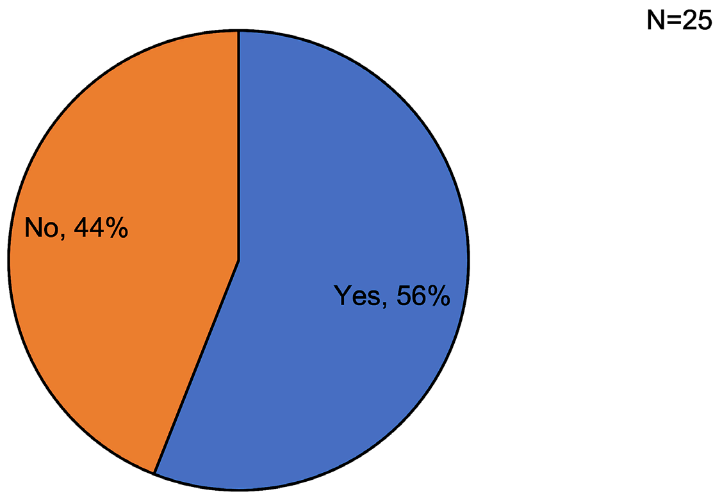


Figure 3-60 *Respondents envision a path to full BEB fleet conversion*

When agencies were asked about the status of updating their plans to accommodate environmental regulations associated with the use and storage of batteries on agency property, nearly three out of every four agencies indicated that they have not yet considered updates due to the environmental regulations associated with battery use or storage. Some agencies have updated plans, including 18% of respondents that have updated their hazardous waste management plans, 4% have updated their battery banks for solar power storage plans, and 4 percent have updated their NFPA plans.

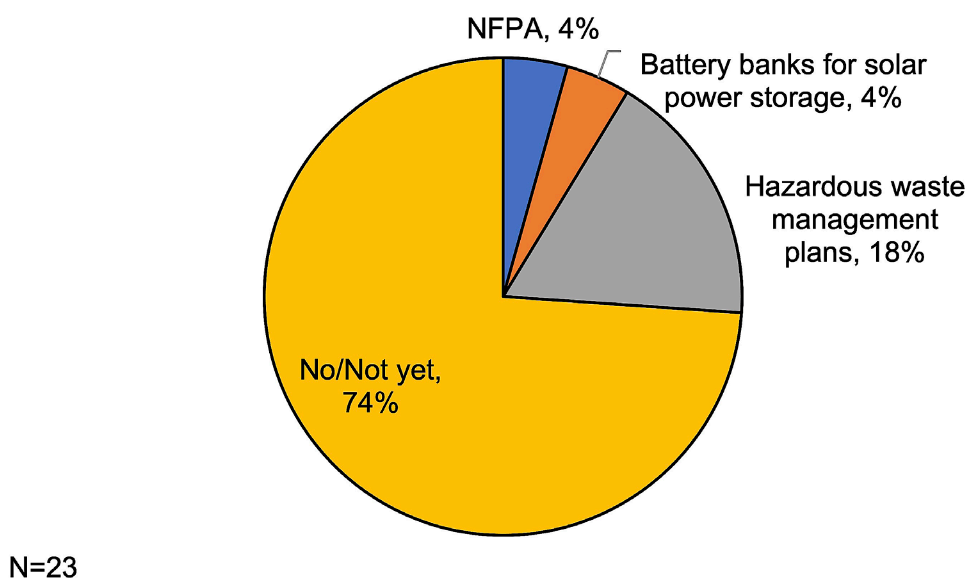


Figure 3-61 *Updated plans to accommodate environmental regulations associated with the use and storage of batteries on agency property*

Section 4 Case Studies

The transit agencies included in this section were selected based on their responses to the survey and their willingness to participate as a case study. Eight case studies were selected from the 25 survey respondents and included the agencies listed in Table 4-1. The research team developed a questionnaire for each of the interviews based on the survey responses. These interviews were conducted virtually using Microsoft Teams.

Table 4-1 *Case Study Agencies*

1	AC Transit	Oakland	CA
2	Foothill Transit	West Covina	CA
3	LYNX	Orlando	FL
4	Pinellas Suncoast Transit Authority	St. Petersburg	FL
5	Port Authority of Allegheny County	Pittsburgh	PA
6	SEPTA	Philadelphia	PA
7	TriMet	Portland	OR
8	Valley Regional Transit	Boise	ID

The interviews with the case study agencies are summarized below, organized alphabetically by each agency. Each summary provides background information on the agency's initial BEB procurement and current BEB fleet, as well as considerations given to BEB and charging equipment technology, constraints and challenges to planning and implementation, as well as lessons learned from their experiences with adopting BEBs.

AC Transit (Alameda and Contra Costa Counties, California)

As a special district under California statute, the Alameda-Contra Costa Transit District (AC Transit) initially launched its service in 1960.[44] AC Transit serves the western portions of Alameda and Contra Costa Counties, which includes the City of Oakland and 20 additional cities and unincorporated communities. In 2004, AC Transit deployed a comprehensive fuel cell demonstration program in partnership with California Fuel Cell Partnerships and Hydrogenic that included the buildout of three hydrogen fueling stations—a primary station at the AC Transit Oakland Division, a secondary station at the Richmond Division, and a tertiary station at the

[44] https://www.actransit.org/

Emeryville Division. In 2019, AC Transit added 10 hydrogen fuel cell buses and 5 New Flyer battery electric buses, bringing the fleet total to 640 buses. The integration of the fuel cell buses and BEBs was part of a transition to a 100% zero-emission transit bus fleet by 2040, in line with the CARB Zero-Emission Bus Rollout Plan.

BEB Procurements

AC Transit received its first BEB delivery in June 2019, which included five 40-foot New Flyer battery electric buses that were used on routes that were also serviced by the agency's hydrogen fuel cell bus fleet. The District had also ordered 15 New Flyer zero-emission buses, including the 5 BEBs and 10 fuel cell buses. These buses were deployed at the agency's Oakland (Division 4) facility, which includes a hydrogen fueling station and DC fast charging stations to support the BEBs.

There are currently 23 GILLIG BEBs on order. Two of those BEBs have arrived and are currently in the acceptance phase, and the remaining 21 buses are expected for delivery starting in January 2022. AC Transit is finalizing vendor selection for the charging infrastructure to support the 23 additional BEBs and is considering a modular arrangement that uses a power bank to support 3 to 4 buses charging. These modular systems can be configured to charge multiple buses at one time and are designed to support larger electric bus fleets. There are plans to install the additional DC fast charging infrastructure at the Emeryville (District 2) facility.

BEB Charging Equipment

To support the first five New Flyer BEBs, AC Transit installed six networked, stationary ChargePoint Express 250 (CPE250) plug-in charging stations, and one mobile CPE250 charging station located at the agency's maintenance bay to support the expanding BEB fleet. These stations are 62.5 kW when single and 125 kW when paired. The pairing installation provides a solution to distribute power between two stations to charge two vehicles at the same time, and to share power based on power allocations that are aligned with site demands. The BEBs are charged overnight and take approximately four hours to reach a full SOC. AC Transit has flexibility with scheduling charge time to avoid charging during peak hours. The charging systems are equipped to allow the District to manage the charging cycles.

For the charging stations, ChargePoint will conduct maintenance on-site. The first maintenance interval for the depot charging stations is five years, though District staff will check on the stations periodically and wipe down the chargers.

Facility Upgrades

Prior to AC Transit purchasing the five initial BEBs, PG&E had released the PG&E EV Fleet program. However, the District moved forward with their internal facilities teams to manage the construction upgrades of the bus facility according to the specifications from PG&E, including construction of the pad, connections, and easement on the property for PG&E to install a transformer at the facility. The upgrade proposal includes plans for two additional BEB charging facilities. Construction is expected to begin in 2021 at the Emeryville facility to install 22 additional charging stations. The agency also plans to construct an additional facility beginning in 2023 that will support 25 to 50 BEB charging stations and include overhead charging and parking deck. The District was able to save on construction and installation costs by managing the upgrades internally.

Warranty

The OEM provides 12 months of on-site warranty repairs. The BEBs are equipped with Siemens and XALT battery systems. AC Transit troubleshoots at the first level, and then escalates to New Flyer. Once escalated to New Flyer, the OEM dispatches a local representative who addresses the issue. Standard training protocol for AC Transit involves in-house technicians conducting the first-level checks to evaluate the potential problem and attempt to diagnose the issue. While the OEM is performing the repairs under the warranty, AC Transit believes that in-house technicians should be capable of running diagnostics on the BEBs and identifying the issue in need of repair.

Training

AC Transit provides a journey level apprenticeship program and has a dedicated training center where a combination of in-house and OEM training is conducted for the battery electric, fuel cell, and diesel vehicle technologies. When new vehicles are purchased, the District conducts line-up training, some of which is strictly OEM specific, that is coordinated with in-house training. AC Transit also works closely with area first responders to conduct periodic first responder safety training at its bus facilities, particularly when new vehicle technologies are introduced.

Partners

AC Transit partnered with the Center for Transportation and the Environment (CTE) and one other organization on the FTA Low-No grant to fund the purchase of the 5 BEBs and 15 hydrogen fuel cell buses. The District had partnered with CTE back in 2017 to conduct a zero-emission bus study, which included an analysis on route specifications for zero-emission buses, technology specifications, bus capacities and range, and other considerations. At the time the report was conducted, it demonstrated that 80% of the District's routes could be done with fuel cell buses and 20% would be handled by battery electric buses.

BEB Performance

The five BEBs have been deployed for two years, and AC Transit has found that the buses are performing better than what was indicated from the 2017 CTE study. The District has a variety of routes, including some that are 200 miles and others that are 90. The BEBs are not, at present, limited in their range capability to operate on the 200-mile routes. However, based on performance, the BEBs can accommodate approximately 35% to 40% of the routes, while the rest could be covered by the fuel cell buses.

Challenges

Impacts to Battery State of Charge

AC Transit has experienced issues with the buses returning at lower SOC than anticipated. One of the reasons for this is that occasionally one of the batteries in the system will experience a communication failure and will not connect with the circuit. This impacts the SOC, and buses are then returned to the depot lower than the standard return SOC, which is typically 20% or higher per AC Transit protocols. Operator behavior has also impacted SOC, which AC Transit is able to track using telematics—Clever Devices—and identify trends of lowered efficiency. Operators are then offered refresher training if needed.

Parts Availability

The District has encountered some challenges with accessing parts, specifically for the BEB battery systems, which resulted in needing to pull the BEBs from service for three months. Vendors would not have parts in stock or were waiting on new components that were being manufactured and distributed to plants so they were not available at distribution centers, resulting in delays.

Battery Specifications

AC Transit has encountered some issues with its specification development regarding battery system warranties. One string of the battery pack may degrade faster than the other individual battery packs, meaning it is possible that the battery system may have individual packs of different ages and state of health. This creates problems if the warranty is specific to the battery system and not individual packs.

Space Constraints

AC Transit anticipates challenges with expanding the battery electric bus fleet and integrating additional charging infrastructure systems. The District is considering a power pack modular system. However, the additional charging systems plus the BEBs are expected to drastically decrease the space available at the bus facility. Alternative charging infrastructure, such as the pantograph systems, also present challenges due to space limitations in the reserved bus parking space lot.

Electricity Rates

In California, it is difficult for agencies to negotiate rates with utility service providers. Promotional rates are offered on a limited-term basis, which creates challenges with planning projected electricity costs given that the kWh prices may vary.

Lessons Learned

AC Transit acknowledges that since the BEB technologies are still new, there are issues that will need to be worked out in this initial phase. The District has experienced some challenges and problems that required creative design solutions to address them. Establishing good working relationships with OEMs is key and providing opportunities to test these technologies and submit feedback is an important part of the process, at least for the early adoption phase of BEBs until the technology matures.

Foothill Transit (Greater Los Angeles, California)

Foothill Transit

Foothill Transit was established in 1988 and is supported by 22 member cities in the San Gabriel and Pomona Valleys. Foothill Transit operates a fixed route bus public transit service in the Greater Los Angeles area and covers a service area of approximately 327 square miles.[45] At present, Foothill Transit operates 328 compressed natural gas (CNG) and 35 all-electric buses. In 2016, the agency committed to fully electrifying its bus fleet by 2030 in line with the agency's goals to provide safer, innovative transit solutions and improve regional air quality. This also follows the State of California's Innovative Clean Transit goal for 100% zero-emission buses by 2040.

BEB Procurements

Foothill Transit initiated its first BEB adoption in 2010. During this time, the California Air Resources Board (CARB) was in the process of developing policies for transit agencies to transition to zero-emission fleets. In 2010, Proterra had a fully battery electric transit bus model available. Foothill Transit applied for and received grant funding under the American Recovery and Reinvestment Act of 2009, which included funding for investments in improvements at the agency's

[45] http://foothilltransit.org/about/history/

bus facilities as well as for BEB procurement. Of the funding, $6 million was used to purchase three Proterra short-range battery electric buses. The agency invested in BEBs back in 2010 to test the technology and to see how the buses would operate in transit service.

Foothill Transit then acquired 14 additional Proterra BEBs by 2017. In 2019, the agency purchased the Proterra E2 extended range BBE with 440 kW battery capacity. In early 2021, Foothill received delivery of double-decker BEBs with 648 kW battery capacity from Alexander Dennis.

BEB Facilities and Charging Equipment

Foothill Transit has one bus facility in the City of Pomona and one in the City of Arcadia. The agency installed two overhead pantograph fast charging stations at the Pomona Transit Center, and one overhead fast charging system at the bus yards to top off the BEBs before deploying them into service. When BEBs stop at the Pomona Transit Center, they are normally at about 60% SOC. A seven-minute layover is usually enough time to fully charge the bus back to almost 100% SOC. There are two additional overcharge chargers at the Azusa Intermodal Transit Center to provide opportunity charging to extend the BEB range to nearly 200 miles.

There are also 12 60 kW depot plug-in chargers as well as a 125 kW charger at the Arcadia yard to support 17 BEBs, including the two double-decker buses. Given that most of the chargers are 60 kW, it takes approximately three to four hours to charge (depending on bus SOC), which is why there is a higher charger-to-BEB ratio at the Arcadia bus yard than at the Pomona Transit Center.

BEB Performance

The agency uses a telematic system—ViriCiti—to monitor bus and operator performance, including layover actual hours, service number of miles, bus efficiency, and kilowatt hours per mile. Foothill Transit currently gets about 1.9 kW/mile for the extended range BEBs, though efficiency can vary depending on operator behavior, traffic patterns, route characteristics, climate, passenger load, and other factors.

Warranty

Battery life expectancy of six years. The agency has found that by the sixth year, the battery degrades and begins depleting at a faster rate. The BEB life expectancy is 12 years/500,000 miles, though the agency is trying to extend that to 14 years.

Maintenance and Repairs

Charging station maintenance is conducted by Proterra. Foothill Transit reported that the agency has several options for bus repair. OEM maintenance techniques are available on-site, and there is an option to send the BEBs to the factory. There is at least one technician assigned to each of the bus yards who is equipped with diagnostic tools specific to Proterra buses. For larger component failures, such as inverters, traction motors, and so on, the on-site technicians review the fault code and that information is sent to the OEM facility. Foothill Transit has encountered some issues with software updates, such as when these updates were not communicated to the agency, which would have caused additional delays with repairs.

Training

Bus Operation and Charging

The OEM provided train-the-trainer material, including driver training and a driver manual to ensure the operators felt comfortable. Foothill Transit continues to perform ongoing training.

While operators are not responsible for charging the BEBs at the overnight depot charging stations, some of the agency's operators were trained to align the bus with the overhead charging system. For the overhead charger to communicate with the BEB, the bus needs to be aligned properly for the charging system to take over. The bus operators must ensure that communication between the bus and the overhead charging system is not interrupted prior to that.

Challenges

Costs

Foothill Transit found that there is a \$200,000–\$250,000 differential between CNG and fuel cell/battery electric buses. Additional capital is also required for BEB charging equipment and hydrogen fueling stations for fuel cell buses.

Funding is a challenge for transit agencies, given the cost of the BEB and infrastructure. Foothill Transit estimates that a 100% battery electric fleet would require substantial capital investment between facility construction costs, pantograph charging equipment and installation, and additional support staff.

Parts Availability

Accessing parts has been a challenge, and the agency has had to pull BEBs out of service for 60 days when parts were not readily available. Foothill attributes these delays to part secession. When the OEM changes a part number and upgrades a part, this creates complexity for the ordering process. For example, the OEM would have a difficult time identifying the new part number, send parts that are incompatible with new BEB models, and have issues with storing parts. At times, the agency has had 40% of the fleet out of service, and experienced challenges with getting the BEBs back in service given delays in acquiring parts for repair.

Space Limitations

Foothill Transit has limited space at its bus facilities, which makes moving toward a 100% BEB fleet a challenge. The agency hired a consultant in 2019 to analyze the existing system and develop a cost estimate and plan of action for transitioning to a full BEB fleet. Due to space constraints, overhead chargers would have to be installed and bus parking would have to be rearranged.

Partnerships

In 2009, Foothill Transit partnered with Southern California Edison (SCE) to get assistance and guidance, especially regarding grid connections, power supply, and the charging stations. SCE designed the infrastructure connection from the grid to the chargers. Initially, Foothill Transit did not have a dedicated EV rate, so it was paying at a commercial rate and incurring high demand charges. The agency worked with SCE to develop a dedicated EV rate, and the utility provided financial support for the charging infrastructure as charging needs grew with additional BEBs added to the fleet. Foothill Transit also participated in a SCE-led pilot program, Transport Ready Charge. Under this pilot, SCE managed the design, permitting, installation, construction work, and connection from the grid to the bus facility. SCE also installed the chargers on the base plate and connected it to the utility, as well as provided a rebate for the cost of the charger.

Since Foothill Transit's initial BEB purchase in 2009, SCE has continued to be a dedicated partner as the agency expands its BEB fleet.

Lessons Learned

One major lesson learned for Foothill Transit was the need to hire a consultant to evaluate the key needs, costs, and variables for transitioning to a zero-emission bus fleet. The consultant prepared a report for the agency that provided insight into the time, costs, and technology needed to support a transition. Factors such as route planning, projected energy consumption (in kWh), technology requirements, range restrictions, evaluation of various zero-emission propulsion systems, and cost estimates were included in the report. The agency recognized the need to model these various factors to better understand the array of potential impacts for integrating BEBs.

After receiving the report, Foothill Transit presented these findings at an all-day workshop with board members to make them fully aware of the needs and costs required to support transitioning to a 100% zero-emission fleet.

LYNX (Orange, Seminole, and Osceola Counties, Florida)

LYNX was initially established in 1972 as Orange Seminole Osceola Transportation Authority, eventually changing its official name to Central Florida Regional Transportation Authority and offering transit services under the name LYNX. The agency serves an area of nearly 2,500 square miles in Orange, Seminole, and Osceola Counties that sustains a population of more than 2.2 million residents.[46] At present, LYNX has more than 300 transit coaches in its fleet that services 72 local routes throughout the tri-county area. Services include fixed route, downtown circulators, commuter services, door-to-door paratransit services, flex-service routes, and roadside assistance programs. The agency uses CNG to fuel approximately 43% of its bus fleet, in addition to biodiesel and electricity. In 2020, LYNX acquired the agency's first electric bus, and has since implemented seven additional BEBs into the fleet with six more on order for 2022. The board of directors at LYNX set the goal of a 50% low or zero-emission fleet, which is consistent with similar environmental goals from the City of Orlando and surrounding communities. LYNX plans to transition to a 50% BEB fleet by 2028. The downtown Orlando LYMMO (circulator) service, which is where the current BEBs operate, is planned to be fully electric by 2025.

BEB Procurements

LYNX received its first Proterra battery electric bus in September 2020 and seven additional BEBs in October 2020. The first BEB was put into service in December of that year and the seven additional BEBs were in service several weeks following that. The first BEB was purchased without the support of grant funding. The agency has since procured six additional BEBs with the assistance of 5339 Bus and Bus Facilities funding. The buses are expected to arrive in FY 2022. The battery electric fleet is operating on LYNX's bus rapid transit (BRT) service, in downtown Orlando.

Charging Equipment

There are fast charging stations at the LYNX bus depot, which can fully charge the BEBs in approximately three to four hours. LYNX has an interlocal agreement with the Orlando Utilities Commission (OUC) to own and manage the charging stations. The stations are located on LYNX property, though they are OUC assets. The agency would consider on-route charging options, but that will depend on cost and placement and if funding is available for the chargers.

[46] https://www.golynx.com/corporate-info/facts-glance.stml

Bus Performance

The BEBs have performed on the BRT service as LYNX expected. Under normal circumstances, the buses are expected to reach the end of life.

Maintenance and Repairs

LYNX uses the field service representation from the bus OEM, though some minor repairs are done in-house. LYNX mechanics receive further training by observing the field service technician making repairs. The agency also trained operators and dispatchers so they understand how to respond to BEB-related issues. LYNX also ensures to build in training time before the new buses are dispatched into service for the first time.

For the charging stations, OUC is responsible for routine filter replacements and inspections. OUC staff provides normal preventative maintenance and if there is a failure, LYNX staff has some basic knowledge on rebooting the station. For anything more complex, OUC arranges for the stations to be serviced, though abuse, vandalism, and negligence are not covered.

Training

The OEM provided the initial maintenance training as well as follow-up maintenance training. The LYNX training department coordinated the first responder training with the City of Orlando Fire Rescue. The Fire Rescue learned about the mechanics of high-voltage systems on the BEBs and charging stations. The training was provided by Proterra but was organized and hosted by LYNX at the agency facility and training rooms. The training was train-the-trainer, so the LYNX training department is now fully able to train additional first responder agencies as needed.

Challenges

Response Time and Parts Delays

The agency has experienced some issues related to response time when the BEBs are down longer than desired. This is expected to slowly improve as the agency learns more about which tools and parts need to be stocked on-site versus shipped. For example, currently there is a part that needs to be replaced that is located underneath the batteries, but LYNX technicians are unable to remove the battery system so they are waiting for the OEM to ship the lift that removes the battery. LYNX plans to order one of these lifts for future repairs. These items would be procured separately, as an effort to ensure the maintenance shop can handle general BEB repairs. LYNX did get initial parts to keep on hand based on vendor recommendations, which was part of the original procurement.

Partnerships

Lynx partnered with the local utility, Orlando Utilities Commission (OUC). OUC contributed the charging equipment for the BEBs, given that the utility has expertise in charging equipment and infrastructure. OUC invested in the BEB project and is managing construction requirements to accommodate the additional charging infrastructure.

In addition to OUC, LYNX partnered with CTE to develop an FTA Low-No application, which was used to fund the purchase of six BEBs.

Lessons Learned

Utility and Transit Partnership

For transit agencies that are partnering with an electric utility to install, own, and manage the charging equipment, it is helpful for the agency to host the procurement for the charging equipment since transit agencies may have more expertise in with working under federal purchasing guidelines. LYNX put out the procurements, received solicitations, and reviewed the solicitations to ensure they met FTA requirements before submitting them to OUC, which selected the vendor.

OEM Equipment and Vehicle Verification

When LYNX first received the BEBs and supporting equipment, there were issues with connecting to the radio system, there were a few wires that were not connected properly, and there were some incompatibility issues. Due to the resulting delay, the agency recommends requiring vendors to install and verify operation of all equipment prior to beginning the post-delivery inspection and requiring delivery of vehicles with a full SOC.

Future Proof Charging Infrastructure

LYNX wanted to design a charging infrastructure plan to accommodate at least 16 BEBs since it plans to continue growing its electric fleet. The agency worked with OUC to oversize the charging so LYNX can implement additional units to eventually support 16 electric buses. Planning for future charging helped to reduce overall costs.

Estimating Total Cost of Ownership for BEBs

LYNX forecasted out all the existing schedule blocks, including miles and hours for weekday, weekend, and holiday services for the next 12 years, determined by year and number of hours, and how that related to supply, which was provided to consultants, the project manager, and OUC. This data was used to forecast how the BEBs would charge based on the infrastructure being installed, including the number of hours that will push into peak demand charges. To figure out the ideal station size, the agency forecasted the cost of the station along with the cost of charging the BEBs, and how those netted costs offset the diesel fuel not being purchased. These figures were then presented to the City of Orlando with the forecasted costs by year for the next 12 years. LYNX presented a cost comparison of the BEB versus the diesel bus, which included electricity costs, capital, and so on.

Avoiding Peak Charges

LYNX learned that it is better to have the bus fueling station and charging stations metered separately. The chargers pushed the fees into peak demand when they were on the same meter. Because agencies are most likely to service buses on the third shift, and that is the same time depot charging occurs, peak demand coincided with charging if on the same meter. With LYNX's permanent charging station arrangement, the station has eight dispensers that run simultaneously. With plans to include additional modules, the agency will be able to charge 16 buses with two sessions.

Reducing Charge Time

LYNX was able to lower charge time by first turning the bus onto battery power so the chargers would recharge the 12-volt batteries. Once those reached top of charge, the buses were then plugged in, which reduced total charging time.

Diversifying Fuel Sources

Given that LYNX provides emergency support functions, the agency decided to diversify the fuel sources that power its transit fleet. The agency currently operates battery electric, diesel hybrid, and CNG buses, and plans to continue to commit to a 50% CNG and 50% battery electric bus fleet.

Pinellas Suncoast Transit Authority (Pinellas County, Florida)

In 1984, the Pinellas Suncoast Transit Authority (PSTA) became the county's official public transit provider.[47] The agency currently serves 40 bus routes, including 3 flex-route neighborhood connectors, the Central Avenue Trolley, Suncoast Beach Trolley, and 2 express routes to neighboring Hillsborough County. PSTA operates a 210-transit bus fleet powered by a mix of diesel, diesel-electric hybrid, and battery electric. The agency received its first two BEBs in 2018 from BYD and has since added four BEBs, bringing the total to six electric buses. Approximately half of PSTA's bus fleet is either hybrid-electric or battery electric.

[47] https://www.psta.net/about-psta/history-and-facts/

BEB Procurements

PSTA initiated its first BEB purchase in 2017 and had various funding resources to support this transition, including funding from the BP oil spill settlement as well as the FTA Low-No program. The first BYD buses were deployed into service in 2018 along a downtown circulator route. Since then, the agency has added four buses with six DC fast charging units and one 250-kW inductive charger to supply electricity to the BEB fleet. By the end of 2021, PSTA anticipates having eight fully electric buses in its fleet.

BEB Facilities and Charging Equipment

PSTA currently has six DC fast chargers for depot charging, four of which were supported by funding from Duke Energy. In 2020, the agency installed a 250-kW Inductive Power Transfer Technology wireless charging station to provide opportunity charging for the expanding electric bus fleet.

The agency also has plans to develop a new terminal to house its electric fleet. PSTA has applied for a Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grant to construct the proposed 75,000-square-foot transit hub, which includes solar-paneled roofing and electric vehicle charging stations.

Warranty

For the first procurement, PSTA had written into the RFP to propose a standard warranty, which at the time (2016–2017) covered key BEB components from one to three years. The OEM that PSTA selected (BYD) stated they offer a 12-year warranty, which surpassed what was being offered by other OEMs at that time.

Training

The OEM provided full maintenance and operation training to the fleet division, and the fleet division then conducted training with the training division and bus operators. The maintenance department was trained before the training department since the maintenance department needs to understand the bus components, how the bus performs, and the unique intricacies and capabilities of the BEBs.

As part of their training curriculum, PSTA operators are instructed on how to drive all the different bus types in the fleet—diesel, cutaway buses, hybrid electric, and battery electric buses. For the electric buses, the operators are taught how to gradually accelerate and lightly brake to maximize the regenerative braking.

PSTA also conducted training on the wireless charging system, which included demonstrations on positioning the bus correctly, identifying the location of reference marks, ensuring proper alignment, and training the operators to develop sight and sensory methods of feedback to determine whether they are positioning the bus correctly to initiate a charge session.

Challenges

OEM Communications and Parts Delay

PSTA has encountered some issues related to parts delays, partly due to a language barrier with the OEM. The vendor-supplied parts manual has been translated, resulting in some lag between what was encountered in terms of specific systems on the buses and communicating those issues back to the vendor engineering team. In addition to communication barriers, the bus parts are manufactured overseas, which has contributed to delays. These delays have also been exacerbated by the COVID-19 pandemic.

BEB Limitations

Given the current BEB range, PSTA estimates it takes approximately two to three battery electric buses to perform the same amount of work as a CNG or diesel bus, even with the supplemental top-off charging from the wireless charger. The BEBs generally receive a top-off charge every three years, which results in about a 10% boost in SOC. However, charge deficit over time occurs with each route trip and return to the wireless charger. This range limitation required that PSTA redesign routes based on BEB capabilities.

Partnerships

PSTA engaged Duke Energy early on, and the utility has been an active partner since initial electric bus plans were developed. The utility has supported PSTA financially by providing plug-in chargers and has offered engineering support to evaluate the power demand and install an additional transformer by the agency's transit transfer hub.

PSTA also worked with CTE, which assisted the agency in filling out grant applications, freeing up internal staff time. Additionally, CTE functioned as program manager and conducted a route analysis to identify optimal BEB routes.

Lessons Learned

Working with Local Utility

Engaging the local utility should be done early on and the utility should be involved from step one. It's important to work with the utility to determine how much electricity will be needed and if the existing infrastructure can accommodate that need, or if additional infrastructure is necessary to power the chargers. Engaging the utilities early on and involving them in planning for future electric and charging infrastructure also helps them to plan for capital infrastructure expansion.

Hiring a Consultant

PSTA recommends hiring a third party to prepare grant applications, particularly for transit authorities that do not have a robust grants department or experience with competitive grant funding.

Managed Charging

While demand charges have not been excessive with PSTA's current BEB fleet, smart charging and charging management strategies will become more important as the agency grows its fleet.

Tooling Costs

PSTA found it was helpful to ensure that tooling is included when evaluating the potential cost of BEBs.

Port Authority of Allegheny County (Allegheny County, Pennsylvania)

Port Authority

The Port Authority of Allegheny County (PAAC) established the agency's first unified transit system in Allegheny County in 1964. The Authority currently operates more than 700 buses, 80 light rail vehicles, and two inclined planes to provide public transportation services within Allegheny County, including the City of Pittsburgh.[48] The Authority also manages the ACCESS paratransit program, which is a door-to-door shared ride service. As of FY 2020, the Port Authority has 741 buses in the fleet, including a mix of 35-foot, 40-foot, and articulated diesel buses, 35-foot hybrid-electric buses, and two 40-foot BEBs.

BEB Procurements and Charging Equipment

PAAC received two 40-foot New Flyer Xcelsior CHARGE™ BEBs in March 2020. The agency had decided to pilot the electric buses before making additional investments in battery electric bus technology. PAAC installed two fast charging stations at its East Liberty Division facility to power the buses. With $5.6 million in support from the FTA Low-No grant program, PAAC also placed an order for six additional 40-foot Xcelsior CHARGE™ buses. The agency does not expect to continue a one-to-one charging ratio for the BEBs and is considering inductive charging as a potential option.

[48] https://www.portauthority.org/siteassets/inside-the-pa/surveys-and-reports/annual_service_report_fy2020_web.pdf

Maintenance and Repairs

The OEM provides on-site technicians to address issues with the BEBs during the warranty period. The OEM will also assist the agency in diagnosing problems. While the warranty provides OEM service, PAAC is also training in-house maintenance technicians in the appropriate repair procedure and processes. For the charging stations, PAAC performs standard maintenance (such as replacing the air filters) and the local utility will also check the stations periodically to ensure airflow is good.

Training

New Flyer provided initial training to PAAC's maintenance department with the goal of maintenance trainers being able to continue replicating the BEB training for new staff. The vendor also supplied first responder training, which PAAC distributed to the local fire departments and other first responder units.

Challenges

Charging Infrastructure Installation Delays

The existing electrical feeds at the East Liberty bus maintenance facility were not adequate to support the two fast charging stations. The local utility had to string extra circuits and install new power poles to boost electricity supply, which required unexpected additional time and resources. PAAC also encountered challenges with city permitting during this process, which caused additional delays.

Delays with Bus Delivery, Repairs, and Parts

The BEB delivery took longer than anticipated, as the buses were held up during the production process at the manufacturing plant. Additionally, the nuances that come with the new battery electric technologies have slowed down the repair process, resulting in lengthy out-of-service time for the BEBs. Some components on the charging stations have also needed to be replaced, and the manufacturer had to service those on several occasions. The wait time on those spare parts caused additional delays, as well as the troubleshooting time for the OEMs to identify the issues particular to the BEBs or charging equipment.

Space Constraints

PAAC, like many other agencies, has physical space constraints that create challenges for installing additional charging infrastructure to support an expanding BEB fleet. It was a challenge to find locations for even the first two charging stations due to limited property availability.

Lessons Learned

BEB Learning Curve

PAAC reported a steep learning curve for management, operators, and maintenance technicians on the unique considerations for BEBs. The agency found that it is critical to have substantial lead time for planning, preparing for, and implementing the BEBs, and to not expect the buses to be in service immediately after receiving delivery. Because these technologies are new, the vendor-provided maintenance support needs to refer to the factory during repairs, which can slow down the process and delay getting the coaches back into service. Additionally, there are unique considerations for the charging infrastructure and safety precautions when handling the charging and bus equipment that require some training and learning.

Incorporate Additional Tooling, PPE, and Training in Procurement Contract

PAAC recommends building all costs, including cost for tooling, PPE, and additional training, into the procurement contract in advance. The agency found that the first procurement did not include enough tooling (specifically arc flash equipment), which resulted in additional costs.

SEPTA (Bucks, Chester, Delaware, Montgomery, and Philadelphia Counties, Pennsylvania)

The Southeastern Pennsylvania Transportation Authority (SEPTA) provides bus, rapid transit, commuter rail, light rail, and electric trolleybus services in a five-county area in southeastern Pennsylvania. SEPTA was created through Pennsylvania legislation in 1963 and launched service the following year.[49] As the main transit provider for the City of Philadelphia and surrounding counties, SEPTA is the fifth largest transit system in the United States, serving approximately 3.4 million customers annually. SEPTA purchased its first hybrid-electric bus fleet in 2002 to increase efficiency and reduce emissions. In 2016, the Authority procured more than 500 new hybrid-electric buses, and in 2017, took delivery of 25 electric buses. SEPTA has initiated a facility readiness study analysis to evaluate the present energy capacity of the existing facility, projected energy demand of zero-emission buses, and space requirements for charging infrastructure.

BEB Procurements

For the first procurement, SEPTA purchased 25 40-foot Proterra Catalyst electric buses, which replaced diesel and hybrid-electric buses. The BEBs were

[49] https://www.septa.org/energyactionplan/bus-fleet.html

implemented on the 29 and 79 routes in Philadelphia, which were previously run with trackless trolleys. SEPTA used a $2.6 million LoNo grant to support the purchase and was awarded two subsequent Low-No grant awards in FY 2018 and FY 2020 at $1.5 million and $4.3 million, respectively.

Bus Facilities and Charging Equipment

SEPTA has seven operating depots and the BEBs are operated out of the Southern Depot, which serves South Philadelphia. There is a one-to-one charging unit ratio to the buses located at the Southern Depot.

Challenges

Quality Issues

In February 2020, SEPTA removed the BEBs from service due to observed defects in the chassis of the buses that were causing hairline cracking along the surface of the vehicles in high-stress areas. The buses continue to be sidelined due to this issue.

Layover Location for On-Route Charger

Initially, SEPTA had planned for on-route charging for the Proterra buses. However, during the planning process, it became apparent that there were a number of constraints to installing the on-route chargers, including logistics over property ownership. Around this time, Proterra released the E2 battery product, which could accommodate plug-in depot charging and ensure adequate range for the buses to handle the routes.

Electrical Capacity at Depot

To accommodate 25 charging stations, SEPTA had to upgrade the facility to support that additional load. Although there was enough power initially at the existing facility to support 5 of the 25 chargers, there was not enough capacity for the remaining 20 units. A temporary 1.5-megawatt (MW) transformer was installed at the facility to help accommodate those power needs, which created some initial challenges and delays.

Lessons Learned

Work with a Consultant to Plan BEB Expansion

Based on the experience with the initial 25 BEBs, the agency found that battery electric bus technologies require significant capital investments. Given the challenges experienced with the initial BEB pilot, SEPTA hired a third-party consultant to evaluate the requirements for supporting an expanded BEB fleet. The first phase of the study considered charging needs and found that the BEB fleet expansion would need additional electrification and more widespread metering. A second phase to the study was initiated in April 2021 to review maintenance, operations, and infrastructure at the bus facility locations to identify locations requiring electric infrastructure upgrades to support an electrified bus fleet. Space constraints and operating environments were also considered. Overall, SEPTA found the BEB transition to be a resource intensive process, and that it needed to bring in external assistance to continue supporting the BEB electrification effort and ensure the process was done efficiently and thoroughly. The agency found that the third-party consultants contributed valuable expertise and insight and identified the extent of the impacts BEBs would have on daily operation logistics, costs, and so on.

TriMet (Portland, Oregon)

TRIMET

Established in 1960 through the Oregon Legislature, TriMet offers mass transit service to the Portland metropolitan area. TriMet provides light rail, commuter rail, bus, and paratransit services, and currently operates a 700-bus fleet that runs on 85 lines.[50] TriMet's mission is to provide transportation options that connect people with their community, while easing traffic congestion and reducing air pollution.[51] TriMet has committed to operating a 100% zero-emission fleet by 2040 and is actively evaluating various zero-emission technologies, including short-range electric, long-range electric, and hydrogen fuel-cell electric bus technologies.

BEB Procurements

In June 2018, TriMet received its first BEB delivery of five New Flyer 40-foot Xcelsior CHARGE buses. In 2021, the agency purchased an additional five long-range GILLIG BEBs and corresponding charging equipment. The long-range BEBs have a range of 150–210 miles and an approximate three-hour charge time. The GILLIG buses were purchased with assistance from a $2.3 million FTA Low-No grant. TriMet is also piloting retrofitted diesel-to-electric bus technology as part of the zero-emission demonstration.

Bus Facilities and Charging Equipment

The five New Flyer BEBs are charged multiple times per day at the Sunset Transit Center using an overhead charger. The ABB overhead charger is owned and operated by the local utility (PGE). In addition to the overhead charger, TriMet has six depot chargers. All of the electric buses are supported by J1772 compliant Combined Charging System (CCS) plugs.

To support the expanding zero-emission fleet, TriMet is constructing a new charging facility at a separate bus yard. The agency is installing raceways and conduits to support the new facility, which will have 12 150-kW capable

[50] https://trimet.org/about/index.htm
[51] *ibid.*

chargers that can charge up to 36 BEBs. The Powell bus facility will be purpose built to support future expansion of charging capabilities.

Bus Performance

Initially the battery electric buses ran well when they were put into service in April 2019. However, the agency began experiencing some issues with the charging infrastructure connections, water leakage, and fiber connection challenges in December 2019, and then again in March 2020, which led to the buses being pulled out of service for a longer duration.

Training

The agency provides training for maintenance and operation of the BEBs. TriMet conducted training for operators on docking procedures for the overhead pantograph charging system. The agency has had to reintroduce and retrain on these procedures and noted there was a need for frequent coaching to get the system up and running. To simplify the on-route charging procedures for operators, TriMet installed bumpers and reinforced with pavement markers. The TriMet training department worked in collaboration with internal stakeholders to refine the curriculum and training tools provided by the OEM. TriMet also provided first responder safety training to local jurisdictions.

Challenges

Delays

During the initial BEB procurement for the first five buses, TriMet encountered delays with processing the procurement due to Buy America provisions. There were pre-build and post-built audits and channeling requirements that contributed to longer lead times and delays in completing the paperwork. From initiating the procurement process to delivery, it took approximately two and half years before TriMet received the short-range BEB buses and supporting charging infrastructure.

Water Intrusion

TriMet encountered some issues with water intrusion into the contactor box and overhead rails, in the overhead charger when the dispensers were opened, and the buses themselves had issues with some water intrusion. The overhead chargers were not sealed properly, which led to leakage inside the high-voltage cables. More recently, the agency has also noticed water leakage on the depot chargers.

Charger Connection/Communication Fallouts

The agency also had some issue with the communications between the overhead charger and bus. For the bus and charger to “speak” to one another, a handshake needs to initiate the charge session. The agency noticed issues with the handshake protocol and disruptions to the communication, requiring them to upgrade the hardware and software. New Flyer developed its proprietary communications box, which involved changing software, hardware, and communications protocols, and worked to get those buses fully tested and vetted.

Partnerships

TriMet partnered with PGE, which provided funding for the charging equipment and retained ownership of the charging stations. TriMet and PGE began collaborating in 2016 to submit for grant funding for the electric buses, and some of the capital planning efforts were developed in partnership. The partnership with PGE is long-term, and the agency relies on PGE to provide electrification expertise to support the ongoing operation of the BEBs.

TriMet also partnered with CTE and the City of Portland, which assisted in planning and specifications and developing comprehensive performance indicators and data collection procedures. CTE performed some route modeling as part of the early planning process. This was especially important given that the short-range BEBs are limited in their capacity to run routes on a single charge; four out of five of TriMet's service blocks exceed the miles limit of the short-range buses.

Lessons Learned

Work Closely with OEMs

It's essential to work closely with OEMs and be firm when issues arise. TriMet stressed the importance of a bumper-to-bumper warranty on buses. Sometimes what is promised by OEMs and what is delivered are on two separate spectrums, so being prepared when issues arise is key. TriMet emphasized that working with OEMs is critical to ensuring the buses and charging technology are operating, and that warranties and other provisions are in place to maintain optimization of bus performance and operability. The agency has extended warranties with OEMs to make certain the buses are maintained and continue operating on the roadways.

Anticipate Worst-Case Scenarios

Anticipating and planning for trouble, which will happen with these newer technologies, is critical, especially noting TriMet's experience with shorter-range buses using the on-route charger. BEBs present unique challenges with the buses and charging systems needing to work effectively together in order to operate. Anticipating issues that may arise is key to having procedures in place for dealing with charger and/or bus malfunctions.

Install a Third-Party Analytic System on BEBs and Charging Equipment

TriMet noticed that as the BEBs ran more frequently, there was discrepancy between electricity charges that were reported on the back end compared to the actual meter reading. The agency installed a third-party monitoring system (ViriCiti) to capture analytics from the buses as well as the chargers.

Plan and Build Out Early for Future Charging Expansion

TriMet is future-proofing for an expanding BEB fleet. To accommodate expansion of charging capabilities, the agency has purpose-built one of its bus facilities to support additional charging, in part through charging and rotating buses through chargers. These stations have 12 independent 150kW capable chargers, which can charge up to 36 buses. TriMet developed creative solutions to maximize its limited real estate for charging by installing the plug-in dispensers on light poles.

There are also plans to accommodate up to 72 battery electric buses. A network of conduits and vaults surrounding the bus yard were designed to manage the future phases of charging infrastructure and growth. TriMet is also considering additional options, such as canopy-type pantograph charging for parked buses.

Valley Regional Transit (Treasure Valley Region, Idaho)

valley regional transit

Valley Regional Transit (VRT) is the public transit provider for Idaho's Treasure Valley region, which includes Ada and Canyon Counties and the City of Boise.[52] The agency offers public bus transit, specialized van services, paratransit, Park & Ride, and other services to a population of nearly 750,000. VRT was initially formed in 1999 under the name Treasure Valley Regional Public Transportation Authority, which changed to Valley Regional Transit in 2004. VRT owns the public bus system and contracts with a private firm to manage transit service operations.[53] CNG buses make up approximately 85% of VRT's fleet. In September 2021, VRT expanded its alternative fuel bus fleet with the delivery of four 40-foot Proterra ZX5 battery electric buses.[54]

BEB Procurements

VRT's first BEB procurement included eight 40-foot Proterra Catalyst buses and six dual dispenser chargers. The agency partnered with Proterra to submit for

[52] https://www.valleyregionaltransit.org/about-us/
[53] *ibid.*
[54] https://www.valleyregionaltransit.org/planning/

an FTA Low-No grant to purchase the BEBs. In addition to the first 8 buses, VRT has placed a second procurement for 4 additional electric buses off the Virginia state contract, which will bring the electric bus fleet to 12. The BEBs will be a mix of 35- and 40-foot buses.

Training

VRT has completed operator training and plans to conduct maintenance and first responder training in late 2021. The BEB OEM provided support for an operator train-the-trainer session, which was attended by VRT's contracted operator service employees for the transit fleet. The training was a mix of classroom and hands-on instruction with the vehicles and charging equipment.

Challenges

Bus Production Delays

VRT had initially ordered 35-foot buses, but production for that size was greatly slowed down due to setbacks in Altoona testing. Because of this issue, VRT agreed to purchase 40-foot buses that were expected to be delivered in 2020. However, the COVID-19 pandemic slowed down production so the agency had to push initiating BEB service until October 2021.

Steep Learning Curve with BEB Technologies

The agency noted there was a steep learning curve with BEBs and charging infrastructure, which is time and resource intensive.

Partnerships

VRT partnered with Proterra, Idaho Power, and support from the Cities of Boise and Meridian for grant funding to purchase the BEBs. Idaho Power provided funding for the charging infrastructure, and the local jurisdictions provided local match to help offset capital costs of the BEBs. Since VRT partnered with Proterra, that eliminated the need for competitive procurement.

Lessons Learned

Work with the Utility Early On

VRT worked closely with Idaho Power to ensure there was adequate infrastructure to support the initial and additional BEBs. The utility was engaged early on with infrastructure construction, and it installed a new transformer on-site that was specific for the charging system.

Consider Various Specifications for Bus and Charging Infrastructure

When VRT made the initial BEB procurement, the set of specifications was specific given that the first purchase was supported through grant funding in partnership with the OEM. VRT recommends adequate research prior to establishing specifications to ensure the particular BEB and charging technology are optimal for the agency.

On-Route Charging

To be able to convert a larger percentage of VRT's fleet to battery electric, considerations would be needed for on-route charging (such as wireless charging) to support future BEB expansion. The cost and construction requirements to maintain adequate depot charging would be challenging, but on-route charging will be necessary to accommodate the longer transit routes.

Case Study Conclusions

Throughout the analysis of the responses received from the case study agencies, a few themes were apparent in both the challenges identified (Figure 4-1) and the lessons learned (Figure 4-2).

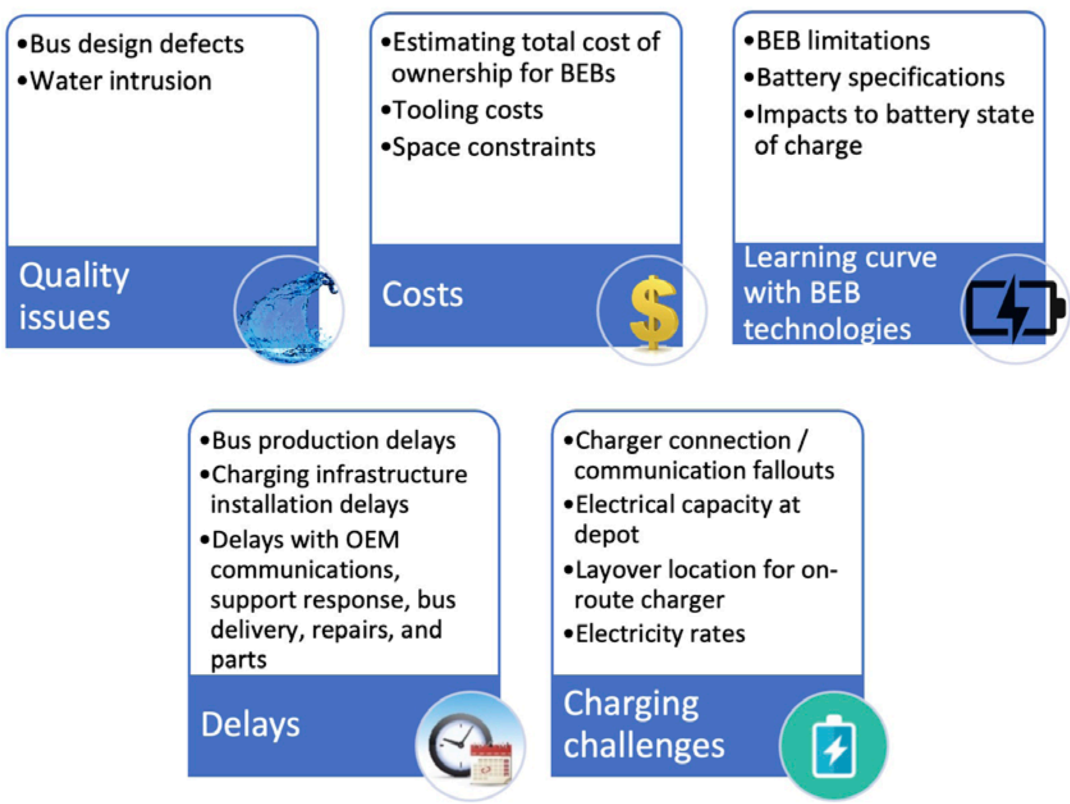


Figure 4-1 *Challenges faced by case study agencies*

Figure 4-2 *Lessons learned from case study agencies*

Section 5

Conclusions and Findings

Conclusions

The primary objective of this project was to identify the best practices for procuring and maintaining battery electric buses (BEBs) and charging systems to accelerate the decarbonization of transit in a safe way. This project, performed with significant industry stakeholder participation and SDOs such as APTA, identifies areas for standards development and lessons learned from agencies that have initiated their fleet conversion to BEBs. While this scope of work did not include an evaluation of processes and procedures associated with battery electric buses, the outcome of this examination includes findings that support the further review, demonstration, and/or testing of processes, procedures, or technologies that may be implemented to accelerate the safe decarbonization of transit.

The overall benefits of this report focus on key challenges agencies should expect as they initiate their transition to battery electric bus fleets. The summarized findings provide insight and considerations that will be most valuable to transit agencies that are not yet mature in their BEB fleet transition. In addition to this report, a holistic guidebook or guidance document will be developed to combine the findings from this report, the findings from the *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* report, and the guidance detailed in the International Transportation Learning Center's report *Providing Training for Zero Emission Buses: Recommended Expanded RFP Language*.[55] The future guidance document will be most beneficial to agencies that are planning their next BEB procurement. Additionally, the guidance document will ultimately be provided to APTA for consideration of inclusion by reference in the Battery Electric Bus sections of its *Standard Bus Procurement Guidelines.*

The literature review revealed common themes that occurred throughout various agencies that have procured BEBs. The literature review led to 12 general preliminary findings that can be broken down into 6 categories: planning, training, cost, space, charger efficiency and interoperability, and challenges accessing parts.

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

Planning

When considering a procurement of BEBs, it is important to start planning early and engage with stakeholders from the initial discussions. This inclusion and communication among stakeholders will likely help identify expected challenges and provide a working relationship to assist in tackling the unexpected challenges that arise as well. Planning should also consider backup power sources so that agencies are not parked in emergencies with no way of powering their fleet. Additionally, planning for operations and route modeling will have to accommodate charging layovers on-route or BEB performance limitations, 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 must not feel rushed and 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 also a best practice to incorporate operator training that focuses on efficiency and expectations, specifically on any differences the BEB may have. Operators should be trained on how to communicate charge challenges with dispatchers. Technicians should be trained to understand the dangers and the differences they will encounter when maintaining a BEB. Technician training would also benefit from including ways in which they 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; acknowledging that will continue to focus efforts on workforce development.

Cost

There are many cost considerations when transitioning to BEB fleets beyond the initial procurement cost, including but not limited to additional training costs, post-warranty maintenance costs, 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 identify optimal charging to reduce demand charges. Demand charges and time of use charges can increase electricity costs, leading back to the value 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 will require space. Many agencies may 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 they will need 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, they will need to ensure that the chargers are interoperable and space limitations are not exacerbated 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 exacerbated the challenges associated with parts availability, many of the challenges were occurring long before the pandemic was in the United States. The literature review and subsequent interviews revealed that many agencies waited several months to receive necessary parts, leaving their BEB fleet or portions of their fleet inoperable. It is a significant cost to an agency to have buses taking up space and aging while unable to be used in revenue service. These challenges are substantial, and thus agencies may benefit from including parts availability language in their procurement language.

Conclusions from Stakeholder Outreach

Through an extensive literature review, followed by a survey of 25 transit agencies that have procured BEBs, case study follow-up interviews with 8 transit agencies, and extensive feedback from the CUTR Transit Standards Working Group, several findings were developed. These findings are the general summary of themes that recurred throughout this research project.

Focusing first on the procurement language that may help agencies as they begin their BEB procurement, a recurring theme throughout each of the respondent agencies and the case studies was the challenge of parts availability. Many times, the lack of availability of a necessary part leads to excessive time that the BEB is out of service, in some cases exceeding several months. This can be especially difficult for agencies with limited space in their depots to accommodate out-of-service fleets. To combat the challenges associated with parts availability, agencies may consider including OEM parts availability expectations in contract negotiations/procurement language. The inclusion of spare part expectations may reduce the amount of time that BEBs are out of service.

Additional procurement related conclusions involve the ability of agencies to leverage economies of scale if they are able to coordinate procurement efforts on a regional or state scale. Using consistent negotiated procurement language reduces the variation by agency, which can lead to improved estimations of costs. Furthermore, pooled funding opportunities may lead to leveraging the economies of scale.

Requesting clear language in the battery warranty that dictates applicability to either the individual battery packs or the entire battery system could reduce the language ambiguity faced by some agencies. Ambiguity in the battery warranty language leads to varied interpretation of that language. Clarifying the ambiguity would help agencies understand when the battery warranty applies. Similarly, most procurements lack clear terminology dictating how the batteries will be disposed of after they have met their useful life. It is beneficial for agencies to include battery storage, repurposing, disposal, and/or recycling details in their procurement language to reduce unexpected challenges associated with disposal.

The stakeholders repeated the statement that route design methodology had to change to implement BEBs. While some agencies only procured their BEBs to run along a specific route or set of routes, others have full zero-emission fleet goals. The expectations of the BEBs should vary based on external factors, such as extreme weather that may vary by season, leading to the necessity of multiple route design configurations. Routes may be dependent upon the location availability of on-route chargers for some short-range BEBs. Routes must also start and stop at a charging facility and route schedules should accommodate the slower acceleration that may be needed to keep the BEBs operating efficiently and achieving range expectations.

Training is an important aspect of any new technology or procedure. When procuring BEBs, it is critical for all stakeholders to be trained accordingly. Training is needed for operators, technicians, route planners, dispatchers, and first responders. For example, operator training that includes details beyond basic familiarization, specifically focusing on techniques to maximize battery efficiency through regenerative braking techniques, may prove beneficial and improve operator confidence in BEB capabilities.

It is imperative that technicians are trained to competency to ensure they understand the capabilities of the tools they will use and how to test the efficacy of the tools before they use them. Safety-focused training may improve the confidence of technicians who work on BEBs, which may in turn reduce the technician shortages that many agencies are experiencing. It is important that the dispatchers and route planners are also trained on the performance characteristics of BEBs so that they can make the adjustments to their procedures accordingly.

Finally, in terms of training, it is beneficial to train local first responders on the differences between a BEB and a traditionally powered bus, including ways to identify if the bus is a BEB and to ensure there are no additional dangers introduced when they respond to an event involving a BEB. First responder training should include topics such as where to prop ladders, dealing with water and BEBs, accessing the top of the bus, and other common challenges they may encounter.

Many agencies mentioned challenges with finding the crucial space for essential facilities accommodations. When planning for a BEB procurement or a BEB fleet expansion, agencies need to consider that facilities may require charging infrastructure installation, lifts that are rated for the weight of a BEB, lifts to accommodate top-of-bus maintenance, additional fall protection, fire suppression systems, and storage space for batteries and spare parts, all of which accumulate space especially as fleet size increases. Additionally, interoperability challenges may exacerbate space limitations for charging infrastructure, especially as agencies add BEBs that may not be manufactured by the same vendor as their initial BEB procurement. The requirement to have specific charging infrastructure that is not interoperable with other manufacturer's BEBs may result in debilitating space limitations. It may be beneficial for agencies to require interoperability in their procurement language to avoid such limitations.

As agencies transition larger shares of their bus fleets to BEBs, the need for resiliency and backup power source considerations becomes more pronounced. Transit agencies are often depended upon in emergency evacuation situations to transport the most vulnerable population. Natural disasters, such as hurricanes or wildfires, also often lead to disruptions in power supply. The ability to power buses in an emergency situation is paramount to transit and/or evacuation operations, and thus resiliency and backup power sources must be considered, especially for agencies that envision a full fleet electrification. Agencies may benefit from partnering with utilities to expand grid connections and implement battery storage and microgrids. In addition, agencies may benefit from States developing statewide power backup plans that could be leveraged locally when necessary.

Finally, many of the stakeholders who were interviewed mentioned that charging technology is advancing at an accelerated pace, and that smart charging and managed charging can optimize the techniques and lead to greater cost savings over time. Smart charging may also help to estimate utility rates, as they vary by time of day and other factors. Each of these conclusions is summarized in concise findings.

Findings

The research and outreach that was performed through this project revealed several significant findings.

1. **Parts availability remains challenging:** Agencies that include OEM parts availability expectations in contract negotiations/procurement language may reduce associated challenges with the unavailability of necessary replacement parts.

2. **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.

3. **Battery warranty ambiguity:** 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 the ambiguity of the warranty.

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

5. **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 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.

6. **Standardized training would be beneficial:**
    - 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, which may in turn reduce the technician shortages that many agencies are experiencing.
    - Route planning and control center training to clarify the capabilities and limitations of BEBs for both route planners and control center

personnel may align the expectations of the BEB with its performance ability, and may in turn reduce unexpected state of charge challenges.
- First responder training to provide familiarization of BEB designs may reduce unanticipated hazards and challenges when emergencies occur.

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

8. **Interoperability challenges will exacerbate space limitations for charging infrastructure:** As agencies begin to mix fleets during 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.

9. **Resiliency and backup power source considerations:** Fuel diversification and availability of backup power may be beneficial when power is unavailable for extended periods of time, such as during 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.

10. **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.

11. **Variable utility rates lead to inconsistent charging costs:** Agencies may have limited negotiating powers with utility providers and should therefore consider variations in utility rates by time of day.

12. **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 transit agency owning full responsibility for the charging infrastructure.

Acronyms and Abbreviations

APTA	American Public Transportation Association
BEB	Battery electric bus
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation (United States, unless otherwise indicated)
FTA	Federal Transit Administration
kWh	Kilowatt hour
LoNo	Low or No Emission Vehicle Deployment Program (through 2015)
Low-No	Low or No Emission Vehicle Program (from 2016)
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
PPE	Personal protective equipment
SAE	Society of Automotive Engineers
SDO	Standards development organization
SOC	State of charge
TRB	Transportation Research Board
TRI	FTA Office of Research, Demonstration and Innovation
UPT	Unlinked passenger trips
ZEB	Zero-emission bus

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https://www.transit.dot.gov/about/research-innovation