FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

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

JANUARY 2021

FTA Report No. 0182

PREPARED BY
Center for Transportation and the Environment

U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT

The Transit Vehicle Innovation Deployment Centers (TVIDC) program was funded by FTA to research the advancement, production, and deployment of advanced vehicle technologies and infrastructure within the public transportation sector. The TVIDC program, managed by the Center for Transportation and the Environment (CTE) and CALSTART, assembled the Transit Vehicle Innovation Deployment Advisory Panel to meet and develop suggested solutions to the challenges of continued innovation, development, and adoption of zero-emission transit technologies. This report is a summary of the panel's suggested solutions and activities.

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Transit Vehicle Innovation Development Centers, TVIDC, advanced vehicle technologies, zero emission bus, ZEB, battery electric bus, BEB, transit bus automation, LoNo-CAP, bus testing facilities, transit workforce development

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EXECUTIVE SUMMARY

The transit industry has achieved considerable technological breakthroughs in recent decades, with transformative changes to vehicle propulsion, transportation operations, and service delivery. In the past 10 years, zero-emission bus (ZEB) technologies have matured from federally-funded demonstration projects to commercial scale. Encouraged by continued development of ZEB technologies, transit agencies have started committing to ambitious timelines for transitioning their entire fleets within the next 10 to 15 years. With the transition to battery and hydrogen fuel cell electric propulsion systems, transit bus original equipment manufacturers (OEMs) have also started integrating auxiliary electric drive components into their vehicles to improve performance and efficiency. Other suppliers have gravitated toward the transit bus industry to develop supporting bus components and infrastructure for ZEBs. OEMs also are beginning to invest in automation and other driver assistance technologies as they look to address persistent issues in transit operations.

The Federal Transit Administration (FTA) established the Transit Vehicle Innovation Deployment Centers (TVIDC) program to research the advancement, production, and deployment of advanced vehicle technologies and infrastructure within the public transportation sector.

The TVIDC program is managed by the Center for Transportation and the Environment (CTE) and CALSTART. This report is the result of one of the primary activities in CTE's workplan—to assemble and manage the Transit Vehicle Innovation Deployment Advisory Panel. The report centers on the activities of the panel and includes its suggested solutions to the challenges of continued innovation, development, and adoption of zero-emission transit technologies. CTE brought together more than a dozen transit agency general managers (GMs), leading transit bus manufacturers, all three federal bus testing centers, and public transit advocacy groups to form an advisory panel. Panel discussions were convened in August 2019 in Los Angeles and in January 2020 in Chicago, and a third panel discussion was planned but due to the COVID-19 public health emergency was postponed, and this report is based on the first two meetings. Panel priorities included the following:

1. Research ways to maximize the value and industry needs for the Low and No Emission Bus Component Assessment Program (LoNo-CAP) into the existing FTA Bus Testing Program
2. Workforce issues and needs relating to the development and adoption of zero emission buses
3. Transit bus automation research and demonstration priorities
4. General zero-emission bus innovation research needs and industry priorities

During the Chicago meeting, working groups were charged with refining solutions for five focus areas for eventual inclusion in the panel report. Throughout March, CTE conducted five separate teleconferences—one for each focus area—using

solutions raised during the Chicago meeting to frame the discussion. CTE used panelist input from these meetings to refine and finalize the drafted solutions. The five focus areas included:

- Bus Testing Facilities
- ZEB Innovation Research
- Transit Bus Automation
- ZEB Workforce Development
- Collaboration with Electric Utilities.

The following solutions were proposed by the advisory panel and the established panel subcommittees for each of the five panel focus areas and are detailed in this report:

- Bus Testing Facilities
  - Eliminate burdensome cost share requirements for LoNo-CAP.
  - Establish a clear division of roles for bus testing centers.
  - Inform bus testing priorities through an industry working group.
- ZEB Innovation Research
  - Prioritize ZEB demonstrations at scale.
  - Focus research on efficiency improvements.
  - Explore resiliency and disaster mitigation strategies.
  - Develop a repository for lessons learned.
- Transit Bus Automation
  - Reassess FTA goals for transit bus automation.
  - Replicate previously-successful consortia models to accelerate commercialization.
- ZEB Workforce Development
  - Dedicate a program for ZEB training and workforce development.
  - Expand NTI's programming to incorporate ZEB training and workforce certification.
  - Leverage existing FTA programs to incentivize use of workforce development centers.
- Collaboration with Electric Utilities
  - Designate a cross-industry working group for transit operators and electric utilities.
  - Develop an infrastructure deployment planning guidebook.

SECTION 1

Background

The transit industry has achieved considerable technological breakthroughs in recent decades, with transformative changes to vehicle propulsion, transportation operations, and service delivery. In the past 10 years, zero-emission bus (ZEB) technologies have matured from federally-funded demonstration projects to commercial scale. At the writing of this report, more than 650 ZEBs are in operation across the United States, and more than double that number are in agency procurement pipelines. ZEB original equipment manufacturers (OEMs) meeting Buy America domestic manufacturing requirements have reached six in total, with other foreign OEMs investing in US manufacturing plants to enter the US transit vehicle market.

Encouraged by continued development of ZEB technologies, transit agencies have started committing to ambitious timelines for transitioning their entire fleets within the next 10 to 15 years. With the transition to battery and hydrogen fuel cell electric propulsion systems, transit bus OEMs have also started integrating auxiliary electric drive components into their vehicles to improve performance and efficiency. Other suppliers have gravitated toward the transit bus industry to develop supporting bus components and infrastructure for ZEBs. Finally, OEMs are beginning to invest in automation and other driver assistance technologies as they look to address persistent issues in transit operations.

Although the adoption of these advanced technologies and supporting infrastructure for transit buses has been impressive, challenges remain for further deployment and commercialization in the industry. To meet these challenges, and research the issues, needs, and potential solutions, the Federal Transit Administration (FTA) established the Transit Vehicle Innovation Deployment Centers (TVIDC) program to research the advancement, production, and deployment of advanced vehicle technologies and infrastructure within the public transportation sector.

The TVIDC program is managed by the Center for Transportation and the Environment (CTE) and CALSTART, two of the nonprofit organizations that were instrumental in managing the National Fuel Cell Bus Program (NFCBP) on behalf of FTA. This report is the result of one of the primary activities in CTE's workplan—to assemble and manage the Transit Vehicle Innovation Deployment Advisory Panel.

This report centers on the activities of that panel—renamed the National Transit Advanced Technology Advisory Panel—assembled and facilitated by

CTE. It includes the panel's suggested solutions to the challenges of continued innovation, development, and adoption of zero-emission transit technologies.

TVIDC National Transit Advanced Technology Advisory Panel

CTE brought together more than a dozen transit agency general managers (GMs), leading transit bus manufacturers, all three federal bus testing centers, and public transit advocacy groups to form an advisory panel. In soliciting panel participation, CTE ensured the transit agencies were representative of many US geographies and agency sizes (large, medium, small). The panel's composition (Table 1-1) was suited to meet TVIDC's program objectives of supporting transit bus innovation by identifying current industry challenges and research needs and identifying potential solutions for addressing them.

Table 1-1 *National Transit Advanced Technology Advisory Panel Organizations*

Organization	Location
Center for Transportation and the Environment (CTE)	Atlanta, GA
Los Angeles County Metropolitan Transportation Authority (LA Metro)	Los Angeles, CA
Chicago Transit Authority (CTA)	Chicago, IL
Metropolitan Atlanta Rapid Transit Authority (MARTA)	Atlanta, GA
Capital Metropolitan Transportation Authority (Capital Metro)	Austin, TX
SunLine Transit Agency	Palm Springs, CA
Stark Area Rapid Transit Authority (SARTA)	Canton, OH
Alameda-Contra Costa Transit District (AC Transit)	Oakland, CA
San Diego Metro Transit System (San Diego MTS)	San Diego, CA
Broward County Transit	Broward County, FL
Connecticut Department of Transportation (CTDOT)	Hartford, CT
Mountain Line	Missoula, MT
Foothill Transit Agency	Ontario, CA
Denver Regional Transportation District (Denver RTD)	Denver, CO
Transit Authority of the Lexington-Fayette Urban County Government (Lextran)	Lexington, KY
Auburn University	Auburn, AL
Ohio State University (OSU)	Columbus, OH
Pennsylvania State University (Penn State)	University Park, PA
American Public Transportation Association (APTA)	Washington, DC
CALSTART	Sacramento, CA
New Flyer of America, Inc.	St. Cloud, MN
Proterra, Inc.	Burlingame, CA
ENC	Riverside, CA
GILLIG	Livermore, CA
Nova Bus	Quebec, Canada
BYD	Los Angeles, CA

The panel priorities were identified as:

1. Research ways to maximize the value and industry needs for the Low and No Emission Bus Component Assessment Program (LoNo-CAP) into the existing FTA Bus Testing Program;
2. Workforce issues and needs relating to the development and adoption of zero emission buses;
3. Transit bus automation research and demonstration priorities;
4. General zero-emission bus innovation research needs and industry priorities.

CTE and CALSTART also hosted teleconference meetings with the university bus testing centers at Auburn University, Ohio State University, and Pennsylvania State University to discuss framing the panel discussion around both full bus and component testing. These discussions laid the foundation for establishing makeup and objectives of the advisory panel.

Panel Discussion 1: August 20, 2019 (Los Angeles, CA)

The advisory panel convened in person for the first time in August 2019. The meeting was hosted by the Los Angeles County Metropolitan Transportation Authority (LA Metro) at its headquarters in Los Angeles. The purpose of the meeting was to introduce the TVIDC program and the panel's objectives, provide participants an overview of each initial focus area and all three bus testing centers, identify additional focus areas for the panel's work, and define research needs for CTE to fulfill prior to the second panel meeting. The discussion covered a range of topics, primarily around the four panel priorities, including specific technology needs for transit innovation research. In addition to the four previously-identified focus areas, the panel added transit agency collaboration with electric utility providers as a priority to help address challenges with deployment of charging infrastructure for battery electric bus (BEB) fleets. As a part of this meeting, CALSTART presented its findings and draft recommendations for the component testing needs as surveyed by the industry for the Low and No Emission Bus Component Testing Centers. Table 1-2 is a list of panel participants for the Los Angeles meeting.

Table 1-2 *Advisory Panel Participants – Los Angeles Meeting*

Organization	Name	Position
CTE	Dan Raudebaugh	Executive Director
LA Metro	Phil Washington	CEO
CTA	Dorval Carter	President
MARTA	Jeffrey Parker	CEO/General Manager
Capital Metro	Randy Clarke	President and CEO
SunLine Transit	Rudy LeFlore	Contractor
SARTA	Kirt Conrad	CEO
AC Transit	Sal Llamas	COO
San Diego MTS	Paul Jablonski	CEO
Broward Transit	Chris Walton	General Manager
CTDOT	Dennis Solensky	Public Transit Administrator
Mountain Line	Corey Aldridge	General Manager
Foothill Transit	Doran Barnes	General Manager
Auburn University	Mark Hoffman	Assistant Professor
OSU	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State–Larson Transportation Institute	David Klinikowski	Director, Center for Bus Research and Testing (Altoona Testing)
APTA	Jeff Hiott	Vice President – Technical Services and Innovation
CALSTART	Fred Silver	Vice President
New Flyer of America, Inc.	David Warren	Director, Sustainable Transportation
Proterra, Inc.	John Walsh	Senior Vice President, Sales
ENC	Oscar Pardinas	Regional Sales Manager
GILLIG	Joe Policarpio	Vice President, Sales and Marketing
Nova Bus	Shawn Remtulla	Regional Sales Manager - South Central
BYD	Bobby Hill	Vice President, Sales

In addition to panel participants, others attending the Los Angeles meeting included:

- Several organizations brought multiple individuals, although only one representative was allowed on the panel.
- Stephen Brady, a consultant to FTA for the Bus Testing Program, attended and offered input on that program throughout the meeting but was not a panel participant.

Panel Discussion 2: January 6, 2020 (Chicago, IL)

The second advisory panel meeting was hosted by the Chicago Transit Authority (CTA) and convened at its headquarters in Chicago. At this meeting, the panel finalized industry priorities for the panel report and began developing potential solutions to address them. CTE completed a research report in December 2019 covering all topics identified before and during the Los Angeles meeting and sent it to all participants; this document has been included herein as Appendix A.

During the Chicago meeting, CTE presented its findings and then split the panelists into two CTE-led breakout groups to discuss and prioritize potential solutions for industry challenges. The first group consisted of transit agencies and the American Public Transportation Association (APTA), and the second included all attending transit bus OEMs, the university test centers, and CALSTART. Both groups brainstormed solutions for all five focus areas and presented them to the wider panel. CTE used those discussions to build this report framework, which the panel would refine at subsequent working group teleconference meetings. A full list of participants for the second panel meeting are shown in Table 1-3. Additional leadership from LA Metro, CTA, and MARTA attended the meeting and participated in the breakout discussion groups.

Table 1-3 *Advisory Panel Participants – Chicago Meeting*

Organization	Name	Position
CTE	Dan Raudebaugh	Executive Director
LA Metro	Phil Washington	CEO
CTA	Dorval Carter	President
MARTA	Jeffrey Parker	CEO/General Manager
SunLine Transit	Lauren Skiver	General Manager
Denver RTD	Michael Ford	COO
Lextran	Carrie Butler	CEO
Mountain Line	Corey Aldridge	General Manager
Auburn	Mark Hoffman	Assistant Professor
OSU	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State–Larson Transportation Institute	David Klinikowski	Director, Center for Bus Research and Testing
APTA	Jeff Hiott	Vice President – Technical Services and Innovation
CALSTART	Fred Silver	Vice President
New Flyer of America, Inc.	David Warren	Director, Sustainable Transportation
Proterra, Inc.	John Walsh	Senior Vice President, Sales
ENC	Oscar Pardinas	Regional Sales Manager
GILLIG	Ben Grunat	Director, Product Planning & Strategy
BYD	Jason Yan	Director of Sales Operations

Work Group Discussions: March 2020

During the Chicago panel meeting, participants were asked to volunteer for at least one of five working groups covering each panel focus area. CTE followed up with all panel participants who were unable to attend the Chicago meeting to debrief them on the proceedings and secure their commitments for working group participation. These working groups were charged with refining solutions for each of the five focus areas identified during the Chicago meeting, for eventual inclusion in the panel report. Throughout March, CTE conducted five separate teleconferences—one for each focus area—using solutions raised during the Chicago meeting to frame the discussion. CTE used panelist input from these meetings to refine and finalize the drafted solutions for inclusion in the panel's final report. A complete list of working group participants has been included in this report as Appendix B.

Panel Discussion 3: TBD (Atlanta, GA)

The original purpose of the third advisory panel meeting was to review this report which was considered a draft based on two of the advisory panel's meetings. This meeting was originally scheduled to be hosted by the Metropolitan Atlanta Rapid Transit Authority (MARTA) and CTE in Atlanta on April 20, 2020. However, the public health emergency forced CTE to postpone the panel from its scheduled date until the public health situation changed enough to permit an in-person meeting. CTE instead is soliciting feedback from the panel on this report virtually and will work with FTA to determine the best use of this next meeting since the report with its initial feedback is being issued in January 2021 per the FY2021 Omnibus Appropriations Act.

SECTION 2

Proposed Solutions

The following is a list of solutions proposed by the advisory panel and the established panel subcommittees for each of the five panel focus areas. More detailed discussion of how the panel reached these solutions follows in the report.

1. Bus Testing Facilities

1a: Eliminate burdensome cost share requirements for LoNo-CAP.

FTA should eliminate cost share requirements for the LoNo-CAP program, which would incentivize increased testing activity at the Ohio State and Auburn facilities.

1b: Establish a clear division of roles for bus testing centers.

A clear division of responsibilities would help each bus testing facility focus investments in capabilities buildout and lead on standards development. The three testing centers agreed upon a split of roles and responsibilities, informed by the panel and consistent with federal statutes. The specific breakdown of these roles and responsibilities is included in Appendix C.

1c: Inform bus testing priorities through an industry working group.

FTA should create a standing working group to define ZEB industry needs and better inform testing priorities. With the elimination of the cost share requirements (Solution 1a), the LoNo-CAP program will likely change from one that is severely underused to one that is severely overcommitted. Establishing a fair, industry-supported method to determine FTA research priorities will be critically important.

This body, comprised of OEMs, transit agencies, the university testing facilities, and other industry stakeholders, would also serve as a channel for comparison and discussion of public testing results, while allowing OEMs to retain their own internal test data. The advisory panel could ultimately fill this role or, at a minimum, serve as a model for it.

2. ZEB Innovation Research

2a: Prioritize ZEB demonstrations at scale.

The advisory panel suggested that large-scale (more than 50 buses) ZEB deployment projects are necessary to fully understand the technical and

operational challenges associated with full fleet transitions and that FTA should prioritize supporting the buildout and analysis of one or more such deployments for both battery electric and fuel cell electric buses.

2b: Focus research on efficiency improvements.

Because ZEBs have reached commercial maturity, FTA should prioritize research efforts on vehicle components and subsystems—including, but not limited to HVAC, regenerative braking, and electric drive technologies—aimed at improving overall vehicle energy efficiency.

2c: Explore resiliency and disaster mitigation strategies.

Further focus on in-service demonstrations of bus exportable power systems to allow hybrid and electric transit buses to be used as generators. By establishing pathways for incentivizing the purchase and maintenance, these systems will help address the growing community need for emergency and disaster response.

2d: Develop a repository for lessons learned.

FTA should develop a clearinghouse for transit agencies and industry stakeholders to share experiences and lessons learned from ZEB deployments. This resource could also serve to inform outreach and education for related industries, policymakers, and the general public.

3. Transit Bus Automation

3a. Reassess FTA goals for transit bus automation.

FTA should incorporate early learnings from transit operators and manufacturers concerning transit bus automation into its research priorities, and potentially re-baseline its STAR plan. Both transit agencies and OEMs expressed an emphasis on Advanced Driver Assistance Systems (ADAS) that improves on-road safety and yard capabilities for automated BEB charging and parking as well as more research into liability implications.

3b. Replicate previously-successful consortia models to accelerate commercialization.

FTA should employ an industry consortia-led approach with a similar structure as the National Fuel Cell Bus Program to advance automated transit bus technologies, while limiting risk to individual manufacturers or agencies. This program would also allow OEMs to share costs of automated driving systems (ADS) technology development promote industry standardization, potentially through open-source technology development. This may include technical specification standards or even shared intellectual property, be it testing data or design features.

4. ZEB Workforce Development

4a: Dedicate a program for ZEB training and workforce development.

FTA should establish a dedicated program to directly support ZEB workforce development. This program should take advantage of the investment FTA has made to date on the ZEB Centers of Excellence (CoEs) as part of the National Fuel Cell Bus Program.

4b: Expand NTI's programming to incorporate ZEB training and workforce certification.

FTA should consider directing the National Transit Institute (NTI) to incorporate ZEB technologies into its workforce development programming, with the aim of building a national ZEB workforce certification program. Focus areas within the program could include high voltage systems training, diagnostics, operations, procurement, charge management and telematics, and executive level and capital planning, among others. Some of these curricula subjects have already been developed at the CoEs and could be shared.

Because workforce development requirements to support ZEB deployments at scale are still not fully defined, the advisory panel suggested FTA provide continued support to define and coordinate workforce development activities through NTI, the existing CoEs, and other transit operators that are currently developing extensive training programs. A steering committee comprised of OEMs, transit agencies, the university testing facilities, and other industry stakeholders could be charged with defining roles within this structure. The advisory panel could serve as this steering committee or, at a minimum, serve as a model for it.

4c: Leverage existing FTA programs to incentivize use of workforce development centers.

FTA should add incentives or requirements within existing grants and programs that reward ZEB grant recipients and other operators for using established workforce development centers.

5. Collaboration with Electric Utilities

5a: Designate a cross-industry working group for transit operators and electric utilities.

FTA should designate or sponsor a cross-industry working group to leverage existing collaborations between the transit and energy industries. Such a working group would provide education and outreach to both parties of the discussion (transit operators and utilities) who currently may be unfamiliar

with the operations and regulations of the other involved parties. This working group could expand or combine existing collaborative efforts from groups such as APTA, Edison Electric Institute, the American Public Power Association, the National Rural Electric Cooperative Association, the Electric Power Research Institute, and others.

5b: Develop an infrastructure deployment planning guidebook.

The advisory panel saw value in developing a planning guidebook to help transit agencies understand electric utility operations, rate-setting, and how those utilities can support agencies through infrastructure deployment and electricity provision for BEB operations.

SECTION 3

Discussion

Through extensive discussion and collaborative working groups, the panel narrowed its focus to those strategies and solutions most critical to support the development and deployment of zero-emission and other innovative transit bus technologies. These five focus areas include:

- Bus Testing Facilities
- ZEB Innovation Research
- Transit Bus Automation
- ZEB Workforce Development
- Collaboration with Electric Utilities

Bus Testing Facilities

The Fixing America's Surface Transportation (FAST) Act established and funded the Low or No Emission Component Assessment Program (LoNo-CAP), which created two new federal bus testing centers to offer independent evaluation of ZEB components for the industry. Ohio State University and Auburn University won competitive bids to join Penn State's existing Altoona Bus Testing Center, which was prohibited from bidding by statute, as federal bus testing centers. The existing Bus Testing Program, which has not seen its funding authorization increase since 1998 and is therefore likely underfunded, remains a requirement for any buses procured with FTA funding, in contrast with the strictly voluntary LoNo-CAP Program.

The industry saw a need for these test centers because ZEBs have faster product development cycles than conventionally-fueled transit buses, and certain components iterate more rapidly. Opening these facilities would both save time for transit bus manufacturers—reducing the amount of full-bus testing required—and accelerate adoption of newer components. However, challenging funding constraints and unclear roles for Ohio State and Auburn have precluded industry participation and federal funding expenditures to date. The panel addressed bus industry testing needs, allocation of responsibilities among the three bus testing centers, and limitations to industry participation.

The panel, particularly the transit agency and OEM participants, wanted to see more testing of new components performed and brought to market faster. However, testing ZEB components is costly and time-consuming. OEMs first test new components internally, prior to their integration and testing on a bus at Penn State's Altoona Bus Testing Center. Further component testing and

validation is valuable to the entire industry, as it can speed up time-to-market for advanced components, boost product confidence, and reduce the likelihood of failing a full bus test at the Altoona test center due to component failure. However, the current statutory framework sets a 1:1 match for federal dollars spent testing ZEB components and provides no capital funding for buildout of test center capabilities.

Given high match requirements and a lack of statutory mandate to conduct component testing, no OEM, component supplier, or agency has opted to do so yet. Ohio State and Auburn have accrued a combined $26 million since FY16 but have been unable to spend it for two reasons—of that funding, $11 million has been awarded through Congressional appropriations, and the entirety is awaiting direction from FTA on which capabilities each testing center needs to build out and manage, and the other $15 million is federal operations funding that requires a local match, so neither test center can spend it without customers. Data sharing requirements also remain a problem, as the result of any test for a vehicle or component is public. Multiple OEMs on the panel contended that as long as agencies were unwilling to pay the full match requirement for tests and they would have to share the results of their test, they would not voluntarily use federally-funded facilities. Reducing match requirements was seen as the simplest path to incentivize use of the LoNo-CAP facilities, given it would require only an FTA rule change and no legislative fix. **See Proposed Solution 1A**.

The specific roles of the LoNo-CAP testing centers have also remained unclear, including as they relate to existing bus testing capabilities and responsibilities at the Bus Testing Center located at Penn State University. The existing policy does not provide a specific breakdown of what and where specific CAP testing activities should be conducted. The Bus Testing Center at Penn State is authorized to conduct mandatory bus testing, and the Ohio State and Auburn sites are authorized to conduct both CAP and mandatory bus testing. Based on multiple discussions with all three bus testing centers and the Atlanta advisory panel meeting, CTE grouped the requirements for FTA's future bus testing program into the following categories:

1. Full bus confirmation testing
    a. Existing durability and performance measures
    b. New requirements for ADAS
    c. New requirements for automated and connected vehicle systems
    d. New requirements for cybersecurity
2. Individual components testing
    a. Standalone components and systems tested outside the context of the vehicle
    b. Components and systems tested in the context of a full vehicle

3. Infrastructure support testing for safety and interoperability
    a. EV charging systems
    b. Hydrogen fueling systems

The transit agencies and OEMs on the panel largely agreed that FTA should define roles to avoid confusion as to test category ownership and limit redundancies. The university test centers ultimately agreed to a distribution of roles that designated one primary test facility for each category, based on existing capabilities and planned investments. Secondary facility designations would allow the program a degree of future flexibility, while at the same time allowing FTA the discretion to limit testing for each category to a single test center.

The panel also agreed capital funding for the program would support the roles designated for each test center. For instance, Ohio State and Penn State have plans for a further buildout of their bus automation and ADAS capabilities that they could accelerate and expand with federal funding. Auburn is exploring a capital investment in the installation of a climatic test chamber equipped with a heavy-duty, two-axle chassis dynamometer for controlled environment component testing on full buses. OEMs on the panel suggested that availability of this equipment would incentivize them to use the facilities even for their own private testing. **See Proposed Solution 1B**. The complete breakdown of role assignments is listed in Appendix B.

Finally, the panel noted a lack of industry-wide consensus on the collective goals of component testing. Few standards exist for individual ZEB components and, due to the nature of business and research development, OEMs have an understandable aversion to sharing the results of internal component testing. Allowing industry demand to drive the discussion would further incentivize OEMs to conduct testing at the university test centers and address the transit agencies' desire for more rigorous performance-based and climate-controlled testing. The panel sought a permanent feedback mechanism to define ZEB industry needs and steer testing priorities. Though not necessarily recommending a continuation of the advisory panel for this purpose, panelists did suggest a similar composition to represent all industry stakeholders. **See Proposed Solution 1C**.

ZEB Innovation Research

FTA research programs were instrumental in establishing ZEBs as viable alternatives to diesel and CNG transit vehicles and should continue to play a central role in stimulating innovation throughout the transit industry. Moreover, other segments of the automotive industry have been able to leverage technical innovations first developed for ZEBs, including a number of medium- and heavy-duty vehicle platforms. Continued federal investment in these technologies is

necessary to stimulate further commercialization, especially around improved component energy efficiency, supporting infrastructure, and management of at-scale deployments. The panel discussed where it would like to see further FTA involvement to support future transit technology development and commercialization efforts and how these research needs should be coordinated through the three bus testing centers.

Federal ZEB deployment programming to date has focused on demonstrating viability, commercialization potential, and benefits across a geographically-diverse set of communities with small deployments of fewer than 10 buses. Although this has provided FTA and the entire transit industry valuable data on varied deployment environments across the United States, agencies still lack an informed roadmap for scaling their fleets with either battery electric or hydrogen fuel cell technologies. Major transit agencies on the panel that have committed to ambitious fleet transition objectives noted they are effectively engaged in educated guesswork as they plan infrastructure and operations for upcoming large procurements. The advisory panel suggested that large-scale (more than 50 buses) ZEB deployment projects are necessary to fully understand the technical and operational challenges associated with full fleet transitions and that FTA should prioritize supporting the buildout of one or more such deployments for both battery electric and fuel cell electric buses.

Targeted large-scale deployments would provide data on vehicle and infrastructure interoperability across multiple vendors, charge management schemes, vehicle-to-grid benefits, route planning, yard and depot management, and partnerships with utility providers. Increasing the size of ZEB rollouts would also allow development of in-field data and modeling on infrastructure needs and potential scalability. This demonstration research activity aims to provide blueprints, models, and best-practices for large-scale, fleet transition to zero-emission operation.

Though several OEMs and transit agencies on the panel had fully committed to battery electric technologies, others were continuing investment in hydrogen fuel cell electric vehicles. Fuel cell electric buses have a proven track record of reliability in varied environmental conditions, route characteristics, and duty cycles. However, infrastructure and vehicle costs at smaller scales remain too high for many transit agencies to adopt these vehicles. Although battery electric buses are currently more affordable, they suffer from limited service range and high dwell times during refueling/charging. Agencies and OEMs that remain committed to hydrogen technologies sought to ensure continued research into vehicle and infrastructure components as well as scaled deployments, remained within scope.

Panelists discussed alternative means of achieving scaled deployment objectives while including agencies of all sizes, and not simply prioritizing larger ones. The

smaller agencies serving small urban communities likewise wanted to see a "model deployment" with comparable service characteristics at their scale. One possible solution involved setting aside funding through an existing deployment program to target scaled ZEB deployments in both large and small (or large, medium, and small) agencies. Another suggestion involved basing award amounts on percentage of a fleet being converted to ZEBs, which could address equity concerns between agencies of different sizes. **See Proposed Solution 2A**.

The panel also turned to other technical challenges, and agencies with mandates to fully convert their fleets to zero-emission vehicles agreed that battery technology simply was not improving quickly enough to meet their needs. Breakthroughs in increased density and lower costs that characterized the industry in the mid-2010s have not been sustained, with gains in battery capacity around 10% annually and no associated cost reductions. Barring potential breakthroughs, OEMs disagreed on whether or not the cost of their vehicles would eventually decrease to become further in line with CNG alternatives, or whether they would end up reinvesting all savings into greater battery capacity. To compensate for slowing battery technology progress, the panel wanted to see FTA invest more research funding into other vehicle components that would support greater energy efficiency and extend range. Agencies and OEMs focused primarily on improvements in HVAC technology but also discussed development of electric driveline components, vehicle light-weighting, and holistic energy management strategies as areas of interest. Similar to other TVIDC focus areas, the panel saw a continued role for it, or a committee with a similar composition, in steering the strategic direction of ZEB innovation funding according to industry needs. **See Proposed Solution 2B**.

Transit innovation research can improve the resiliency of transit agency operations and expand the role of transit for auxiliary uses, including disaster relief and emergency response. Past FTA research funding has explored bus components and other supporting technologies that increase the value of ZEBs. Specifically, the FTA demonstration of a bus exportable power system (BEPS) established technical feasibility to provide emergency power source for disaster response and mitigation. It also validated industry interest in the technology and refined use cases for further development. The panel believes that by funding in-service demonstrations of bus exportable power technologies and establishing incentives and pathways for the purchase and maintenance of these systems will increase the resiliency and response to growing community needs during disasters and emergencies by transit systems. **See Proposed Solution 2C**.

Finally, transit agency representatives on the panel expressed interest in a consolidated repository for data on ZEB deployments. Though some organizations have aggregated data and experiences from the numerous ZEB pilot projects and deployments to date, these are by no means comprehensive

repositories. This lack of knowledge-sharing often results in poorly-informed, exploratory approaches to ZEB deployment by agencies procuring those vehicles for the first time. CALSTART noted that its Clean Transit Innovation Network (CTIN), also funded through the TVIDC program, could offer the basis for such a repository. CTIN is an online clearinghouse that assists transit agencies transitioning to clean bus fleets, sharing reports on efforts to deploy, test, and commercialize low- and zero-emissions transit buses and providing tools to help agencies adopt these vehicles. **See Proposed Solution 2D**.

Transit Bus Automation

Automated driving systems (ADS) offer significant potential benefits for heavy-duty transit buses, including improved energy efficiency and on-road safety through driver assistance, reduced capital costs from yard automation, and more. FTA created the Strategic Transit Automation Research (STAR) program to explore these benefits and drive industry innovation through research and demonstration funding. However, since publishing the STAR plan in early 2018, that program has not received adequate funding to advance development of ADS technologies in the transit bus industry. Moreover, larger funding opportunities through the Federal Highway Administration have omitted transit buses entirely. None of the seven USDOT ADS Demonstration Grants proposals involving automating 40-ft transit buses were among the eight projects awarded under that program. The advisory panel sought to identify where FTA's existing priorities align with industry interests and determine how FTA can best shape and accelerate automated vehicle (AV) technology development moving forward.

Since the STAR plan was published in January 2018, transit operators and manufacturers have learned more about automation and technical obstacles to developing and deploying those capabilities in regular service. Several OEMs have invested resources into developing ADS-equipped prototype vehicles, and multiple transit agencies on the panel participated in the Automated Bus Consortium organized by engineering consultancy AECOM. Agencies were initially motivated by addressing chronic driver shortages, reducing liability and capital costs at their depots, and achieving full automation for their buses. However, through their exploratory activities, transit agencies and manufacturers recognized that complete automation without any driver on board is unlikely in the foreseeable future and will draw significant resistance from organized labor.

Instead, transit agencies interest shifted to nearer-term objectives and less-contentious capabilities, namely those that improve on-road safety and yard capabilities for automated battery electric bus charging and parking. The transit bus industry can achieve the former through development of ADAS, comprising lower levels of automation that augment rather than replace drivers. Automated steering, acceleration, braking, and platform docking are expected to reduce accidents, increase energy efficiency by eliminating aggressive pedal

use and maximizing regenerative braking, and improve accessibility for elderly and disabled riders. Drivers would remain behind the wheel to resume manual operation both for more challenging scenarios (e.g., unprotected left-hand turns, work zones, etc.) and in the instance of a general system failure. Yard automation would primarily facilitate significantly tighter parking arrangements, reducing depot real estate requirements, and reduce the number of charging units an agency needs to procure and install in support of its battery electric bus fleet. As they are charged, vehicles could automatically cycle through fewer charging units rather than remain paired with a single charger overnight. These yard automation capabilities could in theory facilitate reductions in depot personnel; however, infrastructure cost savings are likely significant enough to justify investment without labor impacts. Finally, the panel also wanted to see greater emphasis on research around liability and cybersecurity issues, which the agencies believed would ultimately create significant barriers to adoption unless sufficiently addressed. The panel indicated these learnings should inform FTA's future research priorities and suggested FTA re-baseline those priorities accordingly. **See Proposed Solution 3A**.

To realize FTA's research objectives for automated transit bus technologies, the advisory panel recognized the need for a multi-year program to accelerate development and catalyze commercialization. More than 10 organizations on the panel (including transit agencies, manufacturers, and nonprofits) participated in the NFCBP, and all saw the value in standing up a similar program to spur development and commercialization of bus automation technologies. In fact, the emergence of the current zero-emission bus market can be traced back to the NFCBP. A new program designed to advance automation could support a number of diverse projects, including development of critical components for drive-by-wire capabilities, pilots for yard automation, driver assistance systems, full prototype automated buses, and automated bus rapid transit. Offering dedicated funding on an annual, competitive basis for development and demonstration projects would incentivize investment across the industry, much as it did with zero-emission technologies.

As transit bus manufacturers begin to fund AV technology development internally, they are recognizing the high long-term cost of that development without a near-term path to deployment at scale. Because zero-emission technology improvements represent the most pressing need from their customers, they are reticent to commit significant internal resources for an uncertain market and commercialization horizon. Several OEMs serving on the advisory panel indicated interest in industry-wide collaboration to share costs of AV technology development and to promote industry standardization, potentially through open-source technology development. This effort may include technical specification standards or even shared intellectual property, be it testing data or design features. CALSTART is also working with 13 transit operators nationwide

as part of its Connected and Automated Transportation Users Forum (CATUF), funded through the TVIDC program, to address demand from transit agencies for smaller automated buses. CATUF will develop a specification for a purpose-built zero-emission automated transit vehicle that offers a smaller alternative to automated full-size transit buses. **See Proposed Solution 3B**.

ZEB Workforce Development

The continued deployment of ZEBs requires a workforce of transit operators, technicians, engineers, and planners who are trained in the sourcing, deployment, and management of vehicles and supporting infrastructure with considerably different operational characteristics from diesel and CNG buses. Transit agencies currently rely on OEMs to provide high-level training for the operation and maintenance of the vehicles they sell. Whereas this training and technical support are critical to successful deployments, they are not designed to provide ongoing training after the initial introductory period, especially as new employees onboard. Moreover, this training lacks standardization across the industry, with varying approaches from OEM to OEM and no certification mechanism.

Over the past five years, several early ZEB adopters have established regional training efforts in anticipation of industry demand for ZEB workforce development. FTA funding as part of the NFCBP supported efforts at two transit agencies, SunLine and SARTA, which created ZEB Centers of Excellence (CoEs). The CoEs serve as development engines for innovative training serving transit managers, operators, and maintenance staff. Additionally, AC Transit has established a reputation for its in-house ZEB training program, which it provides to other operators on request. LA Metro is launching a similar initiative for a regional ZEB training and resources hub in the Los Angeles region. Other agencies have demonstrated interest in standing up local or regional programs of their own. However, these workforce development efforts lack coordination and consistent supporting resources. Federal funding for transit workforce development (49 USC Sec 5314). Technical Assistance and Workforce Development) is divided among all transit modes. Though the FTA Low or No Emission Vehicle Program allows some awarded funding to pay for relevant ZEB operations and maintenance training, this is not a dedicated stream. **See Proposed Solution 4A**.

The advisory panel discussed strategies to leverage existing FTA and transit agency workforce development investments, standardize training protocols across the industry, and expand availability of valuable ZEB training and technical assistance programs. After exploring several potential models for organizing this programming, panelists agreed the NTI has to potential to lead a national effort. NTI already receives $5 million annually through Section 5314 funding and has the organizational capacity to both develop training curricula and coordinate its delivery. Panelists wanted to see FTA direct NTI to incorporate ZEB content

into its transit workforce development agenda, including basic training curricula, coordination of training delivery centers, including the CoEs, and some form of a national ZEB workforce certification program. NTI would need to adapt its existing programming and approaches through industry participation to address those areas most critical to ZEB workforce development. Focus areas within the training and certification program could include high voltage systems and safety, electric motor drives, power electronics, hydrogen systems and safety, diagnostics, operations, procurement, charge management and telematics, and executive-level and capital planning, among others. The CoEs have already developed much of this curriculum.

Another approach discussed involved designating regional CoEs, including those already established, to serve as training and technical assistance centers for an NTI-managed ZEB workforce certification program. This geographic footprint would allow delivery of uniform and rigorous curricula, while also leveraging existing local expertise and resources. Several panelists acknowledged potential current funding constraints for NTI, but nonetheless deemed this approach ideal. **See Proposed Solution 4B**.

As with other TVIDC priorities, panelists indicated their preference for a standing committee to inform content and priorities as the industry evolves, especially because transit agencies are the organizations best positioned to determine the workforce needs of implementing and operating ZEBs at scale. One representative of a large transit agency likened ZEBs to the position of rail transit operations in the early 1990s, when the industry was beginning to transition to modern information technology infrastructure and new electronic controls. He noted the industry knew significant changes were coming but could not identify all needs from Day 1. Another representative from a large agency noted his agency is still in a trial-and-error approach with both planning and maintenance.

Finally, current regulatory and funding mechanisms for ZEB procurement are not conducive to incorporating workforce development programming. Agencies that want to include it in their grant proposals or locally-funded procurements must carve out funding that would otherwise fund vehicle and infrastructure procurement and operations. The advisory panel sought a dedicated annual funding stream allocated through existing programs, likely the LoNo Program, to directly support ZEB workforce development objectives. In parallel, the panel discussed adding incentives or requirements that motivate ZEB grant recipients and other operators to utilize established workforce development centers. One way of achieving this would be to allow agencies to add workforce development to their proposals with a reduced or no-match requirement. FTA could also incorporate workforce development programming as a LoNo Program selection criterion to incentivize inclusion in agency proposals. Increasing motivations for

procurement of necessary ZEB training and technical assistance would assure the CoEs and other agencies investing in workforce development facilities that they would have enough sustained demand to justify those investments on behalf of the entire industry. **See Proposed Solution 4C**.

Collaboration with Utilities

The adoption of ZEBs requires strong working relationships between transit agencies and their electric utilities. Though industry collaboration with these electric utilities was not an initial focus area of the advisory panel, nearly every transit agency on the panel had a story to share at the Los Angeles meeting about its challenges deploying charging infrastructure and felt that improved transit industry interaction and partnerships with electric utilities will be necessary for successful experiences. CTE responded to that interest by adding it as a focus area within the panel's objectives.

Prior to the commercialization of BEBs, few agencies had experience working with utilities as suppliers of fuel for their transit bus fleets. The experience gap was smallest between agencies that operate electrified rail and have power substation installations at their rail stations, and those that were bus-only systems. This lack of experience extends to the utilities as well, as the vast majority have never had to supply a heavy-duty vehicle fleet with strict duty and charge cycles. Though electric utilities serving BEB operators have developed familiarity with the technology, agency operating needs, and infrastructure requirements, most are still early on the learning curve or have yet to start. Further, both industries still lack answers for how best to affordably and effectively deploy large-scale electric charging infrastructure at existing transit facilities.

There are more than 3,300 different electric utilities and 6,800 transit operators in the United States. Numerous coalitions, nonprofits, and industry groups have organized to educate stakeholders and facilitate strategic planning and learning for BEB deployment for electric utilities, transit agencies, and other stakeholder groups. As representatives of their respective fields, these organizations have the added benefit of industry credibility. However, these initiatives typically involve single industries and haven't brought together the multi-disciplinary groups necessary to make significant progress in this field. In its Chicago meeting and subsequent discussions, the panel discussed how best to coordinate and bring together these various working groups and educational efforts, including possible roles for federal actors.

Through another TVIDC task, CTE has coordinated on these objectives with multiple trade associations, including the American Public Power Association (APPA) and the National Rural Electric Cooperative Association (NRECA). Other ongoing initiatives include those led by APTA, CALSTART, Edison Electric

Institute, and the Electric Power Research Institute (EPRI). Although these forums and working groups have achieved important successes in advancing BEB deployments, the advisory panel sought to see some consolidation or at least an FTA sponsorship of one cross-industry group to focus its own outreach. Both agencies and OEMs on the panel agreed APTA was a natural option to be a leading industry voice in this capacity, given its wide-reaching national membership, organizational capacity, and ongoing research efforts. They also recognized that the other aforementioned organizations should have some role in steering this forum due to their experience and expertise. By identifying common goals, the working group can influence mutually-beneficial frameworks for addressing industry challenges such as infrastructure scaling and installation, liability, and equipment testing and certification. **See Proposed Solution 5A**.

A clear understanding of deployment objectives, infrastructure requirements, and estimated power demand and energy consumption allows transit agencies to more effectively collaborate with their electricity providers. The advisory panel saw value in developing a planning guidebook to help transit agencies understand electric utility operations, rate-setting, and how those utilities can support them through infrastructure deployment and electricity provision for BEB operations. This resource would contain both technical and regulatory information, and help agencies understand the roles and responsibilities of key actors. The guidebook could also provide case studies of effective strategies developed by other fleet operators during BEB deployments, and incorporate the extensive technical research being conducted on power requirements, charging systems, and bus power usage. The mechanism for this scope could either be an extension of existing TVIDC work, supported by FTA through the aforementioned cross-industry working group, or submitted as a project plan to TRB for TCRP research. **See Proposed Solution 5B**.

Finally, the advisory panel expressed interest in seeing increased collaboration directly between FTA and other important federal stakeholders for BEB industry development and deployment. Though the Department of Energy does not have direct jurisdiction over electric utilities regulation, which is managed at the state level, it can influence state and local policy through a variety of mechanisms. These include education and outreach efforts, grant opportunities for research, demonstration, and deployment programs, and coordination through the DOE-funded Clean Cities coalitions. Increasing awareness of BEB deployment challenges and potential community benefits across other federal agencies may open new opportunities for joint research or boost support for state and local initiatives.

Appendices

Appendix A: TVIDC Chicago Meeting Discussion Research Report

Meeting #2 – Chicago, Illinois

January 6, 2020

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Federal Transit Administration Bus Testing Centers Overview and Recommendations

Overview of Program Requirements

Following the award of Low and No Emissions Component Assessment Program (LoNo-CAP) testing centers to Ohio State University and Auburn University in Fiscal Year 2016, the Federal Transit Administration (FTA) must determine how to integrate these centers into its existing Bus Testing Program. To define the future of that program, FTA is working with the Center for Transportation and the Environment (CTE), CALSTART, and the three test centers (Ohio State, Auburn, and Penn State-Altoona) to suggest roles and identify new industry testing requirements.

Objectives

Penn State currently receives $3 million in FTA funding annually to support the program. This has been Penn State's authorized funding level since 1998, and despite having the facilities to support increased bus testing, underfunding has limited the staff it can maintain. Since the FAST Act's enactment, Ohio State and Auburn have received $1.5 million in mandatory funding annually, each, in Fiscal Years (FY) 2016, 2017, 2018. They will receive the same level of funding in FY19 and FY20, the FAST Act's final year of authorization. Congress has also legislated bonus appropriations over this period to both Penn State and the LoNo-CAP testing centers, which Auburn and OSU split evenly. **Table A1** shows the breakdowns of these appropriations over the past three years.

Table A1. Discretionary Funding to FTA Bus Testing Centers, FY18-20 (total funding)

Funding Year	Penn State	Ohio State/Auburn
FY18	$2 million ($5 million total)	$2 million ($5 million total)
FY19	$1 million ($4 million total)	$6 million ($9 million total)
FY20	$0 ($3 million total)	$3 million ($6 million total)
Total	**$3 million ($12 million total)**	**$11 million ($20 million total)**

However, due to challenges in the structure of the program and alignment with industry needs, neither has spent their awards to date. FTA's Transit Vehicle Innovation and Deployment Centers (TVIDC) program aims to define current and future bus testing objectives, and with input from the industry, suggest a direction for both LoNo-CAP test centers and the full bus durability testing program, currently housed at Penn State.

Based on multiple discussions with all three bus testing centers, as well as the first of three panel meetings with transit bus industry representatives, CTE grouped the requirements for FTA's future bus testing program into the following categories:

1. Full bus confirmation testing
    a. Existing durability and performance measures
    b. New requirements for advanced driver assistance systems (ADAS)
    c. New requirements for automated and connected vehicle systems
    d. New requirements for cybersecurity

2. Individual components testing
    a. Standalone components and systems tested outside the context of the vehicle
    b. Components and systems tested in the context of a full vehicle
3. Infrastructure support testing for safety and interoperability
    a. EV charging systems
    b. Hydrogen fueling systems

Full bus confirmation testing is the only category of services currently performed, at Penn State, and is the only mandatory FTA bus testing. The LoNo-CAP program prohibits Altoona from performing individual components testing within the program framework.

Evaluation of Capabilities

Penn State developed the protocols and procedures for the bus testing program in 1989 and has capacity to support testing of up to 30 buses per year between its two structural durability test tracks. It receives on average only 15 buses per year. As submission volume is not expected to increase significantly beyond current levels, the Altoona facility has sufficient capacity to address current and future full bus testing needs. Moreover, it has both depot charging and hydrogen fueling infrastructure to support battery electric and hydrogen fuel cell buses, as well as a large-roll (72-in diameter) dynamometer. Penn State is ISO 17025 accredited for vehicle testing and has completed testing on more than 500 bus models over the past 30 years. These bus models include conventional and alternative fuel buses, as well as battery electric, hybrid electric and hydrogen fuel cell vehicles. Penn State has extensive vehicle related research capability that includes fuel cell and battery development, materials science, controls and automated vehicle technology, simulation and modeling and a dedicated, full-scale automotive test track and an additional larger automotive test track (PennStar) facility under development

Ohio State and the Transportation Research Center (TRC) have similar full bus confirmation testing capabilities in place on campus and at TRC's proving ground outside Columbus, including some charging and fueling infrastructure to support battery electric, compressed natural gas (CNG), and hydrogen buses. OSU also has multiple laboratories with equipment and personnel capable of testing Low-No powertrain and energy storage components, along with a two-axle transit bus dynamometer. Finally, Ohio State and TRC have developed and installed extensive facilities and infrastructure for to support automation, ADAS testing, and vehicle-to-everything (V2X) communications for commercial vehicles. TRC is an ISO 9001 and 14001 registered and carries ISO 17025 accreditation on many vehicle testing procedures. TRC serves more than 900 customers in the transportation industry with the development and executing of vehicle testing and validation and is home to the National Highway and Traffic Safety Administration's only Vehicle Research and Test Center. Ohio State and TRC have conducted extensive facility designing and planning exercise to estimate the costs and impacts of a variety of potential facility enhancements to further support transit bus testing including enhanced capabilities in laboratory, chassis dynamometer, and on road capabilities including vehicle and infrastructure.

Auburn has an automotive test track capable of supporting full bus durability and individual components testing. It also has the McCrary Institute for Cyber and Critical

Infrastructure Security, which automotive engineering resources plan to leverage for automotive cybersecurity research and testing. Auburn is designing a test facility equipped with a two-axle dynamometer enclosed in a climatic chamber to conduct controlled environment component testing for full busses. This is distinct from the chassis dynamometers at Ohio State and Penn State which do not have the ability to conduct full environmental simulations.

Technical Assistance and Workforce Development

Overview

Commercialization of zero-emission bus technologies requires robust assistance programs that support early adopters of the technology with technical expertise in procurement, installation, deployment, and maintenance. Beyond direct technical assistance, educating and training the wider transit workforce also ensures a successful transition to zero-emission transit fleets.

The Technical Assistance and Workforce Development program administered by FTA offers educational resources, grant opportunities, and other programming necessary for continued support of early adopters, and the development of a skilled and specially-trained workforce required for the successful uptake of zero-emission buses nationwide.

§49 U.S.C 5314

"(A) In general. —The Secretary may make grants and enter into contracts, cooperative agreements, and other agreements (including agreements with departments, agencies, and instrumentalities of the Government) to carry out activities that the Secretary determines will assist recipients of assistance under this chapter to—
(i) more effectively and efficiently provide public transportation service;
(ii) administer funds received under this chapter in compliance with Federal law; and
(iii) improve public transportation."

This statute establishes and funds programs that develop standards, provide technical assistance, and support the creation of a well-trained, diverse transit workforce.

Per FTA's program fact sheet, §5314 aims to:

- Carry out technical assistance activities that enable more effective and efficient delivery of transportation services, foster compliance with Federal laws, and improve public transportation service
- Develop standards and best practices for the transit industry
- Address public transportation workforce needs through research, outreach, training and the implementation of a frontline workforce grant program, and conduct training and educational programs in support of the public transportation industry

To achieve these aims, the statute is broken down into three distinct subsections:

§5314(a): Technical Assistance and Standards Development

Maintaining technical assistance programs helps transit agencies capitalize on numerous technological advancements occurring throughout the industry. Programs funded under

this section offer direct technical expertise for transit agencies to apply best practices before, during, and after implementation of new technologies.

§5314(b): Human Resources and Training

This subsection focuses on supporting programs that promote workforce development and training. The primary competitive grant program created under this subsection is the "Innovative Transit Workforce Development Program." Examples of grant funding awards include apprenticeships, on-the-job training opportunities, developing training partnerships with state and local entities, safety improvements, and addressing current or projected workforce shortages with training and placement programs.

§5314(c): National Transit Institute

§5314 established the National Transit Institute (NTI) at Rutgers University, which it tasked with creating training and educational programs, developed in coordination with all levels of government. The NTI also conducts research supporting innovation in the field of workforce development, safety, and transit management practices. Further details about each subsection of §5314 and their respective funding amounts are listed in the table below.

Of particular interest to the panel discussion on standards and workforce development, the NTI produced an analysis in 2018 that detailed gaps in the current federally funded training programs and identified future transit workforce needs. The current federally funded programs are detailed in **Table A2** below.

Table A2. FTA Technical Assistance and Workforce Development Programs

Program Subsections	FTA Funding (2019)	Areas of Focus
Technical Assistance & Standards	General Fund: **$5 million***	Technical assistance for: • Development of consensus-based industry standards • Americans with Disabilities Act compliance • Improving transportation options for the elderly • Increasing ridership • Transportation equity • Best practices for driver safety • Development and deployment of low or no emissions vehicles and components • Annual reporting on funded programs and projects
Human Resources & Training	Highway Trust (FAST Act): **$4 million**	• Employment training programs • Outreach program to increase employment of veterans, women, minorities, and those with disabilities • Research on personnel and training needs • Training assistance for veterans and minority business opportunities • National training standards and certifications (collaboration with industry stakeholders)

National Transit Institute	Highway Trust (FAST Act): **$5 million**	• Training and educational programs for numerous aspects of public transit development and management. Including: intermodal transit planning, management, environmental factors, acquisition and joint use right-of-way, engineering and architectural design, emission reduction technologies, etc. • Education and training for federal, state, and local transportation employees

**Current appropriation amounts for the Technical Assistance and Workforce Development Program have not been specified. $9 million is automatically authorized for this program by the FAST Act, and will remain unchanged in FY20*

Characteristics of Successful Programs

FTA, in collaboration with Axiom Inc., produced a "Lessons Learned" report to review the most effective initiatives funded by the Innovative Transit Workforce Development Program. The report identified a set of characteristics and practices that led to the most training and job placement of transit staff. These include:

- Identifying and leveraging existing partnerships with stakeholders
- Clearly defined skill sets on which to focus education and training efforts
- Utilizing and cooperating with existing programs
- Leveraging complementary partnerships that provide experience and expertise
- Provision of wrap-around services supporting participants during training (mentoring, providing transportation, childcare, stipends, legal assistance, etc.)
- Opportunity to acquire industry-recognized credentials
- Dedicated placement services or processes
- Post-placement retention support, after completion of training

Potential Program Models for Technical Assistance and Workforce Development

Reviewing existing programs and models that have been successful in achieving similar goals can help in developing technical assistance and workforce development programs that effectively serve the uptake of zero-emission buses. A number of potential programs are listed below:

University Partnerships

Partnering with universities in technical assistance and workforce development programs provides both the technical expertise required for effective assistance programs and built in processes and resources for education and training. FTA has a long and successful history of partnering with institutions of higher learning, which provides a baseline for developing and deploying effective collaborative programs.

Workforce Development Centers of Excellence

Two ZEB workforce development centers of excellence have received funding through different FTA programs to integrate and improve the use of ZEBs in revenue service. Both SunLine and the Stark Area Regional Transit Authority (SARTA) presented at the first panel meeting on their activities and future plans, but generally have worked to develop best practices, and act as a guide for other agencies moving forward with their own ZEB deployments.

There is no recurring funding source supporting these centers of excellence, nor current FTA plans to do so. Therefore, the panel should consider whether these models deserve additional federal investment to sustain operations, and possibly expand designations to other participating agencies in unrepresented geographies.

The Stark Area Regional Transit Authority

SARTA is the host organization for the Midwest Hydrogen Center of Excellence in collaboration with the Center for Automotive Research at Ohio State. The center has acted as a proving ground for the testing, and implementation of hydrogen-powered transit buses. The collaborative environment with nearby universities and other transit-oriented organizations offer important partnerships for developing successful development programs.

SunLine

The SunLine Transit Agency in Thousand Palms, California, provides the location for the West Coast Center of Excellence in Zero-Emission Technology. Like SARTA, the host agency acts as a platform the testing and improvement of zero-emission transit technologies. The agency operates both hydrogen fuel cell and battery electric ZEBs.

In addition to its initial center of excellence funding and focus on zero-emission vehicles, SunLine received a $1.5 million Low No grant award to focus specifically on workforce development related to ZEBs. The center will design, test, and implement new training programs specific to the operation, maintenance, and management of ZEBs. It is the first federally funded program dedicated specifically to train ZEB operators and technicians.

Automated Vehicle Proving Grounds

In the Obama Administration's final month, USDOT launched an Automated Vehicle (AV) Proving Grounds program with 10 designated test beds across the country. Though it carried no funding for those sites, and was shuttered by the Trump Administration, the AV Proving Grounds program was similar to the centers of excellence concept in its geographic distribution, partnerships with agencies, local governments and universities, and its goal of testing and implementing innovative concepts and technology. Though this approach was politically unpopular due to fears from non-selected test beds that they would be disadvantaged in future funding opportunities, it was a valuable concept from the standpoint of geographic distribution. Diverse geographies would ensure exposure to all continental US climates, and a variety of population densities (urban, suburban, rural).

FTA could use a similar multiple facilities model to address ZEB-related objectives in its Technical Assistance and Workforce Development program. Weather will remain a concern for ZEBs for the foreseeable future, requiring technicians and vehicle operators to manage extreme conditions. Workforce composition, labor market competitiveness, and recruiting requirements vary from state to state and between urban and rural areas. Setting a multiple ZEB workforce development centers of excellence as regional models would offer a comprehensive array of transit agency contexts to inform best practices across the entire industry.

Regional Transit District (Denver) – Workforce Initiative NOW (WIN 2011)

Identified by FTA as one of the most successful training programs in the nation, Denver RTD's WIN was responsible for identifying, training, and placing, skilled transit operators and technicians. The program was expanded in 2018 with WIN 2.0. By the conclusion of the program, WIN had provided training for over 2000 individuals in 350 different focus areas and resulted in more than 200 trainees successfully placed and hired in transit industry jobs.

A significant factor in the program's success was RTD's ability to leverage its network of existing partnerships to identify prospective trainees, assist with training, and provide placement opportunities with other transit-related agencies and advocacy groups. Beyond job placement, the program also provided post-training services that provided support and continued training to participants in relation to their new roles.

These components from WIN, and other successful workforce development programs could be utilized in the development of new programs focused or the successful expansion of programs focusing on providing training in the operation, maintenance, and management of ZEBs.

TVIDC Program - External Collaboration, Forums & Working Groups

Project Overview

The External Collaboration, Forums, & Working Group task within the TVIDC program aims to support information transfer between transit agencies and other stakeholder groups.

Since the start of 2019, CTE has performed work under this task to support partnerships between transit agencies and electric utilities through zero-emission bus (ZEB) deployments, and to win the ZEB industry's buy-in on resources to support the procurement of battery charging and hydrogen fueling infrastructure.

Significant Accomplishments

Working Groups – Building Partnerships between Transit Agencies and Electric Utilities

Transit agencies with ZEB fleets may become some of electric utilities' largest customers, raising the importance of strong partnerships throughout ZEB deployments. Both transit agencies and utilities are likely unfamiliar with the other's constraints, so careful planning and coordination is necessary to ensure success.

Much of CTE's work within this task has focused on coordinating with trade associations, such as the American Public Power Association (APPA) and the National Rural Electric Cooperative Association (NRECA), to improve transit agency coordination with municipal electric utilities and rural cooperatives, respectively. CTE has partnered with these and other utility and transit stakeholder groups to:

1. Identify collaboration opportunities and promote partnerships between transit agencies and electric utilities

2. Improve understanding of factors that influence ZEB fleet energy consumption
3. Identify short- and long-term infrastructure needs to support ZEB deployment; and
4. Educate transit agencies on the constraints electric utilities face in supporting ZEB fleet deployment

CTE resources presented at multiple electric utility events throughout the year on the benefits of partnering with transit agencies deploying ZEBs, a full list of which is summarized in **Table A3** below.

Table A3. Presentations Provided on the Benefits of Transit Agency/Utility Partnerships

Project Name	Date and Location	Project Partners	Attendees
Edison Electric Institute (EEI) Government Affairs Conference	April 16-18, 2019 Amelia Island, FL	EEI	Unknown
American Council for an Energy Efficient Economy (ACEEE) Webinar: Utility EV Working Group	July 31, 2019 Webinar	ACEEE King County Metro Transit Chattanooga Area Regional Transportation Authority	37
APPA Webinar: Powering the Zero-Emission Bus Industry: How your Utility can Lead the Charge	August 15, 2019 Webinar	APPA City of Ames, Iowa	25
Beneficial Electrification Workshop Panel	September 5, 2019 Des Moines, IA	Beneficial Electrification League NRECA	94
Beneficial Electrification Workshop Panel	October 8-9, 2019 Bloomington, IN	Beneficial Electrification League NRECA	125
Rural Transit Assistance Partnership (RTAP) Webinar: Rural Transit Zero-Emission Vehicle Deployments: Collaborating with your Electric Utility	November 5, 2019 Webinar	RTAP Holy Cross Energy Roaring Fork Transportation Authority	45
APPA's Public Power Forward Summit Conference Panel	November 21-22, 2019 Nashville, TN	APPA	103

External Collaboration

CTE is also engaging industry stakeholders to develop customizable Request for Information (RFI) templates transit agencies can use when seeking additional information on battery electric bus charging infrastructure and fuel cell electric bus hydrogen fueling stations. **Table A4** summarizes that effort.

Table A4. External Collaboration Accomplishments

Project Name	Description	Estimated Completion Date	Stakeholders
Hydrogen Fuel Cell Station and Battery Electric Charging Infrastructure RFI Templates	Developing customizable RFI templates for charging and hydrogen fueling infrastructure	Spring 2020	Transit agencies, electric utilities, charger manufacturers, ZEB manufacturers, hydrogen station providers, fuel cell OEMs, third party data monitoring & charge management providers, engineering firms

Parallel Industry Working Groups

Other industry groups are engaged in complementary efforts to the work described in Tables A3 and A4 above. CTE is either currently collaborating with these groups or has near-term plans to do so.

- **The American Public Transportation Association (APTA**) has an active working group with EEI to address issues facing transit agencies and electric utilities. CTE engaged with this working group while it was developing a guide for transit agencies to work with electric utilities during ZEB deployments.
- **The Canadian Urban Transit Research & Innovation Consortium (CUTRIC)** is facilitating a Power Providers Working Group, which works to establish a systemic national dialogue reviewing and assessing opportunities, challenges, and solutions associated with the growing role for Canadian utilities in transportation electrification. CTE participated in several working group meetings and provided input to the working group charter.
- **Electric Power Research Institute (EPRI)** has a Utility Bus and Truck Working Council under its Infrastructure Working Council. This group has recently been discussing infrastructure needs for large-scale ZEB deployments. CTE is coordinating with EPRI to increase engagement with this group.

Potential Future Areas of Focus

CTE plans to build upon the work described above as available funding allows. Potential future project areas are listed below in **Table A5**.

Table A5. Potential Future Project Areas

Project Name	Description
Conduct electric utility-focused workshops or learning sessions	Facilitate a half- or full-day workshop for electric utilities on their role during ZEB deployment. Workshops could be connected to an industry conference or meeting. Topics could include: Infrastructure planning Rate design Resilience and emergency response services Renewables integration Fuel cell electric buses
Conduct regional workshops for transit agencies and electric utilities	Facilitate one-day workshops between a small group of utilities and transit agencies in the same service area to share information about requirements for fleet electrification, and discuss challenges and opportunities in establishing pilot programs, incentives, or rate structures.
Webinar series to educate electric utilities	Conduct focused webinars to educate electric utilities on the requirements, challenges, and opportunities to support fleet electrification.
Outreach materials	Develop white papers, fact sheets, or other outreach materials to provide information to electric utilities or transit agencies on best practices for working together throughout ZEB deployments.
Procurement document support	Develop additional templates to support ZEB procurements, such as Requests for Proposals (RFPs) for turnkey charging or hydrogen fueling infrastructure projects.

Transit Bus Automation

Overview

Heavy-duty transit buses stand to reap significant benefits from integration of automated driving system (ADS) technologies, including increased energy efficiency and reduced capital costs. However, due to lengthy procurement cycle, heavily regulated design and testing standards, and a fiscally-constrained customer base, transit bus manufacturers have lagged behind light vehicle and commercial heavy-duty truck manufacturers in developing these capabilities. Transit buses still rely on hydraulic steering and pneumatic braking, which are not conducive to the drive-by-wire functionality required by automation.

Multiple potential applications of ADS technology can facilitate the adoption of zero-emission buses (ZEB), specifically battery electric buses (BEB). Even allowing for power load requirements from sensors and computing hardware, eliminating driving performance variability through automation should substantially increase energy efficiency. Automating bus operations in yard or depot settings would also reduce capital barriers to BEB procurement, minimizing the number of charging units required and allowing agencies to accommodate more vehicles at existing facilities.

The FTA published its Strategic Transit Automation Research (STAR) plan in early 2018, written with the John A. Volpe National Transportation Systems Center (Volpe), which road

mapped future research and demonstration efforts, and detailed projected benefits from transit bus automation.

Impact on Driveline Efficiency

CTE has supported or is currently supporting more than 50 zero-emission bus deployments across dozens of projects in the United States. These deployments are geographically diverse, and include conditions ranging from high heat in the Southwest to extreme cold in the upper Midwest and New England. They also cover a variety of topographical environments, including settings where buses operate on routes featuring high grades. Heating or cooling the vehicles draws a significant power load from buses, as does accelerating up steep terrain.

For each of its zero-emission bus deployments, CTE performs energy modeling activities prior to launch, and then tracks energy consumption and battery performance data while vehicles are in service. Even beyond extra power loads required to heat and cool the cabin, and driving up hilly terrain, CTE has observed that ZEBs can experience significant variability in energy consumption from the driver behind the wheel.

This inefficient driving behavior, particularly acceleration and braking, can reduce battery range by up to 50%. For buses that employ regenerative braking, poor use of the system minimizes potential gains. “Eco-drive” features, essentially automated acceleration and braking, would both reduce this variance and increase battery range.

In its STAR plan document, FTA extrapolates fuel savings from experiments using adaptive cruise control systems in light vehicles, pegging them at greater than 7% for 40-foot transit buses. FTA addresses conventional fuel and hybrid-electric buses in its STAR plan estimates, however, transit bus manufacturers are only developing ADS technology for BEBs. In separate studies, researchers at 1) Carnegie Mellon University, and 2) The University of Michigan and Ford Motor Company have found potential energy savings of anywhere from 7% to 16% for light vehicles, not accounting for ADS operational power loads.

Though FTA expects greater average savings for light vehicles versus transit buses due to the frequency with which buses are either idling at intersections or bus stops, driver performance variability is a far more significant factor in transit bus operations. Agencies struggling to retain experienced drivers may face disadvantages with BEB procurement because driver performance can reduce the safe effective range of vehicles on a given charge cycle.

Additional gains are possible through vehicle-to-infrastructure communications (V2I) and transit signal priority strategies that reduce idle time and allow for synchronized acceleration and braking.

Reduced Capital Barriers to ZEB Procurement

Infrastructure costs are one of the more significant impediments to BEB adoption, as agencies typically need to procure a charger for each BEB they add to their fleet. These can cost anywhere from $75,000 to $150,000 for each depot unit and its installation. Though some agencies design their operations to have personnel on site overnight who can rotate

buses through charging cycles, allowing them to manage with fewer chargers, that model can drive up operating costs.

Transit bus automation can reduce costs by managing charge cycles without human intervention, eventually allowing agencies to use one charger for multiple buses. Plug-in chargers currently lack the capability for automated docking, but demand for automation of other vehicle platforms may incentivize parallel development of that technology. Though overhead pantograph and ground inductive chargers are currently capable of automated docking and charging, both can cost half a million dollars or more per unit.

Similarly, transit agencies are planning to transition to zero-emission fleets at a time when BEBs lack the range to replace legacy CNG and diesel vehicles. As discussed in the previous section on spare ratios, agencies may need to procure multiple BEBs for some legacy vehicles they replace. They also will need to retain more legacy vehicles as insurance against BEB operational limitations. Due to the expected increase in fleet size, demand for depot space will increase with it. Especially for urban agencies facing high real estate costs, expansion may prove challenging and costly to address.

Automation can address these challenges by allowing for more efficient storage of buses by parking them closer together and automating parking and recall. In its Strategic Transit Automation Research plan document for FTA, Volpe assessed the potential impact both of in operational efficiency and cost savings from yard automation. While the analysis found a significant return on investment for the specific scenario used, it assumed a completely mature technology ready for mass deployment. Cost reductions on a $1 million, 12-year investment for a fleet of 50 buses were estimated at $1.93 million, providing a net savings of $930,000. Volpe did acknowledge that requisite enabling technology was not available on the market at the time of writing, and that yard configurations and operations vary significantly between transit agencies. The report provided an example of more efficient parking configurations enabled through automation, shown in **Figures A1 and A2** below.

Figures A1 and A2. Example of depot realignment through use of bus automation, with current conditions (*left*) and potential efficient re-configuration of the same rolling stock (*right*). (Courtesy of FTA's Strategic Automation Research Plan)

Teleoperations

Most yard automation benefits do not actually require full automation of the buses, with teleoperations technology offering similar capabilities. Teleoperations is the use of telecommunications technology to either remote-control a vehicle in real time (telepresence) or map a precise route for the vehicle, with automation managing maneuvers (path planning). In both cases, vehicles require the same drive-by-wire capabilities that a fully-automated bus would but may not require the same extensive sensor architecture and sophisticated automation software. Some states, notably Florida and California, have legislated that all automated vehicles operated on public roads must have teleoperations capabilities in the event an automated driving system cannot safely perform a driving task without human intervention.

Freight and logistics firms are currently piloting the use of teleoperations technology in yard settings to reduce labor costs. Rather than employing runners to move vehicles between the yard entrance, loading bays, and parking spaces, firms would instead use remote teleoperators to maneuver vehicles at low speeds (below 25 miles per hour) around the facilities. These remote operators can activate any authorized vehicle, allowing them to achieve roughly the same efficiencies as complete yard automation with limited labor costs. For instance, what might have previously required five full-time employees may only require two or three. Though this does not achieve the same potential cost reductions as complete automation, it is likely more realistic in the short- to medium-term due to significantly lower development requirements.

The hardware is available today, and both 3G and 4G networks are capable of supporting latency requirements. However, current barriers for transit bus integration include electric drivelines with drive-by-wire capabilities, and accepted protocols for managing cybersecurity concerns.

Testing Facility Requirements

As part of the STAR plan, FTA released a report detailing requirements for automated transit vehicle testing, including all on-road vehicle platforms. It lists all imagined required scenarios for transit vehicles, and accounts for test facility features, functionality and performance, safety, environmental resilience, human factors, and data collection and management. The report envisions testing for the following high-level scenarios:

- Transit Bus Advanced Driver Assistance Systems
    - Smooth Acceleration and Deceleration
    - Automatic Emergency Braking and Pedestrian Collision Avoidance
    - Curb Avoidance
    - Precision Docking
    - Narrow Lane/Shoulder Operations
    - Platooning
- Automated Shuttles
    - Circulator Bus Service
    - Feeder Bus Service
- Maintenance, Yard, Parking Operations
    - Precision Movement for Fueling, Service Bays, and Bus Wash

    - Automated Parking and Recall
- Mobility-on-Demand Service
    - Automated First/Last Mile
    - Automated Americans with Disabilities Act (ADA) Paratransit
    - On-Demand Shared Ride
- Automated Bus Rapid Transit

Though FTA has not designated any bus test center(s) for ADS technology, any future test centers should be designed to accommodate the FTA's priorities detailed in its test facilities report.

Federal Funding

FTA published its STAR plan in early 2018, outlining a program of research and demonstration projects. Though it has completed and published several of these research reports, the agency is more than a year behind its target schedule. To date, none of the demonstration projects have been awarded, despite plans to do so in FY18 and FY19. Through its Integrated Mobility Innovation (IMI) program, FTA allocated $5 million for two demonstration projects in FY19: $2 million for low speed automated shuttles, and $3 million for advanced driver assistance systems (ADAS). Per its FY20 budget request and federal appropriations, FTA has not indicated plans to open additional grant opportunities for transit automation in this fiscal year.

The Federal Highway Administration (FHWA) awarded $60 million across eight projects for its Automated Driving Systems Demonstration grants program in 2019. Though several projects included automated low speed shuttles and light vehicles for rural and paratransit service, none of the seven projects proposing transit bus automation were awarded. FWHA has not publicly indicated whether it will launch a second round of the ADS Demonstration grants program in FY20.

Outside of FTA's research budget, there are currently no other programs offering significant public resources for research and development of full-sized transit bus automation.

Commercialization Status

Though several transit bus manufacturers have invested small amounts in ADS development to date, these investments are a tiny fraction of the tens of billions of dollars automakers and venture-backed firms have spent on other vehicle platforms. Low speed automated shuttle developers, such as Navya, EasyMile, May Mobility, Local Motors, and Optimus Ride, have drawn tens of millions of dollars in investments, and have been able to generate significant revenues through state- and city-led pilot projects. Some federal grants have funded shuttle projects for last-mile connectivity as well. Even with this degree of development, those vehicles have not demonstrated a near-term path to commercial viability.

Though full-sized transit buses have made less progress to date, they do not require the same degree of development for integration of useful features. Rather than aiming for SAE Level 4 or 5 automation and removal of human operators, which does not appear feasible at scale for possibly a decade or more, transit agencies should prioritize specific use cases

for automation. Bus rapid transit (BRT) systems in separated guideways, yard operations with lower operational complexity, and specific on-road capabilities are more feasible in the short- to medium-term, require significant lower development costs, and can produce quantifiable benefits.

Outside cost and ADS software capabilities, one of the more significant barriers to scalable transit bus automation is immaturity of electric driveline systems for these vehicles. FTA highlighted this challenge in its "market assessment" and "transferability of technology" STAR plan research reports. Standard bus drivetrain components simply are not conducive to automation and integrating drive-by-wire capabilities require expensive workarounds. Since drive-by-wire is foundational for any automation use case, the transit bus industry needs to focus greater attention on developing those capabilities.

Transit buses led the automotive industry on development of battery electric and hydrogen fuel cell technologies, but significantly lags behind the light passenger and medium- and heavy-duty trucking industries. Though this may mean a longer path to commercialization, the transit bus industry will reap the benefit of lower costs for ADS components, specifically sensors and highly-precise positioning systems. Manufacturers can also partner (and have partnered) with existing ADS technology developers to port their technology from other vehicle platforms to buses. Additional configuration is necessary, but much of the software development is transferable.

Research and Development Priorities

The National Advanced Technology Transit Vehicle Advisory Panel should consider which strategies for advancing ADS technology on transit buses will be most effective, especially considering federal funding is likely to be sporadic and limited for the foreseeable future. Though increased funding would allow manufacturers, technology developers, and agencies to accelerate ADS commercialization, that is not the status quo. The panel should consider the following potential recommendations for transit bus automation:

- Identify which automation use cases are most feasible and which development is likely to deliver industry-wide benefits in the near-term. Once identified, ask FTA to reprioritize research and demonstration programs along those priorities.
- Support funding research that assesses how ADS can support ZEB procurement and operations. Once benefits are quantified, development funding may be easier to justify.
- Emphasize development of bus subsystems, particular steering and braking systems, that will ultimately accelerate the path of ADS development and adoption
- Organize other non-federal resources to support more limited development objectives
- Prioritize test center development per FTA-identified interests
- Build partnerships with other USDOT administrations to develop testing requirements (i.e. NHSTA, ITS-JPO) and certifications (i.e. safety, ADA) for automated transit solutions

- Build a long-term consortia structure similar to that of the National Fuel Cell Bus Program that progressively addresses transit automation with a focus on achievable development objectives
- Seek partnerships with other USDOT administrations on mutual ADS development interests (e.g. FAA for airport ground transportation, FMCSA for heavy-duty platforms), to share resources and accelerate development

Transit Legislation, Grants, and Budget Review

Overview

FTA offers multiple discretionary grant funding opportunities to state and local transit authorities each year for deployment of new vehicles and development of emerging technologies. However, only a relatively small share of overall appropriations funding programs supports ZEB development and deployment. Effectively leveraging these capital resources is important for continued growth and development of the ZEB market.

FAST Act

The Fixing America's Surface Transportation Act (FAST Act) has served as the federal funding authorization for surface transportation since its passage in 2015 and will lapse at the end of FY20. FTA administers a number of grant programs directly authorized by the FAST Act of particular interest to the TVIDC panel's objectives, including Sections 5312, 5314, and 5318, and 5339 under Title 49 USC Chapter 53 (PUBLIC TRANSPORTATION). These sections emphasize research, testing, and procurement of transit infrastructure, alternative fuel systems, zero-emission buses, and transit workforce development.

Historic FAST Act Funding Amounts

The FAST Act has steadily increased annual funding levels for FTA programs over the past five years, rising to $10.15 billion for FY20. The yearly amounts are detailed in **Table A6** below, totaling $48.904 billion over the legislation's 5-year term.

Table A6. FAST Act FTA Funding Authorized By Fiscal Year

FY16	FY17	FY18	FY19	FY20	Five Year Total
$9.348 billion	$9.734 billion	$9.733 billion	$9.939 billion	**$10.150 billion**	$48.904 billion

Transportation Statutes & Funding Opportunities

Multiple FTA programs directly impact transit innovation, buses and supporting facilities, bus and bus component testing, and transit workforce development. Several programs funded under the Federal Highway Administration (FHWA) have also supported transit bus development and deployment. These statutes and programs are explained in detail below and summarized in Table 8. The funding amounts for the various programs are detailed in Table 9.

§5312: Public Transportation Innovation

"(a) In General. —The Secretary shall provide assistance for projects and activities to advance innovative public transportation research and development in accordance with the requirements of this section."

This statute provides funding for research projects that advance the state of technology in public transit. Activities and programs funded by §5312 include research of alternative fuels, driver assistance systems, automation, and other technologies. §5312(i) also stipulates that $5 million, of the authorized $28 million in annual funding for §5312, be allocated for the Transit Cooperative Research Program (TCRP).

5312(h) provides funding for the development and testing of low or no emission bus components, the aforementioned LowNo-CAP program. Since 2016, the FAST Act has authorized funding for this component testing section at an annual rate of $3 million through FY20. Congress provided additional appropriated funding for FY's 18, 19, and 20 ($2 million, $6 million, and $3 million respectively). Since 2016, FTA and congressional appropriations have provided $23 million for this testing program. The funds are split between Ohio State and Auburn. Recent funding amounts are shown in **Table 1** above.

Of the total $10.2 billion set aside for formula grants in the FY20 budget, $28 million is specifically allocated to this program, accounting for about 0.3% of total formula grant disbursements.

§5314: Technical Assistance and Workforce Development

"(a) In general. —The Secretary may make grants and enter into contracts, cooperative agreements, and other agreement…to carry out activities that the Secretary determines will assist recipients of assistance under this chapter to—

> *(i) more effectively and efficiently provide public transportation service;*
> *(ii) administer funds received under this chapter in compliance with Federal law;*
> *(iii) improve public transportation."*

The programs and initiatives funded under §5314 provide training, education, and work placement opportunities for transit system employees, managers, and stakeholders. The statute also includes funding for the National Transit Institute, housed at Rutgers University. Of the total $10.2 billion for formula grants in the FY20 budget, $14 million is allocated to §5314, totaling making up about 0.15% of total formula grant disbursements.

§5318: Bus Testing Facility

"(a)Facility. —The Secretary shall maintain one facility for testing a new bus model for maintainability, reliability, safety, performance (including braking performance), structural integrity, fuel economy, emissions, and noise."

This statute is responsible for maintaining the Bus Testing Facility in Altoona, Pennsylvania. The FAST Act authorizes $3 million per fiscal year for all activities and upkeep at the facility. The amount set aside for the Altoona facility constitutes 0.03% of all FTA formula grant funding. Funding levels for Section 5318 have remained constant since 1998.

§5339: Bus and Bus Facilities Grants

"(2) General authority. —The Secretary may make grants under this subsection to assist eligible recipients … in financing capital projects—

(A) to replace, rehabilitate, and purchase buses and related equipment, including technological changes or innovations to modify low or no emission vehicles or facilities

(B) to construct bus-related facilities."

The FY20 budget authorizes $808 million (via the FAST Act) for the Bus and Bus Facilities grant programs, making up about 8% of all authorized FTA formula grant funds. The Congressional appropriations process provides additional funding for specific grant programs. This funding is used for the upkeep and improvement of bus fleets, and is divided into three subsections: formula grants, competitive grants, and a separate competitive grant program dedicated to the procurement of reduced and zero-emission vehicles.

§5339(a): Formula Grants

These grants are awarded annually in accordance with a designated formula, in this case, a set amount apportioned to all 50 states, and all US Territories. The states may then allocate this money directly or to subrecipients (transit agencies, nonprofits working in public transportation, etc.). In FY20, the FAST Act authorizes $464.6 million, with Congressional appropriations allocating an additional $168 million, for a total of $632.6 million for §5339(a).

§5339(b): Competitive Grants

Under this subsection, competitive grants are awarded based on FTA's assessment of the age and condition of buses, bus fleets, and any related equipment or infrastructure. These grants may be awarded to states, or to any eligible recipient that applies for funding. The award amounts are based on the necessity of upgrades, as determined by FTA. There is not a set amount awarded to every state, and no award may be greater than 10% of all funds made available by this subsection.

§5339(c): Low-No Program

The Low or No Emissions Vehicle Grant Program (Low-No) was specifically created to provide funding to projects focused on the development and implementation of low or zero-emission transit bus technologies. The FAST Act authorized $55 million dollars annually to fund Low-No. Additional funding is added to this base amount via Congressional appropriations. Since its authorization in FY16, the Low-No Program has provided nearly $280 million in capital resources to public and private institutions for the purchase of low or no emissions vehicles.

For FY20, Congress appropriated the program $75 million, accounting for 18% of funds appropriated to the Bus and Bus Facilities program this year. Overall, Low-No receives approximately 10.6% of all funding (authorized and appropriated) allocated for Bus and Bus Facilities grants.

Federal Highway Administration (FHWA) Discretionary Programs

The FHWA administers a number of discretionary funding programs with resources provided from the USDOT's discretionary funding. While not specifically earmarked for ZEB procurement, the funds may be used for zero-emission transit infrastructure development, and innovation of clean, efficient, transit technologies.

USDOT: BUILD (TIGER) Discretionary Grants

The "Consolidated Appropriations Act, 2020" appropriated $1 billion to be awarded by the USDOT for infrastructure investments. This appropriation stems from the "Transportation Investment Generating Economic Recovery" (TIGER) grants program funded and implemented pursuant to the American Recovery and Reinvestment Act of 2009. The Trump Administration rebranded the grant program as the "Better Utilizing Investments to Leverage Development" (BUILD) Discretionary Transportation Grants program. The FY19 BUILD Transportation grants were awarded in November for the funding of surface transportation infrastructure projects expected to have significant local or regional impact.

Two projects funded by BUILD 2019 specifically allocated money for the procurement and deployment of zero-emission buses:

- **Antelope Valley Transit Authority, Lancaster CA:** Purchasing eight 40-foot and twelve 30-foot zero-emission battery electric buses.
- **Memphis Area Transit Authority, Memphis TN:** Construction of a bus rapid transit line, with nine zero-emission battery electric buses.

Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD)

The ATCMTD program specifically provides funding for technological innovations to improve transit systems. While they have not previously been used for the deployment of full-size zero emission transit buses, the funding may be used for projects that utilize innovative technologies to improve transportation management systems and infrastructure. Multiple awards have funded low speed automated shuttle projects for transit uses in previous years. The ATCMTD program funds projects focused on improving safety, efficiency, system performance, and infrastructure return on investment. The FAST Act authorizes $60 million each year for ATCMTD from FY16 through FY20.

Automated Driving Systems (ADS) Demonstration Grants

USDOT announced the ADS Demonstration Grants program in December 2018 to support the development and implementation of automated driving systems for on-road transportation applications.

A total of 73 universities, transit authorities, state departments of transportation, municipalities, and other government organizations submitted applications in 2019 for ADS grants. The round of awards provided $60 million in funding to 8 grantees. Details are listed in **Table A7** below. As with ATCMTD, FHWA administers the program, but it does not have annually recurring authorized funding. Therefore, as of December 2019, we still do not know whether FWHA intends to fund a second round.

Table A7. ADS Grant Awards and Amounts

Grantee	Award Amount
Texas A&M Engineering Experiment Station	$7,063,787
University of Iowa	$7,026,769
Virginia Tech (Safety Demonstration)	$7,500,000
Virginia Tech (Trucking Fleets)	$7,500,000
Ohio DOT	$7,500,000
Pennsylvania DOT	$8,409,444
City of Detroit, MI	$7,500,000
Contra Costa Transportation Authority, CA	$7,500,000
TOTAL	**$60,000,000**

Table A8. Transit Statutes and Funding Programs Summaries

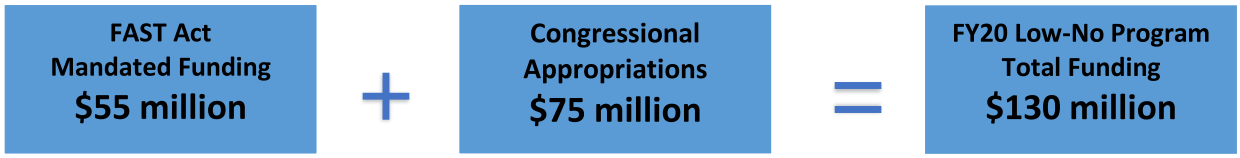
Statute	Title	Summary
§5312	Public Transportation Innovation	Provides funding for research, development, testing, and deployment of new transit technologies. Also provides funding for the Transit Cooperative Research Program (TCRP)
§5314	Technical Assistance and Workplace Development	Grants and programs to create employment opportunities, training programs, and funds the National Transit Institute
§5318	Bus Testing Facilities	Funds Federal Bus Testing at Penn State's Altoona, PA facility
§5339(a)	Bus and Bus Facilities: Formula Grants	Provides consistent funding to state governments based on legislative formulas. In turn, states allocate to grant applicants
§5339(b)	Bus and Bus Facilities: Competitive Grants	These are competitive grants, awarded under consideration of bus fleet size, age, condition
§5339(c)	Bus and Bus Facilities: Lo-No Program	Provides funding for the procurement of low or no emission buses, and supporting infrastructure
---	BUILD (TIGER)	Funds appropriated by Congress via the National Transportation Investment Trust. Awarded by USDOT to 50+ transit projects, including zero-emission technologies and vehicles
---	ATCMTD	Funds authorized for competitive grants by the FAST Act. Awarded to 10 state and local DOTs and research institutions for advanced transportation technology programs for FY18.

Current Legislative and Budgetary Situation

Lo-No Funding Levels: FY20

During the FY20 appropriations process, the FTA requested an additional $30 million in discretionary supplemental funds for Low-No. The House version of the FY20 appropriations bill proposed $102 million in additional funding, with the corresponding

Senate version proposing a $40 million supplement. After conference, Congress settled on $75 million in appropriated funding for Low-No, bringing the FY20 total funding level to $130 million. While the overall discretionary budget for USDOT, FTA, and a number of the grant programs under their direction have seen a decline in discretionary supplemental funding, the Low-No program saw an increase of $45 million over FY19 budget levels.



This increase ($85 million in FY19 and FY18) provides greater available resources for the acquisition of low or zero-emission transit vehicles. New program rules per the FY20 appropriations legislation require a minimum of $750,000 for each grant awards. A set award floor ensures that awards to a single agency provide enough funding to procure and deploy their zero-emission buses. Continued federal support for procurement of low and zero-emission vehicles will also drive down manufacturing and purchasing costs, as economy of scale thresholds are reached.

Table A9: Transit Statutes and Funding Programs: FY19 and FY20 Budget Review

Statute	Title	FAST Act Authorized FY20	FY19 Amt.*	FY20 Amt.*
§5312	Public Transportation Innovation	$28 million	$28 million	$33 million
§5314	Technical Assistance and Workplace Development	$9 million	$14 million	$14 million
§5318	Bus Testing Facilities	$3 million	$10 million	$6 million
§5339(a)	Bus and Bus Facilities: Formula Grants	$464 million	$610 million	$632 million
§5339(b)	Bus and Bus Facilities: Competitive Grants	$289 million	$423 million	$459 million
§5339(c)	Bus and Bus Facilities: Lo-No Program	$55 million	$85 million	$130 million
---	BUILD (TIGER)	---	$900 million	$1 billion

** Amounts include pre-authorized funds, and* Congressionally appropriated funds.

FY20 Federal Budget & Appropriations

The FTA submitted its FY20 Budget Proposal in April 2019, after receiving a draft budget developed by the White House. FTA requested a total combined budget of $12.4 billion in for FY20. Within that amount is $10.2 billion for the funding of transit formula grants. This amount is the authorized level stipulated in the FAST Act and provides the funding for FTA's formula grant programs. Accordingly, the Senate held a vote and passed the "Bipartisan Budget Act 2019," increasing the cap on discretionary funding for both defense and non-defense programs.

The president signed that authorization act into law on August 2, 2019. Congress appropriated an additional $510 million to be used for FTA formula grant programs.

Funding for FTA's FY20 budget was included in H.R.1865 - Further Consolidated Appropriations Act, 2020. This act was signed into law by the president on December 20, 2019.

Spare Ratio for Transit Buses

Overview

Though not governed by a formal statute or regulation, FTA has recommended a "spare ratio" to transit agencies for nearly three decades that sets aside a percentage of their total fleet count as reserve rolling stock. FTA has consistently implemented its recommendations via guidance circulars and grant management procedures.

Spare Ratio and Zero-Emission Buses

The major concern with regard to zero-emission bus procurement is that, currently, zero-emission buses cannot effectively replace traditionally fueled buses at a 1:1 ratio. In many situations, more than one zero-emission bus would be required to meet the service needs of a specific route without any potential lapses in service. This discrepancy varies from case to case, and stems from individual bus technology, range limitations, fueling needs, and the numerous environmental demands for each specific transit route. Zero-emission bus technology is rapidly improving, but in the practical process of planning, procuring, and implementing these buses, a transit agency cannot assume a 1:1 replacement ratio. As a result, this complicates the calculation of fleet spare ratio requirements as new zero-emission buses are added to a transit fleet.

Research focusing specifically on this discrepancy, and the resulting ramifications for maintaining fleet spare ratio, is limited. Some spare ratio analyses have tangentially touched on zero-emission buses in transit fleets, but mainly include them to estimate and evaluate overall fleet diversity. With so few zero-emission buses operating in the US public transit fleet, and their relatively recent introduction into revenue service, there is a distinct lack of data available to analyze spare ratio specific to zero-emission buses.

Understanding the existing FTA recommended spare ratio, how it is applied to fleets, the potential exemptions, and the numerous variables at play in assessing an efficient spare ratio, can provide a base from which an effective strategy may be developed to reconcile zero-emission bus deployments and maintaining an efficient spare ratio.

Definition and Policy

The official FTA definition of the spare ratio is: *"The total number of spare vehicles available for fixed route service (regardless of type), divided by the total number of fixed route vehicles available for annual maximum service (regardless of type)."*

Spare Ratio = [VAMS – VOMS] / VOMS
VAMS = Vehicles Available for Maximum Service (Total Active Bus Fleet)
VOMS = Vehicles Operated in Maximum Service

The ratio is only applied to fleets of a certain size, detailed below in **Table A10**.

Table A10. Fleet Size and Spare Ratio

Fleet Size	Spare Ratio (%)
Greater than 50 Buses in Revenue Service	FTA recommends that a transit authority not exceed a spare ratio of **20%** of the total number of buses in revenue service
Fewer than 50 Buses in Revenue Service	No FTA mandated spare ratio

Exemptions

Some exceptions are not included in the total fleet count used to calculate FTA's recommended spare ratio. **Table A11** lists these specific situations and bus types that are exempt from the total fleet count.

Table A11. Exemptions From Spare Ratio Fleet Count

Bus Type	Exempt from Spare Ratio Count?
Bus Fleet operating < 50 Buses	**Yes** – small bus fleets are not required to maintain a set spare ratio
Contingency Fleet Buses	**Yes** – contingency fleets are comprised of buses that have reached the end of their service life, but are still operational
Newly Acquired Buses	**Yes*** - under certain circumstances, newly acquired buses may be exempt from spare ratio calculations
Alternate Fuel & Zero-Emission Buses	**No** – there are currently no exemptions for specific types of buses, including those powered by alternative fuels, or zero-emission powertrain

** If an agency has recently acquired new transit buses and has established a plan to retire currently active buses into spare ratio service, or to a contingency fleet, then that agency may receive a spare ratio waiver for up to two years, with written approval from the corresponding FTA regional administrator.*

FTA currently provides no spare ratio exception or special consideration for zero-emission or alternative fuel buses. Regardless of powertrain, all active service buses are added to the fleet count used to calculate spare ratio. This fails to account for the spare ratio discrepancy between zero-emission buses and their traditionally fueled counterparts. An exemption for early adopters of zero-emission buses would protect those agencies from negative impacts associated with an inflated spare ratio.

Application and Effects of Spare Ratio

Table A12 below provides a breakdown of not meeting, maintaining, or exceeding the set spare ratio percentage.

Table A12. Effects of Not Meeting or Meeting FTA's Recommended Spare Ratio

Below Spare Ratio	Meets Spare Ratio	Exceeds Spare Ratio
Risk inability to meet unexpected adjustments to service requirements Inability to maintain level of service negatively affects customers	Achieves equilibrium that maximizes the utility of the spare fleet, and avoids unnecessary costs associated with extra buses	Maintaining a number of buses greater than that necessary to meet all adjustments to regular service requirements results in excessive O&M costs

In each FTA grant application, transit agencies are required to provide breakdowns of their current spare ratio levels and estimated changes should they procure additional buses with award funding. FTA maintains that while a 20% spare ratio is the goal, it accounts for local circumstances and works with individual transit agencies to maintain compliance with the recommended percentage.

This policy provides flexibility in FTA's decision making and avoids the need for spare ratio waivers or variances. Non-compliance with the recommended 20% spare ratio is not alone a disqualifying factor in FTA's decision-making process, i.e. FTA will not deny a grant application solely because the 20% ratio has not been maintained. However, it can factor into grant competitiveness or total award amounts.

Any bus that has reached the end of its service life, but is still operational, may be added to an agency's "contingency fleet". Contingency fleets are comprised of older buses and must be accounted for in an agency's contingency plan. These buses are not kept for the purpose of meeting regular service requirements but are instead for emergency purposes (disaster relief/evacuation).

Variables Impacting Spare Ratio

The following is a list of variables that have a marked influence on maintaining an appropriate spare ratio:

- **Age of fleet** – Lower average fleet age results in reduced maintenance costs
- **Size of fleet** – Larger fleets may have access to greater financial resources that can be used to maintain the 20% spare ratio, as opposed to smaller fleet
- **Fleet mix** – Maintaining the spare ratio of a fleet with greater complexity in fuel type, drivetrain, passenger capacity, vehicle function, etc. may result in additional challenges
- **Location** – Urban, suburban, rural
- **Route characteristics** – Length, grade, number of stops, speed of travel, etc.
- **Ambient climate** – extreme heat and cold, rain, snow, and ice all have an impact on fleet performance (especially for zero-emission bus performance)
- **Technological sophistication** – Better technology improves performance, but also requires additional maintenance. Zero-emission buses have an advantage in this area in that their drivetrains and supporting systems are require fewer parts and are easier to maintain than those of internal combustion engines

- **Alternative fuels** – Various fuel types have different requirements, benefits, and drawbacks when calculating a spare ratio sufficient to maintain the expected level of service. While zero-emission buses can reduce energy costs, their charging infrastructure and charging and refueling schedules, and fluctuating fuel and energy costs could complicate their integration into existing fleet plans
- **Sub-fleets service requirements** – Seasonal fleets, special use fleets, and other service types outside of regular revenue service may require spares with special characteristics that are required to meet that service
- **Maintenance Programs and Training** – the number of available mechanics, and their level of training with specific bus types

Potential Spare Ratio Solutions to Accommodate ZEBs

Additional research, outreach and education, and implementation guidelines for accommodating ZEBs in spare ratio requirements would inform better policies that meet the needs of transit agency bus fleets.

Table A13 details broad areas of focus, important to the uptake of zero-emission buses, and corresponding strategies to promote a more effective utilization of spare ratio.

Table A13. Areas of Focus & Spare Ratio Recommendations

Areas of Focus	Spare Ratio Recommendations
Prototype Development & Demonstration	Flexibility in Funding: Accelerated development and demonstration results in expedited deployment of buses carrying state-of-the-art technologies.
Supporting Early Adopters	A spare ratio change or outright exemption for zero-emission buses reduces risks of procuring those vehicles by reducing impacts on federal grant competitiveness.
Fleet Transition Planning	Understanding spare ratio implications for zero-emission vehicles is an important consideration when planning fleet transitions
Additional Research	FTA currently has no frame of reference for adjusting spare ratio requirements to address zero-emission bus adoption. Additional research

Appendix B: TVIDC Panel Working Groups

At the Chicago meeting, CTE asked panelists to volunteer for a working group in at least one of the five TVIDC advisory panel focus areas. CTE followed up with panelists who were unable to attend the Chicago meeting. Most panelists selected multiple working groups, and either they or delegates attended these virtual meetings.

March 2, 2020 – Utilities Collaboration Working Group

Organization	Participant Name	Position
San Diego MTS	Mike Wygant	COO
San Diego MTS	Kyle Whatley	ZEB Project Specialist
Lextran	Matt Winkler	Planning Coordinator
Broward County Transit	Cindy Corbett-Elder	Assistant to the Director of the Department of Transportation and Director of the Transit Division
MARTA	Collie Greenwood	Chief of Bus Operations
Denver RTD	Michael Ford	COO
Mountain Line	Corey Aldridge	General Manager
CTA	Jason House	Senior Project Manager, Vehicle Engineering
CTA	Islam Youssef	Chief Bus Equipment Engineer
Proterra	John Walsh	Senior Vice President, Sales
New Flyer	David Warren	Director, Sustainable Transportation
GILLIG	Richard Bissell	Product Planning Manager
Auburn	Christian Brodbeck	Research Engineer
Ohio State	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
CTE	Nathaniel Horadam	Managing Consultant
CTE	Jason Hanlin	Director, Technology Development
CTE	Amy Posner	Managing Consultant
CALSTART	Bryan Lee	Project Manager
APTA	Lisa Jerram	Director – Bus Programs & Emerging Vehicle Technologies

March 4, 2020 – Transit Bus Automation Working Group

Organization	Participant Name	Position
CTDOT	Dennis Solensky	Public Transit Administrator
CTDOT	Eric Dorsey	Transportation Planner
San Diego MTS	Kyle Whatley	ZEB Project Specialist
Lextran	Carrie Butler	CEO
Broward County Transit	Arethia Douglas	Expansion Project Administrator
Broward County Transit	Lena Kulikowski	Transit Innovation Program Administrator
MARTA	Collie Greenwood	Chief of Bus Operations
Denver RTD	Michael Ford	COO
Mountain Line	Corey Aldridge	General Manager
CTA	Jason House	Senior Project Manager, Vehicle Engineering
New Flyer	David Warren	Director, Sustainable Transportation
GILLIG	Ben Grunat	Director, Product Planning & Strategy
Auburn	Christian Brodbeck	Research Engineer
Ohio State	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State	David Klinikowski	Director, Center for Bus Research and Testing
CTE	Nathaniel Horadam	Managing Consultant
CTE	Jason Hanlin	Director, Technology Development
CALSTART	Bryan Lee	Project Manager
APTA	Jeff Hiott	Vice President – Technical Services and Innovation

March 26, 2020 – ZEB Workforce Development Working Group

Organization	Participant Name	Position
MARTA	Jeffrey Parker	CEO/GM
MARTA	Collie Greenwood	Chief of Bus Operations
San Diego MTS	Mike Wygant	COO
SunLine	Lauren Skiver	General Manager
SunLine	Brittney Sowell	Chief of Public Affairs/Clerk of the Board
SARTA	Kirt Conrad	CEO
LA Metro	Jesus Montes	Sr. Executive Officer, Vehicle Acquisition
AC Transit	Salvador Llamas	COO
New Flyer	David Warren	Director, Sustainable Transportation
Proterra	John Walsh	Senior Vice President, Sales
Ohio State	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State	David Klinikowski	Director, Center for Bus Research and Testing
CTE	Dan Raudebaugh	Executive Director
CTE	Nathaniel Horadam	Managing Consultant
CTE	Lauren Justice	Development Director
CALSTART	Bryan Lee	Project Manager

March 27, 2020 – Bus Testing Centers Working Group

Organization	Participant Name	Position
LA Metro	Jesus Montes	Sr. Executive Officer, Vehicle Acquisition
LA Metro	Marc Manning	Senior Director, Vehicle Engineering & Acquisition
New Flyer	David Warren	Director, Sustainable Transportation
Proterra	John Walsh	Senior Vice President, Sales
GILLIG	Ben Grunat	Director, Product Planning & Strategy
GILLIG	Richard Bissell	Product Planning Manager
Auburn	Mark Hoffman	Assistant Professor
Ohio State	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State	David Klinikowski	Director, Center for Bus Research and Testing
CTE	Dan Raudebaugh	Executive Director
CTE	Nathaniel Horadam	Managing Consultant
CALSTART	Fred Silver	Vice President
CALSTART	Bryan Lee	Project Manager

March 30, 2020 – ZEB Innovation Research Working Group

Organization	Participant Name	Position
CTA	Jason House	Senior Project Manager, Vehicle Engineering
LA Metro	Marc Manning	Senior Director, Vehicle Engineering & Acquisition
SunLine	Lauren Skiver	GM
Mountain Line	Corey Aldridge	GM
New Flyer	David Warren	Director, Sustainable Transportation
BYD	Jason Yan	Senior Vice President, Sales
CTE	Jason Hanlin	Director, Technology Development
CTE	Nathaniel Horadam	Managing Consultant
Auburn	Mark Hoffman	Assistant Professor
Ohio State	Walt Dudek	Director – Commercial Vehicle Research and Test Laboratory
Penn State	David Klinikowski	Director, Center for Bus Research and Testing
CALSTART	Bryan Lee	Project Manager

Appendix C: Suggested Division of Roles and Responsibilities for Bus Testing Centers

Prior to the first panel meeting in Los Angeles, CTE, CALSTART, Auburn University, Ohio State University, and Penn State-Altoona held a call to discuss all current and future bus testing requirements. With input from the panel at the Los Angeles meeting, all five organizations held additional calls to discuss allocation of roles and responsibilities for those testing requirements. This division of roles and responsibilities accounted for federal requirements and limitations, current facilities and other resources, and planned investments and programming at each of the three bus testing centers. At the second panel meeting in Chicago, and in the subsequent working group meeting for Bus Testing Centers, the panel confirmed the following recommended division of responsibilities:

- Penn State is designated the primary bus test center for full bus confirmation testing and the sole test center for non-Low-No bus models. Penn State has the facilities and capacity in place to continue to support the bus test program, including the testing of low and no emissions buses.
    - Ohio State is designated as the secondary facility for full Low-No bus confirmation testing. Ohio State will complete facility upgrades and provide full bus testing following FTA direction on the coordination of test activities and work flow with Penn State. Ohio State requests to be directed 2 or more full bus tests per year at a minimum to keep the program operational and in compliance.
    - The panel was unable to determine the precise assignment of zero-emission buses between Penn State and Ohio State (i.e. who gets battery electric vs. hydrogen fuel cell electric, including infrastructure).
- Ohio State/TRC is designated the primary FTA testing center for bus automation, connectivity, and driver assistance systems. Ohio State/TRC has the sole responsibility to develop future bus test automation and ADAS protocols for FTA. Ohio State's facility/program design will draw from previous FTA/Volpe research on automated bus testing facility capabilities.
    - Penn State and Auburn are designated as secondary facilities for automated vehicle and ADAS testing. Penn State will incorporate the facilities and equipment required for the newly developing test protocols into its new test track facility.
- Penn State is designated the primary test center for battery electric bus charging infrastructure and interface testing.
    - Ohio State is designated the secondary test center for battery electric bus charging infrastructure and interface testing.

- Auburn is designated the primary FTA testing center for cybersecurity. Auburn has the sole responsibility to develop future cybersecurity bus test protocols for FTA.
    - Ohio State is designated as the secondary facility for cybersecurity testing. Ohio State will incorporate the facilities and equipment required for the newly developing test protocols into their facility.
- Ohio State is designated the primary individual components testing center.
    - Auburn is designated the secondary individual component testing center.
    - *Penn State is ineligible to perform this role.*
- Auburn is designated the primary full bus level climatic chamber component testing center, including testing of bus ventilation systems to mitigate the spread of pathogens.[i]

[i] Due to investments made prior to the COVID-19 pandemic, Auburn is uniquely positioned to test bus HVAC/ventilation systems for reduced virus transport within the cabin, with multiple potential means of doing so:

- Auburn has soot particulate quantification equipment, which enables the utilization of appropriately-sized soot particulates to study transport phenomena within the cabin. However, the university is currently unable to simultaneously sample multiple cabin locations, and the validity of using soot particulates as a virus allegory remains an open question
- Auburn has the in-house expertise to create a non-proliferating virus that mimics SARS-CoV-2. Capital investment for appropriate bioaerosol samplers and nebulizers would be necessary, but the manpower and know how are already present. The capability to produce non-proliferating, efficacious encapsulated viruses is uncommon, and Auburn researchers have multiple human clinical trials doing so.

Auburn's design team is currently sourcing the appropriate equipment for the viral studies. This includes data acquisition equipment to be located within the bus so there are no cables interfering with doors/windows and changing the ventilation characteristics. These tests would not need to wait for the proposed facility to be built out. Ultimately, results from these precompetitive, systematic studies would generate insights and inform recommendations for transit bus air turnover rate, ventilation design, cabin temperature, and filtration techniques to minimize the health risk to all transit bus passengers and operators.

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