FTA Report No. 0266

National Bus Rapid Transit Institute (NBRTI) Program Report

PREPARED BY
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U.S. Department of Transportation
Federal Transit Administration

AUGUST 2024

COVER PHOTO

Victoria Perk – Center for Urban Transportation Research (CUTR)

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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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Abstract

This report documents the activities of the National Bus Rapid Transit Institute (NBRTI), from its inception in January 2001 to June 2024 (the final year of the program grant). The NBRTI program is housed at the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF). The federal grant was received through the United States Department of Transportation's Federal Transit Administration (FTA). The Institute was charged with creating a national program for training, technical assistance, research, innovation, and evaluation of existing and proposed bus rapid transit (BRT) projects. This program report summarizes all of the NBRTI activities and includes two appendices documenting additional short research efforts.

Executive Summary

This report documents the activities of the National Bus Rapid Transit Institute (NBRTI), from its inception in January 2001 to June 2024 (the final year of the program grant). The NBRTI program is housed at the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF). The federal grant was received through the United States Department of Transportation's Federal Transit Administration (FTA). The Institute was charged with creating a national program for training, technical assistance, research, innovation, and evaluation of existing and proposed bus rapid transit (BRT) projects. This program report summarizes all of the NBRTI activities and includes two appendices documenting additional short research efforts.

In less than two decades, BRT has progressed from a little-known innovation to one of the fastest growing transit modes in the nation. The potential for swift and cost-effective implementation makes BRT an attractive option for cities contending with increasing traffic congestion and constrained budgets for public transportation. Today, BRT is operating or in development in most major cities and is a modal alternative in nearly every planning study. The rise of BRT in the United States traces its roots back to several early initiatives by FTA. Inspired by the impressive performance and cost-effectiveness of successful BRT systems in Latin America, FTA created a BRT Demonstration Program in 1998, partnering with several competitively selected transit agencies for the implementation, operation, and evaluation of BRT projects. As the need for a practical resource quickly arose within the emerging BRT community in the United States, FTA in January 2001 sponsored the NBRTI, a program of research, innovation, training, and technical assistance in the field of BRT.

Through numerous research studies, decision tools, technology demonstrations, and evaluations, NBRTI helped to forge key industry relationships, catalyzed crucial early milestones such as the development of consensus-based standards, and produced a foundational body of knowledge for the advancement of BRT. These activities are summarized in this program report. Ultimately, FTA’s early BRT initiatives, along with the Small Starts and Very Small Starts federal funding programs, ushered in a national BRT boom that began in the early 2000s and continued throughout the decade, including projects in Los Angeles; Boston; Oakland, California; Las Vegas; Kansas City, Missouri; Eugene, Oregon; and Cleveland. Several of these forerunners were particularly innovative and emerged as models of success.

Demonstrations and evaluations conducted by NBRTI and other FTA research partners have shown that, by delivering a broad array of benefits such as higher ridership, decreased travel times, improved service reliability, greater carrying capacity, and increased convenience, BRT is capable of matching the quality of

light rail transit (LRT), but with quicker implementation and for a fraction of the up-front capital expenditures. Moreover, “BRT lite” systems such as the Metro Rapid in Los Angeles provide evidence that significant operational and cost efficiencies can be attained on typical urban arterials when certain low-cost, key BRT applications are implemented together.

Notably, the 2009 NBRTI study Quantifying the Importance of Image and Perception to BRT found that quality of service is more important for attracting ridership than the mode of travel, and that BRT, even in its lower investment forms, is perceived in much the same way as LRT. This has important implications for BRT’s potential to impact congestion and carbon emissions, since the ability to induce mode shift depends in large part on attracting choice riders. Early quantitative research by NBRTI has also found that BRT in the United States can have statistically significant positive effects on property values similar to other high-quality rapid transit modes.

The mission of NBRTI is to facilitate the sharing of knowledge and innovation for increasing the speed, efficiency, and reliability of high-capacity bus service through the implementation of BRT systems in the United States. This mission has been achieved by using advanced technologies and methodologies developed in the field of intelligent transportation systems (ITS), bus, and rail systems. In addition, NBRTI has employed a series of resources including workshops, conferences, publications, research, and knowledgeable staff to achieve the goals of the program. The NBRTI Program is divided into three core program areas: Clearinghouse, Technical Assistance/Support, and Research/Evaluation. The full Program Report summarizes and describes the activities conducted under each of the program areas. Activities included a website, informational brochures and newsletters, a listserv, conference support, conference presentations, site visits, BRT system evaluations, research, journal publications and other articles, technical assistance to FTA, transit agencies, and local governments, and other activities.

To fully realize the improvements in mobility, congestion, and economic growth that BRT can produce, the transition from individual BRT lines to integrated BRT route networks would be a major step forward. Also, BRT features are increasingly spreading to non-BRT corridors, meaning that BRT-lite may become the de facto bus system of the future. Given that buses account for almost half of the nation’s transit trips, improved bus services could have a significant impact on transit’s overall mode share in the future. As new BRT systems are implemented and early deployments evolve, the continued study and documentation of BRT’s challenges, benefits, and new lessons learned would be of great value to the transit industry.

Introduction

In less than two decades, bus rapid transit (BRT) has progressed from a little-known innovation to one of the fastest growing transit modes in the nation. The potential for swift and cost-effective implementation makes BRT an attractive option for cities contending with increasing traffic congestion and constrained budgets for public transportation. Today, BRT is operating or in development in most major cities and is a modal alternative in nearly every planning study. The rise of BRT in the United States traces its roots back to several early initiatives of the Federal Transit Administration (FTA). Inspired by the impressive performance and cost-effectiveness of successful BRT systems in Latin America, FTA created a BRT Demonstration Program in 1998, partnering with several competitively selected transit agencies for the implementation, operation, and evaluation of BRT projects. As the need for a practical resource quickly arose within the emerging BRT community in the United States, FTA in January 2001 sponsored the National Bus Rapid Transit Institute (NBRTI), a program of research, innovation, training, and technical assistance in the field of BRT, housed at the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF). This report documents NBRTI's activities, from its inception in January 2001 to June 2023 (the final year of the program grant).

Historical Work of NBRTI

Through numerous research studies, decision tools, technology demonstrations, and evaluations, NBRTI helped to forge key industry relationships, catalyzed crucial early milestones such as the development of consensus-based standards, and produced a foundational body of knowledge for the advancement of BRT. Ultimately, FTA's early BRT initiatives, along with the Small Starts and Very Small Starts federal funding programs, ushered in a national BRT boom that began in the early 2000s and continued throughout the decade, including projects in Los Angeles; Boston; Oakland, California; Las Vegas; Kansas City, Missouri; Eugene, Oregon; and Cleveland. Several of these forerunners were particularly innovative and emerged as models of success.

Demonstrations and evaluations conducted by NBRTI and other FTA research partners have shown that, by delivering a broad array of benefits such as higher ridership, decreased travel times, improved service reliability, greater carrying capacity, and increased convenience, BRT is capable of matching the quality of light rail transit (LRT), but with quicker implementation and for a fraction of the up-front capital expenditures. Moreover, "BRT lite" systems such as the Metro Rapid in Los Angeles provide evidence that significant operational and cost efficiencies can be attained on typical urban arterials when certain low-cost, key BRT applications are implemented together.

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Program Mission and Structure

The mission of NBRTI is to facilitate the sharing of knowledge and innovation for increasing the speed, efficiency, and reliability of high-capacity bus service through the implementation of BRT systems in the United States. This mission has been achieved by using advanced technologies and methodologies developed in the field of intelligent transportation systems (ITS), bus, and rail systems. In addition, NBRTI has employed a series of resources including workshops, conferences, publications, research, and knowledgeable staff to achieve the goals of the program. The NBRTI Program is divided into the three core areas described below.

1. **Clearinghouse** – The NBRTI Clearinghouse provides a centralized source for current BRT-related information. NBRTI helps interested users retrieve general BRT information, as well as information on the progress of the BRT projects in the United States and worldwide. The clearinghouse effort builds on the work completed as part of the Transit Cooperative Research Program (TCRP) A-23 project "Implementation Guidelines for Bus Rapid Transit Systems," which included a collection of images and videos of BRT systems and components. The clearinghouse also contains press clippings, technical reports, system evaluations, presentations, and other documents related to BRT.

2. **Technical Assistance/Support** – NBRTI has been called upon to give technical assistance to numerous individuals and agencies, including metropolitan planning organizations, departments of transportation, transit agencies, private consulting firms, international organizations, elected officials, and others who are considering BRT applications in their communities. To meet this need, NBRTI draws upon research findings, field visits, and the prior experience of the BRT community. This usually involves presenting to boards or other governmental agencies at the local or regional level and/or meeting with agency staff to discuss technology options, implementation issues, and other topics of interest. This work includes assistance in developing and evaluating proposals and participation in technical advisory review committees. A few recent examples of this activity include being invited to present on

and discuss regional transit and BRT plans at meetings in Hillsborough County, Florida, in 2018, and being invited to share how high-quality transit such as BRT can induce property value capture (in Tampa, Florida, 2000). Also, in 2019, NBRTI staff was invited to participate in the Hillsborough Area Regional Transit (HART) Transit Oriented Development (TOD) Working Group to explore the TOD possibilities of BRT corridors in the community.

To promote the continued sharing of knowledge, NBRTI offers conference support through the planning and development of regional and national BRT conferences. Staff of the Institute regularly lead, moderate, and present at numerous conferences in association with industry partners, including the American Public Transportation Association (APTA), the Transportation Research Board (TRB), the Institute of Transportation Engineers (ITE), and the American Society of Civil Engineers (ASCE). NBRTI is also responsible for developing white papers and BRT-related presentation materials for FTA staff. In addition, NBRTI staff organize field visits of BRT systems to give elected officials, board members, and transit professionals hands-on experience and the opportunity to establish relationships for the continued sharing of knowledge.

3. **Research and Evaluation** – As requested by FTA, NBRTI conducts new research in areas related to BRT and develops "best practices" manuals and tools to assist the BRT community. Topic areas for further research may come from FTA, through committees of TRB or APTA, or directly from the BRT community. These ideas are then formally discussed and prioritized by the NBRTI Advisory Board (see Appendix C for more details on the Advisory Board). Additionally, NBRTI conducts and/or assists in the evaluation of BRT projects through onboard surveys, performance evaluations, and summaries of lessons learned.

   At various times during the life of NBRTI, FTA provided input and guidance as to what activities should be conducted, including the selection of research topics. Given this guidance, the focus of NBRTI would shift over the years. In the early years, the focus was on site visits and information development and dissemination (brochures, newsletters, listserv, initial website development). Focus shifted to research, additional evaluation efforts, technical assistance, and conference support in the middle years. In the later years of the Program, remaining funds were allocated to short research projects.

Summary of NBRTI Activities

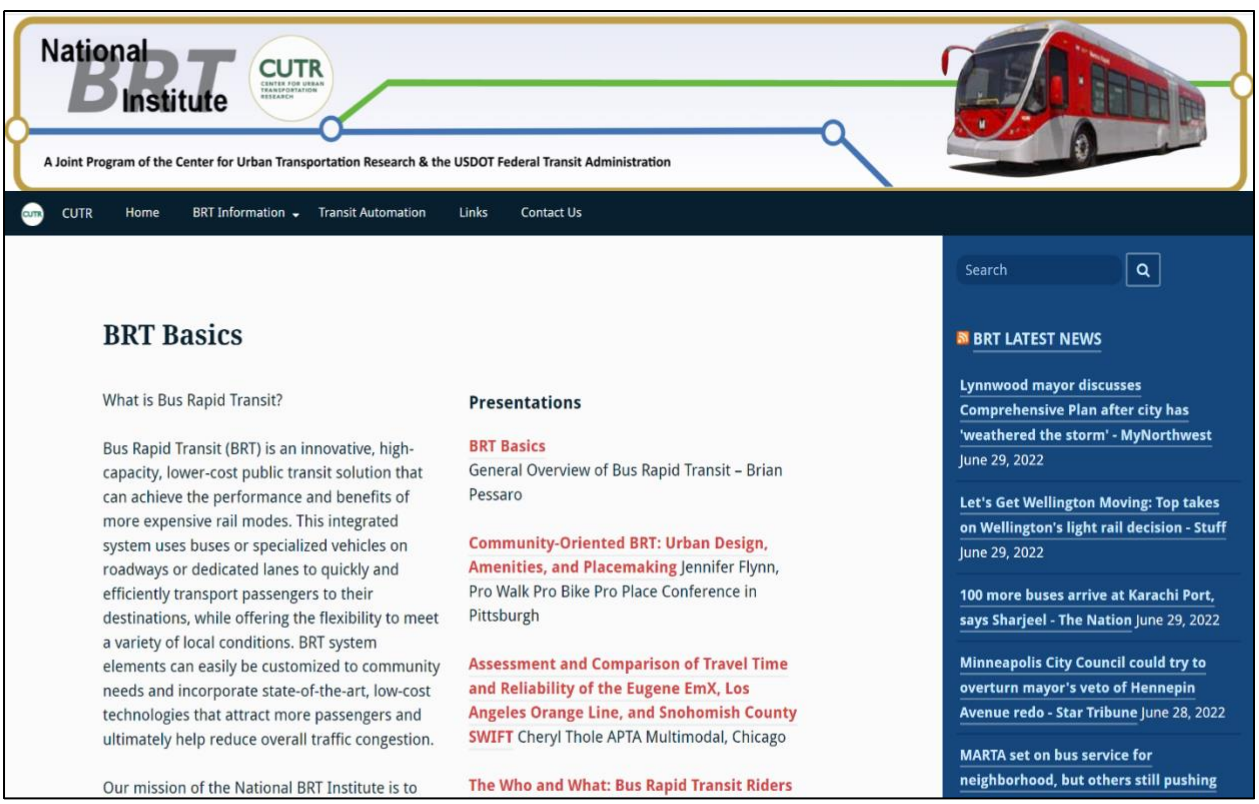
The sections that follow provide a summary of NBRTI activities, organized according to the three core program areas.

Clearinghouse

NBRTI Website

Information about BRT, such as press clippings, system evaluations, conference and workshop presentations, research reports published by both NBRTI and other organizations, and other relevant documents, is made available on the NBRTI website at www.nbrti.org/. The website offers a newsfeed on current affairs in the world of BRT and enables interested parties to retrieve general BRT information, as well as information on the progress of BRT projects in the United States and worldwide. The website also provides details of upcoming events of interest to the BRT community, such as conferences, workshops, and scanning tours. The website was redesigned periodically to include more advanced functionality, including a tool to allow users to search by keyword or type of information (i.e., photos, presentations, videos, reports).

To offer a forum for BRT community members and researchers to exchange ideas and information, a listserv was integrated into the design of the website. The listserv has 621 subscribers and was most active during



BRT's transition in the United States from an emergent technology to a rapidly growing transit mode. The last listserv post was in January 2016. From April 7, 2008 (when website data began to be collected), to June 30, 2023, the website had 136,117 users and 347,237 page views.

Newsletters

NBRTI produced the BRT Quarterly newsletter focusing on BRT-related articles, news, and events. Articles covered BRT systems in cities including Vancouver, Boston, Cleveland, Eugene, and Los Angeles, and examined topics such as transit signal priority (TSP) and vehicle assist and automation (VAA) technologies. The newsletter was distributed widely, both nationally and internationally. Subscribers had the ability to request either a hard or electronic version of the newsletter, with approximately three-quarters of subscribers receiving it via email. The majority of printed copies were distributed at conferences, workshops, and meetings. A winter issue was printed to directly coincide with the TRB Annual Meeting in Washington, D.C. The last edition of the BRT Quarterly was issued in October 2011.

Information Brochure and Inserts

To provide BRT information in a "quick facts" format, NBRTI created a trifold informational brochure in 2006 for printing and distribution at workshops and conferences. The brochure mirrored the layout of the Characteristics of Bus Rapid Transit (CBRT) document, with sections covering (1) the major elements of BRT, (2) system performance, and (3) benefits. As a complement to the trifold brochure, NBRTI designed one-page inserts for distribution to the BRT community. Each insert highlighted a BRT system, presenting facts about capital costs, length of service, vehicle type, ridership figures, and additional items of interest.

Technical Assistance/Support

Conference Support

To promote the continued sharing of knowledge, NBRTI provided conference support through the planning and development of the following regional and national BRT conferences:

- Collaborated with APTA on the development of BRT Tuesday at the 2020 APTA Mobility Conference in San Antonio, TX (cancelled).

- Collaborated with FTA, APTA, and TRB to plan and host the Sixth National Bus Rapid Transit Conference: No Longer an Emerging Mode in June 2018 in Los Angeles, CA. There were 14 conference sessions, nearly 60 presentations, and tours of the Wilshire Boulevard Metro Rapid "BRT Lite" service, the Metro Orange Line BRT, the Metro Silver Line BRT, and El Monte Station.

- Collaborated with TRB and APTA to organize sessions and presentations for APTA 2017 Bus & Paratransit Conference and TRB Annual Meeting.

- Collaborated with TRB and APTA to organize sessions and presentations for APTA 2015 Bus & Paratransit Conference and TRB Annual Meeting.

- Collaborated with FTA, APTA, and TRB to plan and host the Fifth National Bus Rapid Transit Conference in August 2012 in Las Vegas, NV. This event comprised more than 20 presentations, a separate poster session, and a technical tour of Las Vegas's BRT services.

- Moderated "Innovations in Bus Rapid Transit Operations" at TRB Annual Meeting, January 2011.

- Chaired TRB BRT Subcommittee meeting at TRB Annual Meeting, January 2010 and January 2011.

- Assisted in the development of the BRT World Conference in Boston, MA, June 2010.

- Moderated BRT session at the APTA Bus & Paratransit Conference, Cleveland, OH, May 3, 2010.

- Moderated "Developing Ridership for Bus Rapid Transit" session at the Annual TRB Meeting in Washington, DC, January 2010.

- Collaborated with FTA, APTA, and TRB to plan and host the Fourth Bus Rapid Transit Conference in May 2009 in Seattle, WA. More than 150 participants discussed bus rapid transit over eight program sessions and two tours. The conference was held in conjunction with the APTA Bus and Paratransit Conference.

- Planned and hosted the Cleveland BRT Workshop in July 2008, Cleveland, OH. The workshop focused on the history, design, construction, operations, safety, real estate and economic development, and project oversight associated with the Greater Cleveland Regional Transit Authority Euclid Corridor BRT system.

- Moderated the session “Bus Rapid Transit: Not One Size Fits All” at the APTA Bus and Paratransit Conference, Austin, TX, May 2008.

- Moderated the session “Efficiency in Urban Bus Operations” at the annual meeting of the Transportation Research Board, Washington, DC, January 2008.

- Collaborated with the Canadian Urban Transit Association (CUTA) to plan, develop, and attend the Canadian BRT Conference. Quebec City, Canada, November 2007.

- Organized and participated in the BRT Workshop, El Paso, TX, September 2007.

- Moderated the session “Bus Rapid Transit” at the APTA Intermodal Operations Planning Conference, San Francisco, CA, August 2007.

- Hosted and moderated the ASCE CBRT Workshop, Cleveland, OH, February 2007.

- Moderated the session “Bus Rapid Transit Finance and Implementation” at the annual meeting of the Transportation Research Board, Washington, DC, January 2007.

- Hosted and moderated the December 2006 ASCE CBRT Workshop in Las Vegas, NV.

- Provided support for the planning and development of FTA’s Bus Rapid Transit Technical Workshop; served as moderator for the conference held in Seattle, WA, September 2006.

- Collaborated with FTA, APTA, and TRB to plan, host, and chair an International Bus Rapid Transit Conference in August 2006 in Toronto, Canada. Over 200 people attended the conference. There were seven conference sessions held (with presentations by 30 speakers), a separate poster session, and a tour of the York BRT system.

- Moderated the BRT session at the ITE Annual Meeting, Milwaukee, WI, August 2006

Presentations

To promote the continued sharing of knowledge, NBRTI staff participated in various industry conferences and spoke to other groups by giving the following presentations:

- *Impacts of Lane Transit District's EmX Bus Rapid Transit (BRT) on Area Residential Property Values*. 100th Annual Meeting of the Transportation Research Board. Washington, DC. January 2021.
- *Transit Impacts on Property Value Capture.* Plan Hillsborough Value Added Mobility Study (VAMS) Workshop. Tampa, FL. September 2020.
- *Synopsis of TRB 6th National BRT Conference: No Longer an Emerging Mode*. Florida Public Transportation Association (FPTA) Annual Conference and EXPO. Daytona Beach, FL. October 2018.
- *Tampa Bay Regional Transit Feasibility Plan – The Bus Rapid Transit Option*. Regional Transit/TB Next Coordination Meeting. Tampa, FL. July 2018.
- Regular guest lectures on BRT in USF engineering courses such as *Transportation and Society* and *Transportation Engineering.* 2012–2018.
- *Transit's Impact on Property: Value, Use, and Opportunity*. 2017 Geographic Information Systems (GIS) in Transit Conference. Washington, DC. September 2017.
- *BRT and Property Values.* 9th National GIS in Transit Conference. Washington, DC. September 2015.
- *BRT and Economic Development*, presentation and roundtable discussion. 2015 APTA Bus and Paratransit Conference. Fort Worth, TX. May 2015.
- *Community-Oriented BRT: Urban Design, Amenities, and Placemaking.* Pro Walk Pro Bike Pro Place. Pittsburgh, PA. September 2014.
- *Community-Oriented BRT: Urban Design, Amenities, and Placemaking* (poster). APTA Multimodal Operations Planning Workshop. Chicago, IL. August 2014.
- *Land Use and Property Value Impacts of BRT*. Transit and Place: First Steps. Albuquerque, NM. February 2013.
- *Bus Rapid Transit (BRT) in the U.S.* Transit and Place: First Steps. Albuquerque, NM. February 2013.

- *Impacts of Boston's Silver Line Bus Rapid Transit (BRT) on Sale Prices of Condominiums Along Washington Street*. 92nd Annual Meeting of the Transportation Research Board. Washington, DC. January 2013.

- *Tangible and Intangible Service Attributes: Quantifying the Importance of Image and Perception to Bus Rapid Transit.* Transportation Research Board 5th National Bus Rapid Transit Conference. Las Vegas, NV. August 2012.

- *Land Use and Property Values of BRT*. Transportation Research Board 5th National Bus Rapid Transit Conference. Las Vegas, NV. August 2012.

- *Land Use Impacts of BRT*. Commuter Choice Webinar, BRT Session Part II. Tampa, FL. January 2012.

- *Bus Rapid Transit (BRT) in the United States*. 1st U.S.-China Symposium on Sustainable Transportation and Development. Tampa, FL. December 2011.

- *Overview of Bus Rapid Transit.* CUTR Webinar Series. Tampa, FL. January 2012.

- *Characteristics and Elements of BRT Systems.* APEC Meeting. San Francisco, CA. September 2011.

- *A Change in Accessibility and Convenience? Implementing BRT and the Impact on Transit Riders.* GIS Conference. St. Petersburg, FL. September 2011.

- *Land Use Impacts of Bus Rapid Transit: The Boston Silver Line*. GIS in Public Transportation Conference. St. Petersburg, FL. September 2011.

- *A Change in Accessibility and Convenience? Implementing BRT and the Impact on Transit Riders.* APTA Multimodal Workshop. Seattle, WA. August 2011.

- *Bus Rapid Transit Systems in the United States.* Transportation Summit. Irving, TX. August 2011.

- *Transit Improvements from the Urban Partnership Agreement Program: What Have We Seen So Far?* Center for Urban Transportation Research Webinar. Tampa, FL. June 2011.

- *BRT and Land Use*. Florida Department of Transportation District 5 Quarterly Transit Workshop. Orlando, FL. June 2011.

- *Bus Rapid Transit (BRT): Examples and Possibilities.* Transportation in Pinellas County Forum. St. Petersburg, FL. June 2011.

- *BRT and Land Use.* Florida Department of Transportation District 5 Quarterly Transit Workshop. Orlando, FL. June 2011.

- *Tangible and Intangible Service Attributes: Quantifying the Importance of Image and Perception to Bus Rapid Transit*. Transportation Research Board (TRB) Transit Research Analysis Committee (TRAC). Washington, DC. June 2011.

- *The Status of Bus Rapid Transit in the United States.* APTA Bus and Paratransit Conference. Memphis, TN. May 2011.

- *Status of BRT in the U.S.* Mobility Choice Roundtable. Washington, DC. May 2011.

- *Transit Operations in a Priced Corridor Is a Win-Win Situation in the Miami I-95 Express Corridor* (poster). 90th Annual Meeting of the Transportation Research Board (TRB). Washington, DC. January 2011.

- *Vehicle Assist and Automation Technologies in Bus Revenue Service.* Center for Urban Transportation Research Webinar. Tampa, FL. November 2010.

- *Advanced Bus Rapid Transit.* 2010 Florida Section of Institute of Transportation Engineers (FSITE) Annual Conference. Orlando, FL. October 2010.

- *Bus Rapid Transit.* Meeting of the American Institute of Architects Committee on the Environment and Urban Design. Tampa, FL. October 2010.

- *Building BRT with New Starts/Small Starts Funds.* FPTA Annual Meeting. Miami, FL. October 2010.

- *BRT Basics.* Pittsburgh Bus Rapid Transit Forum. Pittsburgh, PA. September 2010.

- *Bus Rapid Transit.* American Dream Coalition Conference. Orlando, FL. September 2010.

- *Land Use Impacts of Bus Rapid Transit.* Commuter Choice Workshop Webinar. Tampa, FL. September 2010.

- *Innovations in Bus Rapid Transit.* Commuter Choice Workshop Webinar. Tampa, FL. August 2010.

- *Innovations in Bus Rapid Transit.* 13th Annual Transportation Summit. Irving, TX. August 2010.

- *FTA Overview of Public Bus Transit Operations.* 13th Annual Transportation Summit. Irving, TX. August 2010.

- *Tangible and Intangible Service Attributes: Quantifying the Importance of Image and Perception to Bus Rapid Transit.* Annual meeting of TRB's Transit Research Analysis Committee (TRAC). Washington, DC. June 2010.

- *Taking Advantage of Evolving BRT Technologies.* 2010 Bus Rapid Transit World Conference. Boston, MA. June 2010.

- *Vehicle Assist and Automation Technologies in Bus Revenue Service.* 2010 American Public Transportation Association (APTA) Bus and Paratransit Conference. Cleveland, OH. May 2010.

- *Transit Signal Priority – Status and Lessons Learned from BRT Implementation.* 2010 ITE Technical Conference and Exhibit. Savannah, GA. March 2010.

- *Land Use Impacts of Bus Rapid Transit.* National Transit Institute Webinar. March 2010.

- *BRT and Transit-Oriented Development.* National Transit Institute (NTI) Webinar. March 2010.

- *The Perception, Image, and Branding of Bus Rapid Transit.* National Transit Institute (NTI) Webinar. February 2010.

- *Impact of Miami UPA Phase 1A Implementation on Transit User Perceptions of the 95 Express Bus Service.* 89th Annual Meeting of the Transportation Research Board (TRB). Washington, DC. January 2010.

- *Tangible and Intangible Service Attributes: Quantifying the Importance of Image and Perception to Bus Rapid Transit.* 89th Annual Meeting of the Transportation Research Board (TRB). Washington, DC. January 2010.

- *Impacts of BRT Stations on Surrounding Single-Family Home Values: A Study of Pittsburgh's East Busway.* 89th Annual Meeting of the Transportation Research Board (TRB). Washington, DC. January 2010.

- *Land Use Impacts of BRT: Effects of BRT Station Proximity on Property Values.* Transit Seminar: Bus Rapid Transit and Transit-Oriented Development. Madison, WI. October 2009.

- *Tangible and Intangible Service Attributes: Assessing Rapid Transit Modes in the Los Angeles Area.* American Public Transportation Association (APTA) Multimodal Operations Planning Workshop. Salt Lake City, UT. August 2009.

- *Quantifying the Importance of Image and Perception to BRT.* American Public Transportation Association (APTA) Bus and Paratransit Conference. Seattle, WA. May 2009.

- *Land Use Impacts of Bus Rapid Transit.* American Public Transportation Association (APTA) Bus and Paratransit Conference. Seattle, WA. May 2009.

- *Quantifying the Importance of Image and Perception to Bus Rapid Transit.* Florida Public Transportation Association/Center for Urban Transportation Research Professional Development Workshop. Tampa, FL. May 2009.

- *Land Use Impacts of Bus Rapid Transit*. Florida Public Transportation Association/Center for Urban Transportation Research Professional Development Workshop. Tampa, FL. May 2009.

- *Land Use Impacts of Bus Rapid Transit*. Tampa Bay Applications Group Meeting. Tampa, FL. May 2009.

- *Bus Rapid Transit: What is it and What's Happening in the U.S.* Transpo Exhibition and Conference. Orlando, FL. September 2008.

- *An Overview of Bus Rapid Transit.* Bus Rapid Transit Workshop. Eagan, MN. August 2008.

- *The Status of Bus Rapid Transit in the United States.* 2008 Transportation Summit. Irving, TX. August 2008.

- *BRT and Land Use*. APTA Bus and Paratransit Conference. Austin, TX. May 2008.

- *Bus Rapid Transit and Sustainability: A Promising Alternative to Light Rail*. Going Green Tampa Bay Expo. Tampa, FL. April 2008.

- *An Overview of Bus Rapid Transit in the United States.* United States and the Republic of Korea – Workshop on Public Transportation – "Developing Effective Mass Transit Systems". Honolulu, HI. February 2008.

- *Bus Rapid Transit in the United States – Current Issues and Future Considerations.* Transforming Transportation – EMBARQ / World Bank Conference. Washington, DC. January 2008.

- *The Role of BRT in Mitigating Congestion*. Indore City Council Meeting. Indore, India. September 2007.

- *BRT in the US*. Easter Seals Annual Meeting. Washington, DC. September 2007.

- *Integrating Transit and Land Use.* Session Moderator, 2007 American Public Transportation Association (APTA) Intermodal Operations Planning Workshop. San Francisco, CA. August 2007.

- *Land Use Impacts of BRT*. APTA Intermodal Operations Planning Conference. San Francisco, CA. August 2007.

- *The Bogotá Model – Maximizing Mobility and Operational Efficiency*. Americas Competitiveness Forum. Atlanta, GA. June 2007.

- *Integration of Accessibility into Bus Rapid Transit Projects in the United States.* Fifth International Workshop on Public Transportation. Moscow, Russia. May 2007.

- *Quantifying the Importance of Image and Perception to BRT*. APTA Bus and Paratransit Conference. Nashville, TN. May 2007.

- *Tracking the Evolution of the Bogotá Model – Findings from Three South American BRT Systems*. APTA Bus and Paratransit Conference. Nashville, TN. May 2007.

- *Performance and Lessons from Implementation of BRT in the United States*. Annual meeting of the Transportation Research Board. Washington, DC. January 2007.

- *Applicability of Bogotá's TransMilenio BRT System to the United States*. Annual meeting of the Transportation Research Board. Washington, DC. January 2007.

- *Bus Rapid Transit.* Transportation Growth and Change Seminar. West Coast Branch of the ASCE Florida Section. August 2006.

- *Status of Bus Rapid Transit in the United States*. Bus Rapid Transit Vehicle Working Group Meeting. Washington, DC. July 2006.

- *Update to the CBRT Document*. Florida Section ITE Meeting. Fort Lauderdale, FL. June 2006.

General Technical Assistance

NBRTI has often advised and assisted organizations and elected officials who are considering BRT applications in their communities by presenting to boards or other governmental agencies at the local and regional levels, and/or meeting with agency staff to discuss technology options, implementation issues, and other topics of interest. The following is a sampling of these more general technical assistance/support activities.

- Panel participation, TCRP A-47, Transit Capacity and Quality of Service Manual, 4th Edition, as a transit and BRT expert, 2022–2025.

- Participation on the Hillsborough Area Regional Transit Authority Transit-Oriented Development Working Group as a BRT expert, 2019–2022.

- Drafted the documents for APTA BRT Standards Working Group, November 2018.

- Review of draft and final reports for TRB Cooperative Research Panel D-13, Guide for Implementing Bus on Shoulder Systems, 2011–2012.

- Participation as BRT expert in the Mobility Choice Roundtable in Washington, DC, May 2010.

- Prepared the presentation "Overview of Public Transit Bus Operations in the U.S." for FTA at the Texas Transportation Summit, August 2010.

- Assisted with data compilation for the Cleveland BRT Summit, October 2010.

- Compiled photos for ITS America, news reporters, consultants, and students.

- Composed background briefing materials for 2008 FTA Mission to Africa, March 2008.

- As part of the FTA Lane Guidance Demonstration Program, NBRTI developed an RFP seeking transit agencies and technology providers to create a partnership for testing, and to monitor and interact in that process.

- Coordinated with Easter Seals Project Action on the development of an Americans with Disabilities Act (ADA) BRT Guidebook, 2007–2008. NBRTI research funds were used to add case studies to the project.

- Advised the New Jersey Institute of Technology on the undertaking of a study on the deployment of BRT in Newark, NJ, attending two design studio meetings, October 2007.

- Composed background briefing materials for FTA Mission to India, September 2007.

- Participated in FTA Trade Mission to Russia, May 2007.

- Participated in an interview with a Kansas City newspaper reporter for an Urban Land Institute article, 2007.

- Conducted and analyzed a survey of systems operating or planning BRT service regarding visual simulation of BRT components, February 2007.

- Participated in sustainable urban transport meetings co-sponsored by World Bank/Embarq/WRI in Washington, January 2007.

- As project panel member, participated in meetings of TCRP Project Panel D-13: A Guide for Implementing Bus-On-Shoulder (BOS) Systems, 2006–2008.

- Chaired, moderated, and participated in the Brainstorming and Research Coordination Meeting in July 2006 at APTA's Washington, DC, offices. The findings of invited transportation research and policy experts validated NBRTI's current research agenda and program of activities for upcoming years.

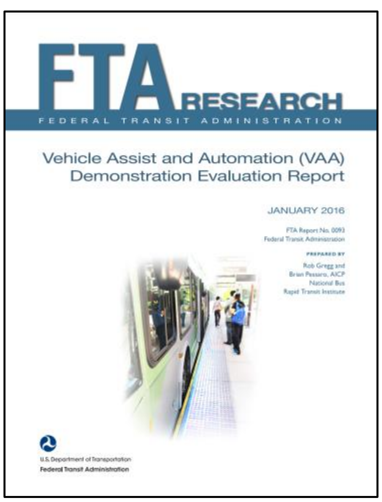
- Finalized summary notes of the April 2006 ASCE CBRT Workshop held in Washington, DC.

- Advised Pinellas Suncoast Transit Authority on the prioritization of bus rapid transit corridors and assisted in developing a related scope of study, March 2006.

- Reviewed and offered comments on the initial draft of the Transit Systems Engineering Guidebook, developed by the International Council on Systems Engineering (INCOSE) and published by Caltrans, 2006.

Research and Evaluation

Evaluation Reports



Vehicle Assist and Automation (VAA) Demonstration Evaluation (January 2016)

This report summarizes an evaluation of a VAA system used by Lane Transit District in Eugene, Oregon, for its Emerald Express (EmX) BRT line. The 1.5-mile demonstration involved the use of magnetic sensors for precision docking at three stations and lane guidance between the stations. The VAA system was evaluated in six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including customer surveys, driver surveys and focus groups, accident reports, maintenance reports, and lane position data from the VAA onboard computer system. Key findings indicated that the VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The VAA was widely praised by the bus operators and passengers for its precision docking at the station platforms.

LYMMO BRT: 15 Years Later (June 2013)
This report is a follow-up of NBRTI's initial 2003 evaluation of the Lynx LYMMO in Orlando, Florida. Beginning in 2010, average daily ridership on LYMMO fell for three consecutive years. The drop in ridership is partially attributable to a 15 percent loss in jobs located within one-quarter mile of LYMMO service between 2002 and 2010. Nevertheless, LYMMO continues to rank as one of Lynx Transit's top five routes. It has also outperformed several rail streetcar systems in the United States in annual passenger trips and cost per trip. LYMMO continues to be rated highly by passengers, scoring a 4.5 out of 5 in overall customer satisfaction. Fifteen percent of downtown Orlando employers said in a survey that LYMMO was a factor in their decision to remain downtown. A majority agreed that LYMMO contributed to the economic development of downtown, made downtown a more attractive place to live and work, and improved mobility downtown.

Cedar Avenue Driver Assist System Evaluation Report (December 2011)
This report summarizes an evaluation of the Driver Assist System (DAS) used by the Minnesota Valley Transit Authority (MVTA) for bus shoulder operations. The DAS is a GPS-based technology suite that provides lane position feedback to the driver via a head-up display, virtual mirror, vibrating seat, and actuated steering. MVTA's primary goal was to enhance driver confidence, especially during adverse weather. Secondary goals included reduced travel times and increased reliability, safety, and customer satisfaction. The evaluation used a "with and without" approach. Performance data were collected from the same drivers, with the DAS set to passive and then active mode. When the DAS was in active mode, the drivers stayed in the shoulders 10 percent longer and drove 3 miles per hour faster. Lateral (side-to-side) movement was reduced by 5.5 inches. These results should be considered preliminary, as only 6 of the 25 trained drivers used the shoulders during both test periods. When surveyed, 32 percent of the bus drivers said their level of confidence for driving in the shoulder was greater when using the DAS, while 60 percent said it was the same. A majority believed the DAS made driving in the shoulder safer and less stressful. Nevertheless, many drivers raised concerns about the head-up display being a distraction. By contrast, the vibrating seat was praised as the best feature of the entire system. For customer satisfaction, more than 80 percent of surveyed passengers rated the ride quality in the shoulder as very good or good.

Metro Orange Line BRT Project Evaluation (October 2011)
This report summarizes NBRTI's evaluation of the Metro Orange Line BRT service, which debuted in October 2005 as one of the first full-service BRT lines in the United States and the first exclusive busway in Los Angeles. The evaluation contains a comprehensive overview of the Orange Line, including a historical narrative; a profile of project elements, project costs, and issues in planning, design, and implementation; technology applications; and a summary of lessons learned. The report also provides an evaluation of project performance by analyzing data on capacity, travel time, reliability, and safety and security. For the examination of travel-time performance, run-time data were collected and analyzed, offering insight into the directional and temporal components of running time and producing a useful "before" dataset for future study of the project. The performance evaluation also includes an analysis of data from NBRTI's onboard survey of user perceptions and satisfaction and an assessment of the project's image and brand identity. The report concludes with an overall appraisal of the Orange Line's benefits, including assessments of ridership, financial feasibility, transit supportive land development, environmental quality, and overall performance of the Orange Line in meeting project goals.

Miami UPA Pines Boulevard Transit Signal Priority Evaluation (September 2011)
The Miami Urban Partnership Agreement (UPA) included the conversion of high occupancy vehicle (HOV) lanes on I-95 to high occupancy toll (HOT) lanes and additional express bus service. It also included funding for the installation of TSP at 50 intersections on Pines/Hollywood and Broward Boulevards in Broward County. This report summarizes the findings of TSP data collection on Pines/Hollywood Blvd. from December 2010 to February 2011. The data showed an average time savings of four minutes in the AM peak period due to TSP, which amounted to a 12 percent reduction in travel times. On-time performance improved from 66.7 percent to 75 percent. In the PM peak period, the travel time and signal delay were similar with or without the TSP activated. This could be an indication that afternoon traffic volumes on westbound Pines/Hollywood Blvd. are so heavy that TSP is of only marginal benefit.

An Evaluation of the Cleveland HealthLine Mechanical Guide Wheel

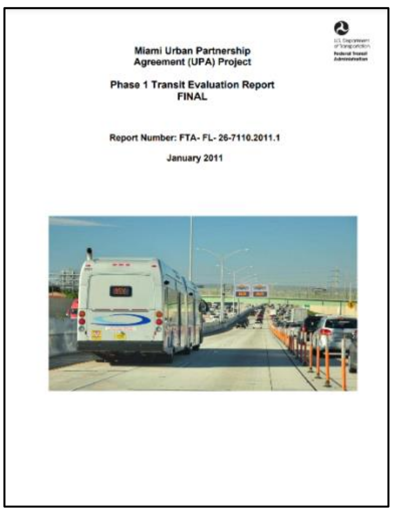
FINAL

Report Number: FTA- FL- 26-7110.2011.2

March 2011

Evaluation of the Cleveland HealthLine Mechanical Guide Wheel (March 2011)

Vehicles on the Cleveland HealthLine BRT system are equipped with a mechanical docking arm and guide wheel to assist with precision docking at the stations. This report documents the evaluation of the guide wheel in four areas: how close to the platform the vehicles were able to dock; how fast the vehicles were able to dock; how much money was spent on damages related to docking; and how well the guide wheels are regarded by the HealthLine drivers. The evaluation compared the performance of the HealthLine to the EmX BRT in Eugene, Oregon. The EmX uses the same model vehicle as the HealthLine but does not come equipped with a docking arm and guide wheel.



Miami Urban Partnership Agreement (UPA) Project

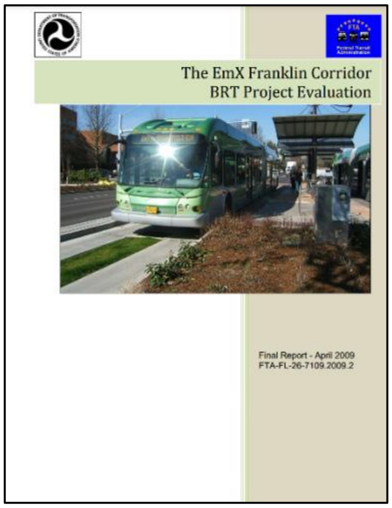
Phase 1 Transit Evaluation Report
FINAL

Report Number: FTA- FL- 26-7110.2011.1

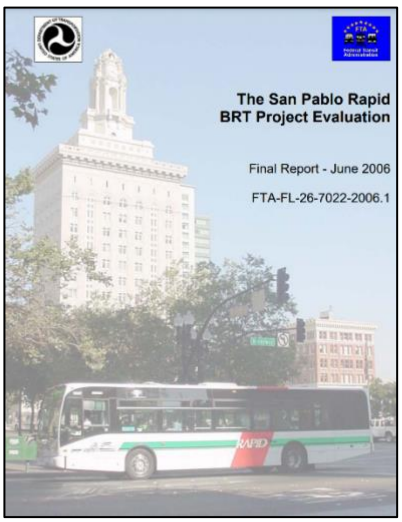
January 2011

Miami UPA Phase 1 Evaluation (January 2011)

The 95 Express Lanes in Miami-Dade County have been in operation since December 2008. This project involved the conversion of a single HOV lane in both directions to two HOT lanes in both directions. These lanes rely on dynamic pricing to keep the lanes free-flowing. A portion of the toll revenues is used to fund operations of the 95 Express Bus Service, which is composed of four routes that provide service between Broward County, northern Miami-Dade County, and downtown Miami. This report summarizes an evaluation of the impacts of the express lanes on the 95 Express Bus service. There were several positive findings. The 95 Express Bus Service benefited from the HOV-to-HOT conversion in improved travel times and on-time performance. The service attracted a large percentage of choice riders, and ridership grew despite rising unemployment in Miami-Dade County. Onboard transit surveys revealed that the HOT lanes influenced riders' decisions to use the bus.

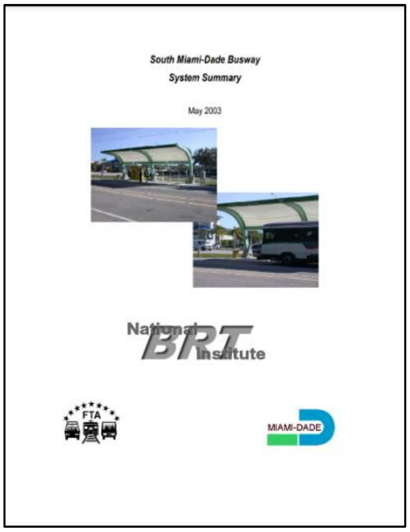


EmX Franklin Corridor BRT Project Evaluation (April 2009)
This report summarizes an evaluation of Lane Transit District's (LTD) Franklin Corridor Emerald Express (EmX) BRT, which began service in January 2007. The four-mile route connects downtown Eugene and downtown Springfield, the two main hubs for LTD's system. The evaluation contains a comprehensive overview of the EmX, including a profile of project elements, costs, and performance. System performance was evaluated by analyzing data on capacity, travel time, reliability, and safety and security. For the examination of travel-time performance, run-time data were collected and analyzed, offering insight into the directional and temporal components of running time and producing a useful "before" dataset for future study of the project. The report also includes an analysis of data from NBRTI's onboard survey of user perceptions and satisfaction.



San Pablo Rapid Evaluation (June 2006)
This report summarizes an evaluation of AC Transit's San Pablo Rapid BRT service, which replaced the limited stop service in June 2003. The new service runs in mixed traffic along a 14-mile route from Contra Costa College to 2nd Street (Jack London Square) in downtown Oakland, California. The evaluation contains a comprehensive overview of the San Pablo Rapid, including a profile of project elements, costs, and performance. System performance was evaluated by analyzing data on capacity, travel time, reliability, and safety and security. Rapid bus service reduced end-to-end travel times by an average of 12 minutes, equating to a 21 percent reduction compared to the local service and 17 percent compared to the limited stop service. "Travel time on the Rapid Bus" was rated by users as one of the best aspects of the service. Overall, implementation of the service produced an 8.5 percent ridership increase along the sections of the San Pablo Avenue corridor served by the rapid bus.

Lynx LYMMO Bus Rapid Transit Evaluation (July 2003)
This evaluation report contains a comprehensive profile of the Lynx LYMMO BRT service from inception to operation, including a historical narrative of engineering, construction, and institutional documentation. In addition, the report provides an evaluation of the performance of LYMMO by identifying performance strengths and weaknesses, customer satisfaction, effectiveness of technology in meeting project goals, and the benefits of LYMMO to the downtown Orlando community. Finally, the report concludes with an overall assessment of LYMMO's various technology applications, financial feasibility compared to alternative public transit modes considered for downtown Orlando, LYMMO's operational performance, and overall performance of LYMMO in meeting project objectives.



South Miami-Dade Busway System Summary (May 2003)
The South Miami-Dade Busway is one of FTA's BRT demonstration projects. The demonstration projects, located throughout the United States, were selected based on a solicitation published in the Federal Register. The aim of FTA's BRT Demonstration Program was to implement features of successful BRT systems located throughout the world in a manner that would be compatible with conditions in the United States. The purpose of evaluating each site was to determine what specifications were the most effective among BRT systems and the types of features that benefited and hindered the operation of the system in order to develop an approach to BRT that was suitable within the United States. This evaluation report provides an initial record and analysis of the South Miami-Dade Busway system as a newly implemented BRT system. Information compiled and presented in Chapter One acts as a historical summary, including details of system characteristics, ridership data, marketing efforts, and the use of technologies. Chapter Two reports results extracted through an onboard survey distributed among Busway users to serve as a review of the system. NBRTI completed the evaluation of the Busway system with assistance from the Miami-Dade Transit (MDT) and FTA.

Research Reports

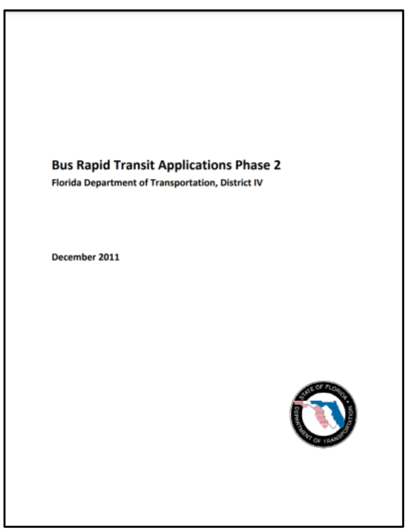
Evaluation of Alternative Fuel Vehicles in Bus Rapid Transit Service (June 2023)
Multiple BRT transit systems are currently operating alternative fuel vehicles (AFV) and advanced propulsion technologies in their fleets. The main benefits of alternative fuel vehicles compared to diesel vehicles include a reduction in harmful emissions, decrease in vehicle operating costs, and (in some cases) decrease in noise pollution. The most notable challenges associated with AFVs compared to diesel vehicles include higher vehicle acquisition costs, a higher cost of fueling infrastructure, higher fueling time, and lower range. The analysis of operations and maintenance cost data collected from 11 BRT systems for this study demonstrated that some AFVs can provide significant benefits in terms of lower operating costs and environmental benefits compared to conventional diesel vehicles. Compressed natural gas (CNG) and battery-electric buses seem to stand out as the most promising alternatives to diesel vehicles. Additionally, CNG and battery-electric vehicles provide significantly lower greenhouse gas (GHG) emissions than comparable diesel vehicles, as well as offer a noticeable reduction in most criteria pollutants. As a result, CNG and battery-electric buses have lower total cost of ownership, including social costs, than comparable diesel buses. Finally, alternative fuel vehicles may offer resilience benefits through diversification of fuels and fuel supply channels.

Bus Rapid Transit Safety (June 2023)
This report contains a detailed analysis of National Transit Database (NTD) Safety and Security data for BRT systems. From 2014 through 2022, 852 safety and security events occurred for the BRT mode: 77 security events and 775 safety events. Out of 775 safety events, 706 are collisions. Of the 77 security events, 71 are assaults. A total of 6 fatalities and 1,270 injuries resulted from the 852 events. Current research acknowledges equity implications, accessibility impacts, and impacts to vulnerable persons. This report presented evidence of this shifted focus and noted the importance of planning and design for BRT systems to be universal and inclusive to all people. There are also some additional operational issues to consider, such as roundabouts. Researchers are studying the best ways to operate transit vehicles through roundabouts with ease relative to the vehicle size and with minimal delays. As more BRT systems begin operations and others mature, there is still much to learn about inclusive planning and design practices and measures to reduce the frequency and severity of safety and security events.

Community-Oriented BRT: Urban Design, Amenities, and Placemaking (November 2012)
This report is a useful resource for communities that wish to learn how BRT can be used as a tool for enhancing the public realm. Information for this effort was gathered through a literature review, in-depth profiles of three BRT systems, and a detailed questionnaire that was administered to transit agencies in the United States, Canada, and Australia. While the literature review offers historical background on the relationship between transit projects and the public realm, the questionnaire focuses specifically on the interaction between BRT and public space. The system profiles provide an in-depth account of the Los Angeles Orange Line, the Cleveland HealthLine, and the EmX in Eugene, Oregon, along with recommendations and lessons learned. It should be noted that this report does offer detailed instructions of the type that would be found in design manuals or other highly technical literature. Rather, the focus is on sharing lessons and practices from agencies that have been successful at designing and building community value into BRT projects.

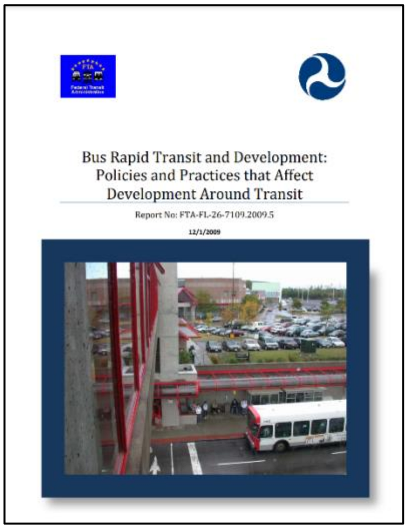
Land Use Impacts of Bus Rapid Transit Phase II – Effects of BRT Station Proximity on Property Values along the Boston Silver Line Washington Street Corridor (July 2012)

The development of BRT systems is relatively recent in the United States; however, several systems are operating and many more are being planned. A comprehensive understanding of the relationship between land uses and BRT systems is needed, particularly in comparison to other fixed-guideway modes such as rail. This report describes an effort to quantify the impacts of access to BRT stations on the sale prices of surrounding condominiums located along Boston's Washington Street where Phase I of the Silver Line BRT began in 2002. To test the hypothesis that the BRT stations have an impact on market value that is commensurate with rail transit projects (considering the level and permanence of services and facilities), a hedonic regression methodology was used to estimate the impact of access to the BRT station on sale prices of condo units. A key result is that for condo sales that occurred in 2007 or 2009, the BRT premium was approximately 7.6 percent. For condo sales in 2000 and 2001, prior to the opening of the Silver Line, no sales premium existed for proximity to the corridor. Further, changes in land uses along the corridor were examined over the period from 2003 to 2009. As more BRT systems continue operating in the United States, this methodology should be applied to other cities as well as to other types of properties. These studies can help policy makers and those in the transit industry gain a better understanding of the overall impacts of proximity to BRT stations on property values, land uses, and economic development.



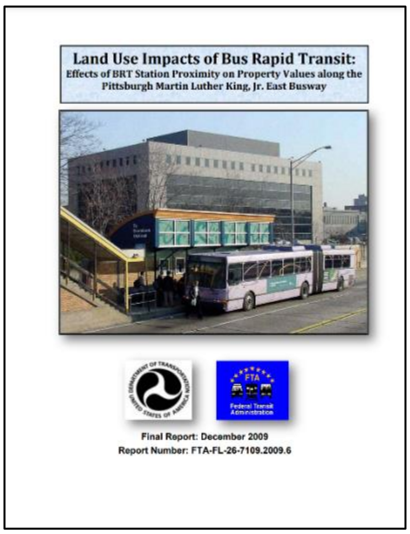
Bus Rapid Transit Applications Phase 2 (December 2011)

This report, prepared for the Florida Department of Transportation (FDOT) District Four office, provides a detailed summary of various U.S. BRT systems to support development of BRT in correlation with the Broward Metropolitan Planning Organization 2035 Long Range Transportation Plan. There are eight BRT systems included in this report: the Cleveland HealthLine, the Eugene EmX, the Kansas City MAX, the Los Angeles Metro Rapid system, the Los Angeles Orange Line, the San Pablo Rapid, the Boston Silver Line, and the Las Vegas MAX. The summary for each system comprises six parts: project background, costs, before and after performance, system characteristics, lessons learned, and future plans. Under system characteristics, information is provided on the running way, stations, vehicles, method of fare collection, ITS technologies, service and operations, and branding.



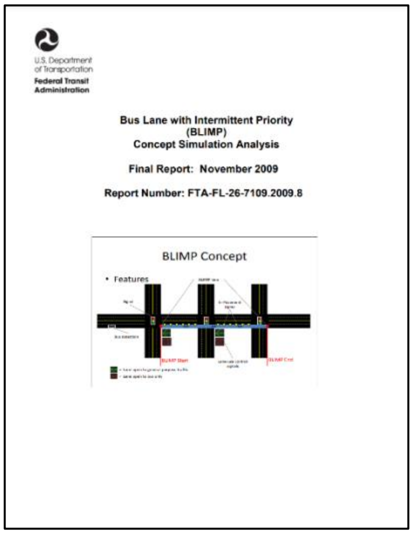
Bus Rapid Transit and Development: Policies and Practices that Affect Development Around Transit (December 2009)

There is a need for a more comprehensive understanding of the relationship between land use and BRT system development, particularly in comparison to other fixed-guideway modes such as heavy and light rail. While recognizing that existing land uses have an important and complex influence on the development costs and benefits of fixed-guideway projects, this report focuses primarily on the impact such projects have had on existing and future land uses and economic development, as well as the policies and practices used by local governments that have the potential to affect development. Additionally, this research examines whether the benefits and incentives offered along transit corridors between BRT and LRT are equitable in cities where both modes operate.



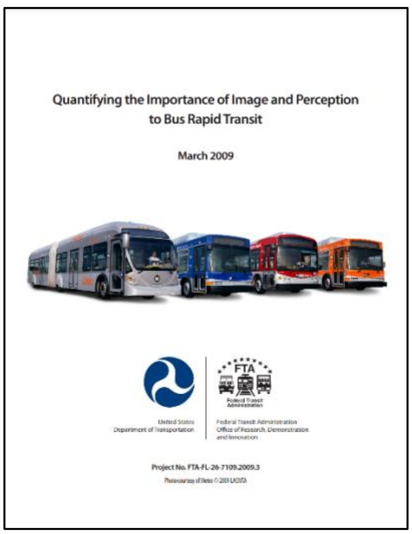
Land Use Impacts of Bus Rapid Transit: Effects of BRT Station Proximity on Property Values along the Pittsburgh Martin Luther King, Jr. East Busway (December 2009)

This report documents an effort to quantify the impacts of BRT stations on the values of surrounding single-family homes. The hypothesis is that BRT stations have an impact on property value that is commensurate with rail transit projects considering the level and permanence of services and facilities. To test this hypothesis, a hedonic regression model was used to estimate the impact of distance to a BRT station on the fair market value of single-family homes. Because many BRT systems operating in the United States may be too new to find evidence of capitalization into property values, data from Pittsburgh's East Busway, one of the oldest operating BRT systems in the country, was used. Decreasing marginal effects were found: moving from 101 to 100 feet from a station increases property value approximately $19.00, while moving from 1001 to 1000 feet increases property value approximately $2.75. The results shown in this report are only valid for the data used in Pittsburgh's case. As more BRT systems continue operating in the United States for more years, this method should be applied to other cities and other types of properties to gain a better understanding of the general property value and land use impacts of proximity to BRT.



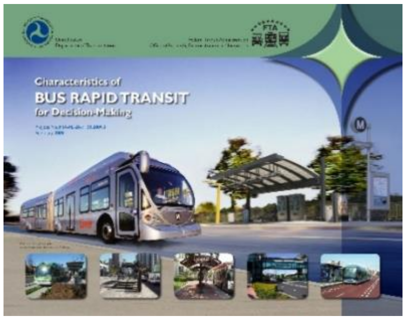
Bus Lane with Intermittent Priority (BLIMP) Concept Simulation Analysis (November 2009)

In cooperation with Lane Transit District, NBRTI completed a preliminary implementation study to determine the potential impacts of a new and innovative transit priority treatment along a BRT corridor in Eugene, Oregon. The bus lane with intermittent priority (BLIMP) utilizes dynamic lane assignment to designate an exclusive bus lane on a temporary, bus-actuated basis. The temporary lane is designated via overhead variable message signs and in-ground dynamic lane markings. With no existing reference, a VISSIM microscopic traffic and transit simulation model was developed for the study corridor. The simulation model was used to identify potential benefits and disadvantages of the BLIMP concept and to compare BLIMP to other potential BRT treatments including no-build, transit signal priority, and exclusive bus lanes. The results indicate that travel time and travel time reliability would improve upon implementation of the BLIMP concept while having minimal impact on overall intersection delay. Additionally, evaluation of movement delays indicated that concurrent movements would see improvement while conflicting movements would see minimal change with the BLIMP concept.

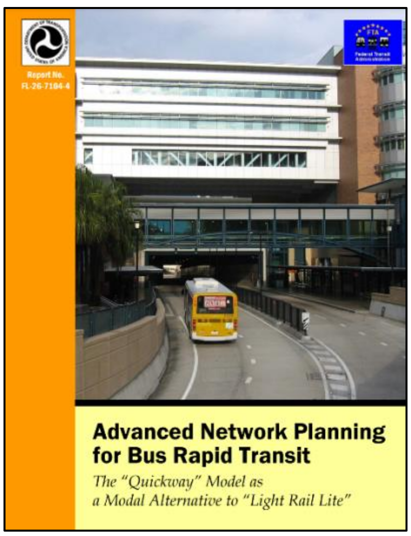


Quantifying the Importance of Image and Perception to Bus Rapid Transit (March 2009)

This study quantified the importance of image and perception to BRT by identifying the different underlying tangible and intangible factors that drive differences in perception between BRT and other forms of rapid transit. *Tangible* service attributes refer to those that are functional and objectively quantifiable, whereas attributes that are abstract, subjective, and more difficult to measure and quantify are termed *intangible*. A series of focus groups were conducted in late 2007, followed in 2008 with an attitudinal survey of 2,400 transit users and non-users in the Los Angeles area. Survey data analysis showed that statistically significant differences exist in the overall ratings achieved by the alternative transit modes. These overall ratings were compared against the level of investment associated with each mode, defined in terms of capital cost per mile. Given that the investment level associated with the Metro Rapid is much closer to that of the local bus than to any of the other modes, it was concluded that the Metro Rapid performs remarkably well in terms of overall rating achieved per dollar of investment, and therefore represents a very cost-effective form of BRT. The Orange Line BRT also performed well in terms of overall rating achieved per dollar of investment, though not to the dramatic level associated with the Metro Rapid. Overall, these findings showed that, even in its lower investment forms, BRT can compete with rail-based transit (at least in the perception of the general public) in return for lower capital cost investments.



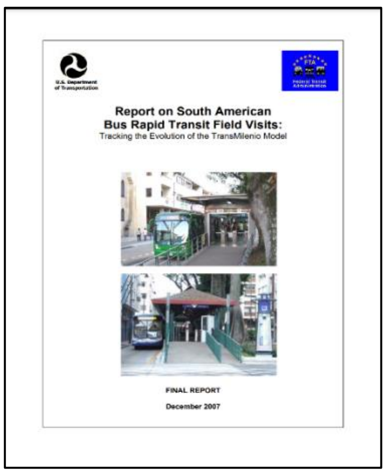
Characteristics of Bus Rapid Transit for Decision-Making (February 2009)
The Characteristics of Bus Rapid Transit for Decision-Making (CBRT) document, originally published in 2004, was updated and revised for FTA by a consortium of organizations led by NBRTI. The updated CBRT document provides transportation planners and decision-makers with basic information and data to support the development and evaluation of BRT concepts as one of many options during alternatives analyses and subsequent project planning. Information on BRT systems is given in a single, easy-to-use reference tool for transportation planners in selecting from the large array of BRT elements and integrating them into comprehensive systems. Additionally, the CBRT explores BRT through a progression of three different perspectives. First, seven major elements of BRT are presented along with their respective features and attributes. Second, the BRT elements are related to attributes of system performance. Finally, the benefits of BRT systems are discussed.



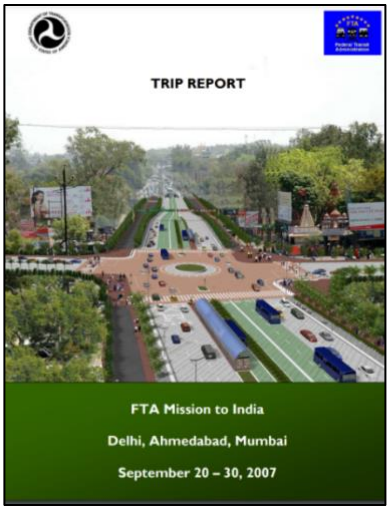
Advanced Network Planning for Bus Rapid Transit (February 2008)
Transit planning in the United States has tended toward viewing BRT as an analogue to light rail transit, with similar operating patterns. This model, referred to as "Light Rail Lite," is compared to international best practices, which have often favored the development of a grade-separated bus infrastructure ("Quickways") that in turn supports a varied mix of all-stops, express, and branching services. This model, dubbed the Quickway model, evolved out of the practical necessity of cities to meet ambitious ridership or mode split targets. In this report, the two models are contrasted along the key dimensions of BRT service, and significant differences are identified. Three international case studies—Ottawa, Bogotá, and Brisbane—are reviewed for their particular application of this model and of the results they obtained. Four domestic cities are compared to these international examples: Eugene, Oregon, and Los Angeles are profiled for their adoption of the Light Rail Lite model, and Pittsburgh and Miami are profiled for their BRT implementations that share elements in common with the Quickway model. A set of lessons is drawn from this comparison, including a review of conditions that may favor the adoption of either model or light rail in any given urban context. Recommendations are offered at the levels of the federal government, metropolitan planning organizations, and planning and engineering firms for the proper planning and evaluation of Quickway-based alternatives.

Scanning Tour Reports

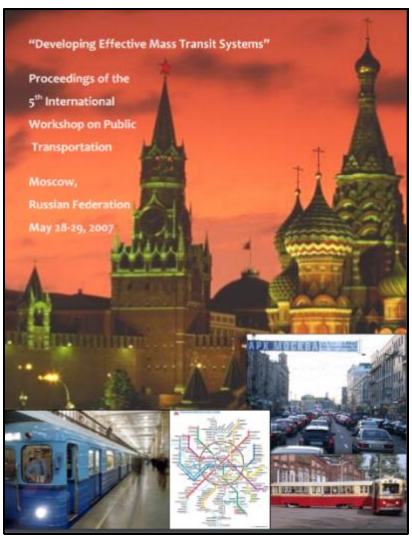
FTA Mission to India – Delhi, Visakhapatnam, Hyderabad, Mumbai (November 2008)
This report summarizes the activities that occurred as part of the FTA Mission to India in September 2008. The mission provided the opportunity for members of the U.S. delegation to meet with senior Indian transportation officials, and to learn of India's current plans for transportation infrastructure improvements. The tour was also designed to identify lessons learned for the U.S. transit industry, particularly in relation to the implementation and operation of BRT systems, and to identify opportunities for U.S. transit industry involvement in the development of India's transportation infrastructure. The mission itinerary included visits to Delhi, Visakhapatnam, Hyderabad, and Mumbai. A highlight of the mission was the signing of a Memorandum of Cooperation between the United States Department of Transportation and the State of Maharashtra while in Mumbai. The Memorandum is designed to facilitate knowledge exchange between the two countries in the fields of public transportation, science, and technology.



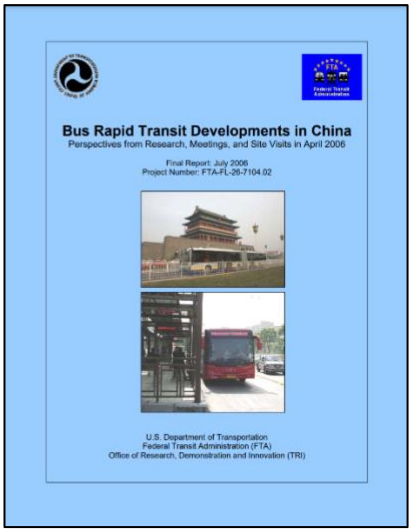
Report on South American Bus Rapid Transit Field Visits: Tracking the Evolution of the TransMilenio Model (December 2007)
This report summarizes the background, status, and lessons from BRT plans and operations in three South American cities—Bogotá, Colombia; Pereira, Colombia; and Guayaquil, Ecuador—gathered through independent research, technical visits, and meetings with operators and officials on February 11–16, 2007. Pereira's Megabús and Guayaquil's Metrovía represent the latest generation of BRT systems in South America, modeled after Bogotá's very successful TransMilenio system. The findings of this report focus on observations about cost-effective investments and standards, service and operations models, and institutional models to improve the performance and sustainability of BRT.



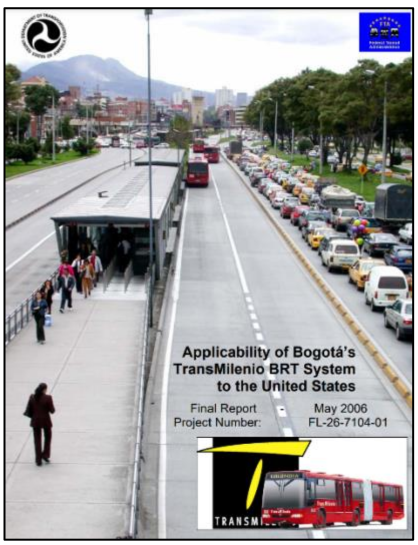
FTA Mission to India: Delhi, Ahmedabad, Mumbai (September 2007)
This report summarizes the activities associated with the FTA Mission to India conducted in September 2007. The mission provided the U.S. delegation with the opportunity to meet with senior Indian transportation officials, and to gain first-hand knowledge of India's current plans for transportation infrastructure improvements. The tour was also designed to identify any lessons learned for the U.S. transit industry, particularly in relation to the implementation and operation of BRT systems, and to identify opportunities for U.S. transit industry involvement in the development of India's transportation infrastructure. The mission itinerary included visits to Delhi, Ahmedabad, and Mumbai, as well as attending a BRT Workshop in Ahmedabad and the India Urban Space Conference in Mumbai. A highlight was the formal ratification of a Memorandum of Cooperation between the U.S. Department of Transportation and the Ministry of Urban Development, Government of the Republic of India. It was designed to enable the two countries to collaborate in the fields of public transportation, intermodal transportation, intelligent transportation systems, traffic information, capacity building, and training in public transportation, in addition to other fields of mutual interest.



Developing Effective Mass Transit Systems: 2007 Moscow Conference Proceedings (May 2007)
FTA, in conjunction with the U.S. Embassy, the Russian Ministry of Transportation, the City of Moscow, and the Ministry of Transport of the Moscow Oblast (Regional) Government, hosted a bilateral conference to discuss the effective implementation of public transit systems. The conference was convened in Moscow, May 28–29, 2007, to provide a forum through which the relevant government officials of the United States and Russia, as well as representatives of the public and private sectors of the public transit industry, could hold in-depth discussions on the four identified conference themes: Transit Planning and Congestion Management, Ensuring Safety and Security on Public Transit Systems, Providing Accessible Public Transit to the Mobility Impaired, and Training Public Transit Professionals. This report was produced to document the material presented at the conference, to provide a synthesis of the conference findings, and to define the action items to be pursued in further collaborative efforts between the United States and the Russian Federation.



Bus Rapid Transit Developments in China (July 2006)
This report summarizes the information related to BRT developments in China collected through independent research and a visit to China, April 17–26, 2006, as part of an FTA Public Transportation Trade Mission. The purpose NBRTI's participation in the mission was to visit operational BRT systems and to meet with organizations engaged in BRT planning or operations in China. By establishing initial contact with such organizations, a channel of communications has been opened to exchange information and allow for future cooperation on common problems or programs. Specifically, it is hoped that data from BRT systems in China can be included in the update of the FTA publication *Characteristics of Bus Rapid Transit for Decision-Making* to expand the understanding of viable systems and the range of possible performance, cost, and benefits. This report also synthesizes the relevant background on China's institutions, demographic and economic growth, policies, and initial data on BRT systems in China in operations and planning. It concludes with observations and recommendations for future cooperation in areas of common interest.



Applicability of Bogotá's TransMilenio BRT System to the United States (May 2006)
Serving the city of Bogotá, Colombia, TransMilenio is one of the world's premier BRT systems. Commencing service in December 2000, the system was carrying over one million passengers per day by early 2006 on a 40-mile network of high-capacity trunk corridors, supported by feeder services that extend system coverage to peripheral areas of the city. The city Masterplan consists of a 241-mile network of trunk corridors and supporting feeder routes that would carry an estimated five million passengers per day. TransMilenio is also the centerpiece of a long-term urban renewal and mobility strategy that prioritizes walking and cycling and discourages private vehicle use. In November 2005, NBRTI sent a delegation of U.S.-based BRT professionals to Bogotá to observe the operation of the TransMilenio system, attend the First International Mass Transport Conference, and meet with Colombian transportation officials. This report provides a description of the TransMilenio system and its impacts and discusses its applicability to the U.S. transit context.

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Conclusion

Despite BRT's rapid rise to prominence, it is still a relatively recent development in the United States, and the transit industry continues to rely on guidance from targeted research activities. To provide decision-makers with a more complete understanding of the mode's cost, performance, and impacts, research on BRT in the United States must progress beyond case studies to consider the life cycle costs of maturing systems. At the same time, agencies need more information on the physical, operational, cost, performance, and other potential benefits of BRT, especially amid new operating environments and the continuing trend toward smaller, corridor-based projects.

Additionally, recent technological advancements in ITS, big data, and vehicle automation show strong potential for benefiting BRT implementations. Indeed, FTA's Strategic Transit Automation Research (STAR) Plan includes BRT as a major use case for demonstration and evaluation of automation technologies. However, public transportation faces some unique challenges with regard to vehicle automation. Bus manufacturing is a relatively small industry and is therefore not able to take on a high level of risk when developing new vehicle technologies. Also, few agencies are collecting the data necessary to safely deploy vehicle automation at SAE levels 3–5 on BRT corridors.

To fully realize the improvements in mobility, congestion, and economic growth that BRT can produce, the transition from individual BRT lines to integrated BRT route networks would be a major step forward. Also, BRT features are increasingly spreading to non-BRT corridors, meaning that BRT-lite may become the de facto bus system of the future. Given that buses account for almost half of the nation's transit trips, improved bus services could have a significant impact on transit's overall mode share in the future. As new BRT systems are implemented and early deployments evolve, the continued study and documentation of BRT's challenges, benefits, and new lessons learned would be of great value to the transit industry.

Appendix A

Evaluation of Alternative Fuel Vehicles in Bus Rapid Transit Service

Photo Credit Alexander Kolpakov

Abstract

Multiple BRT transit systems are currently operating alternative fuel vehicles (AFV) and advanced propulsion technologies in their fleets. The main benefits of alternative fuel vehicles compared to diesel vehicles include a reduction in harmful emissions, decrease in vehicle operating costs, and (in some cases) decrease in noise pollution. The most notable challenges associated with AFVs compared to diesel vehicles include higher vehicle acquisition costs, a higher cost of fueling infrastructure, higher fueling time, and lower range.

The analysis of operations and maintenance cost data collected from 11 BRT systems for this study demonstrated that some AFVs can provide significant benefits in terms of lower operating costs and environmental benefits compared to conventional diesel vehicles. CNG and battery-electric buses seem to stand out as the most promising alternatives to diesel vehicles. Additionally, CNG and battery-electric vehicles provide significantly lower GHG emissions than comparable diesel vehicles, as well as offer a noticeable reduction in most criteria pollutants. As a result, CNG and battery-electric buses have lower total cost of ownership, including social costs, than comparable diesel buses. Finally, alternative fuel vehicles may offer resilience benefits through diversification of fuels and fuel supply channels

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Executive Summary

The current analysis synthesizes relevant information on the use of alternative fuel vehicles in bus rapid transit (BRT) service in the United States, as well as summarizes recent data on the performance and operating costs of these technologies, allowing the evaluation of their advantages and limitations. The information used in this report was mainly collected through surveying transit providers around the country that operate BRT service. Some general information was also collected through a literature search and discussions with industry professionals.

The main benefits of alternative fuel vehicles (AFVs) compared to diesel vehicles include a reduction in harmful emissions, decrease in vehicle operating costs, and (in some cases) a decrease in noise pollution. The most notable challenges associated with AFVs compared to traditional diesel vehicles include higher vehicle acquisition costs, a higher cost of fueling infrastructure, higher fueling time, and lower range.

Bus rapid transit providers were among the first to embrace alternative fuels and advanced propulsion technologies. Multiple BRT transit systems, both urban and rural, currently operate alternative fuel vehicles and advanced propulsion technologies in their fleets.

The survey of 14 BRT providers revealed the following results:

- Of the total 243 BRT vehicles reported by the agencies responding to the survey, 35.0% are diesel hybrids, 27.6% are diesel vehicles, 20.2% are battery-electric buses, and 17.3% are compressed natural gas (CNG) vehicles. Practically all vehicles of all propulsion types reported by the agencies are either 40-foot buses or 60-foot articulated buses.

- The majority of surveyed agencies perform vehicle maintenance in-house for both conventional and alternative fuel vehicles in their fleet. Only one agency reported contracting out maintenance for both conventional and alternative fuel vehicles. The survey did not identify noticeable differences in maintenance approaches between conventional diesel and alternative fuel vehicles, except for the use of different mechanic job classifications.

- None of the surveyed transit agencies currently use autonomous vehicles (AVs) in their BRT service. The BRT providers surveyed for this study remain cautious about implementing vehicle automation in BRT service. Three agencies (27.3% of responders) reported that they would be comfortable using AVs in BRT service now. More than 45.0% of surveyed BRT providers reported not being comfortable using AVs in BRT service in the next five years, and 18.2% will not consider using AVs in the next 10 years.

- The majority of surveyed transit agencies (75.0% of responders) reported not planning to implement AV technologies in BRT service in

the next one to three years. The agencies that indicated willingness to implement AV technologies in BRT listed two potential AV projects that they may consider, including Level-4 automation of 40-foot electric buses and braking and steering assist for station docking control.

- The primary reasons for not implementing AV technologies in BRT include the following: technology is not yet capable of ensuring safe operations, the high cost of new technology and infrastructure, limited internal knowledge on AVs, lack of local leaders' support, conflicts with local code, and other reasons.

The analysis of detailed operations and maintenance cost data collected from 11 BRT agencies revealed the following results:

- Of the 274 reported BRT vehicles in the data sample, more than 39.0% (107 vehicles) are CNG and approximately 23.0% (64 vehicles) are conventional diesel vehicles. Diesel hybrid and battery-electric vehicles represent 18.2% (50 vehicles) and 17.2% (47 vehicles) of the reported BRT fleet, respectively. Biodiesel vehicles account for slightly over 2.0% (6 vehicles) of the reported BRT vehicles.
- Sixty-foot articulated buses seem to be the most popular vehicle size for all types of reported BRT vehicles. Almost two-thirds of the reported CNG vehicles, 64.1% of diesel and 83.0% of battery-electric vehicles in the sample, are 60 feet in length. Additionally, all reported biodiesel vehicles and 54.0% of diesel hybrid vehicles are 60-foot buses.
- Sixty-foot CNG buses demonstrate 11.2% higher fuel mileage, 49.0% higher scheduled parts cost per mile, 52.1% lower unscheduled parts cost per mile, 22.2% lower scheduled labor cost per mile, 74.5% lower unscheduled labor cost per mile, and 53.1% lower fuel cost per mile[1] than comparable diesel buses. At the same time, 60-foot CNG buses are comparable in price to similar diesel buses (CNG vehicles are 5.5% more expensive to acquire than comparable diesel buses).
- Sixty-foot battery-electric buses have fuel mileage that is almost four times higher than comparable 60-foot diesel buses.[2] Additionally, 60-foot battery-electric buses demonstrate 68.2% lower scheduled parts cost per mile, 86.7% lower unscheduled parts cost per mile, 42.4% lower scheduled labor cost per mile, 46.9% lower unscheduled labor cost per mile, and 71.1% lower fuel cost per mile, compared to 60-foot diesel buses. Articulated battery-electric buses are 33.0% more expensive to purchase than comparable diesel vehicles.

[1] All fuel prices are reported as of July 2022: Diesel – $5.64/gal; Electricity – $0.16/kWh; CNG – $2.76/DGE; B-20 – $5.34/gal.

[2] Fuel mileage for battery-electric buses is calculated based on diesel gallon equivalent conversion (1 diesel gallon equivalent = 40.26 kWh).

- Articulated battery-electric buses demonstrate the lowest overall vehicle costs per mile, followed by CNG and biodiesel. Diesel hybrid BRT buses in this data sample show the highest overall cost per mile.

- The data demonstrate that 60-foot battery electric buses have the lowest parts cost per mile, fuel cost per mile, and the overall operating cost per mile than similar vehicles of other propulsion types. Total operating costs of 60-foot articulated battery-electric buses are 67.8% lower than total operating costs of comparable diesel BRT buses. Sixty-foot CNG vehicles have the lowest labor cost per mile and the second lowest overall operating cost per mile, which is still 51.0% lower than the overall operating cost per mile of comparable diesel vehicles. Diesel hybrid buses demonstrate the highest labor cost per mile (almost twice that of 60-foot diesel buses) of all reviewed propulsion types and the highest overall operating cost per mile (12.3% higher than for diesel vehicles) of all 60-foot articulated buses in the data sample.

- Forty-foot buses are the second most popular vehicle size for BRT buses in the data sample. Forty-foot CNG buses have the lowest parts cost per mile, lowest fuel cost per mile, and the lowest overall operating cost per mile. Forty-foot diesel hybrid buses demonstrate the highest parts cost of all propulsion types, the highest fuel cost, and the highest overall operating cost per mile. Total operating cost per mile of 40-foot diesel hybrid BRT buses is 43.4% higher than CNG vehicles and 15.2% higher than diesel vehicles of the same size.

- CNG vehicles of all sizes demonstrate the lowest labor cost per mile and the second lowest overall operating cost per mile, compared to vehicles of other propulsion types. Biodiesel vehicles, on the other hand, show the highest labor cost, the highest fuel cost, and the highest overall operating cost per mile of all compared propulsion types. Battery-electric buses of all sizes demonstrate the lowest parts cost per mile, the lowest fuel cost per mile, and the lowest overall operating cost per mile of all propulsion types considered in this analysis.

The analysis presented in the current report demonstrates that some alternative fuel vehicles can provide significant benefits in terms of lower operating costs and environmental benefits compared to conventional diesel vehicles. CNG and battery-electric buses stand out as the most promising alternatives to diesel vehicles. Additionally, CNG and battery-electric vehicles provide significantly lower GHG emissions than comparable diesel vehicles, as well as offer a noticeable reduction in most criteria pollutants. As a result, CNG and battery-electric buses have lower total cost of ownership, including social costs, than comparable diesel buses.

Overall, except for initial acquisition cost, battery-electric buses demonstrate the largest benefits over diesel buses among other reviewed transit technologies. Dramatic increase in funding for zero-emission buses provided by Bipartisan Infrastructure Law (BIL) intends to decrease the upfront acquisition cost of battery-electric buses to transit agencies and make them comparable to diesel buses in the long run. If these efforts succeed in lowering incremental cost of battery electric buses, this will likely result in the increased pace of electrification of transit fleets.

In addition to a reduction in operating costs, AFVs can potentially offer resilience benefits. There are several notable case studies where alternative fuels provided critical transportation needs after natural disasters when conventional fuels were not available or were in short supply. These examples include the use of CNG minibuses in Atlantic City and the use of CNG bi-fuel pickup trucks in New York and New Jersey after Hurricane Sandy, and CNG transit buses in Houston after Hurricane Harvey.

A side-by-side comparison of the environmental costs of 60-foot buses of different propulsion types using the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool shows that:

- Diesel buses have the highest total externality costs ($177,478 over the life of the vehicle), followed by diesel hybrid buses ($175,681 over the life of the vehicle) and biodiesel buses ($151,719 over the life of the vehicle). Of all propulsion types, electric and CNG buses demonstrate the lowest total externality costs ($34,930 for electric and $71,094 for CNG). Greenhouse gas (GHG) emissions costs represent the largest share of all externality costs, while air pollution costs represent the smallest share of total externality costs for vehicles of all propulsion/fuel types.
- Diesel hybrid buses have the highest total cost of ownership ($3,418,230 over the life of the vehicle), while battery-electric and CNG buses have the lowest ($1,864,866 for battery-electric and $1,975,260 for CNG over the life of the vehicle). Total cost of ownership (TCO) for battery-electric buses is 37.1% lower than for diesel buses. Total cost of ownership for CNG buses is 33.4% lower than for diesel buses, while TCO for biodiesel vehicles is 7.4% lower than for comparable diesel buses. At the same time, TCO for diesel hybrid buses is 15.3% higher than for comparable diesel vehicles.

The results of the analysis presented in the current study are based on a small data sample and may not represent the entire population of BRT providers and vehicles in the country. The analysis is based on real-life performance and costs of vehicles in the field, reported by the agencies, rather than technology testing conditions. Additionally, the analysis relies on primary data collected through a stated preference survey that may not always reflect the true preferences of responders. Recognizing these limitations, the results of the current analysis should be interpreted with caution.

Introduction

Public transit can reduce congestion and achieve better energy efficiency in the transportation sector since transit vehicles carry more passengers per vehicle than personal autos. Bus rapid transit (BRT) service that provides comfortable, fast, and cost-effective service with metro-level capacity is particularly appealing for addressing road capacity limitations and environmental challenges in the urban environment.

Transit buses are well-suited for alternative fuel technologies that improve energy efficiency and reduce harmful emissions. Transit agencies around the country continue to be under pressure to reduce operating costs and to run a more sustainable and environmentally friendly fleet in the urban environment, including the agencies that run BRT service. Funding made available through the federal economic stimulus effort known as the American Recovery and Reinvestment Act of 2009 (ARRA) has aided growth in the acquisition of alternative fuel transit vehicles. In addition, technological changes or innovations to modify low- or no-emission vehicles or facilities may receive funding through FTA's Buses and Bus Facilities Competitive Program. Given the ability of bus rapid transit service to move a large number of people in highly congested urban areas, implementing advanced propulsion and alternative fuel technologies on BRT has a great potential for achieving environmental and energy efficiency benefits.

The current analysis attempts to synthesize relevant information on the use of alternative fuel vehicles in BRT service in the United States, as well as summarize recent data on the performance and operating costs of these technologies to evaluate their advantages and limitations. This study is intended to assist decision-makers considering the pros and cons of using alternative fuel vehicles and other advanced propulsion transit technologies to provide BRT service.

Methodology

The information used in this report was mainly collected through surveying transit providers around the country that operate BRT service and a few engineering consulting companies with experience in implementing alternative fuel or automated vehicle transit projects. Some general information was also collected through literature search and discussions with industry professionals.

The survey for transit providers included 25 questions aimed at gaining basic information on their experience and attitudes regarding the implementation of alternative fuel vehicle (AFV) and autonomous vehicle (AV) technologies in BRT service. The questionnaire for BRT providers is included in Sub-Appendix 1.

The survey was administered online and was distributed to all BRT providers in the United States. The American Public Transportation Association (APTA) BRT committee played an active role in providing outreach for the survey, distributing the survey link to BRT providers, and encouraging agencies to participate. Additionally, Center for Urban Transportation Research (CUTR) researchers reached out individually to agencies known to run alternative fuel vehicles to request their participation in the survey and data collection. In addition to the survey, researchers also requested that BRT providers supply vehicle-specific operating and maintenance (O&M) cost data for their fleets running in BRT service, including both alternative fueled and conventional vehicles. Agencies were asked to complete a spreadsheet-based data collection form and return it to CUTR. The fleet operating cost data collection form is included in Sub-Appendix 2.

Overall, 14 BRT providers responded to the survey with meaningful data, including partial responses. Additionally, 11 transit agencies offered more detailed O&M data covering fuel use, mileage, and parts and labor costs for their AFV fleets. While the data request was sent together with the request to complete the survey, some agencies completed the survey but did not provide O&M data, while others provided the data without completing the survey. Therefore, there is no perfect overlap between the agencies that gave survey responses and the agencies that gave cost data.

The results of the survey of BRT providers, as well as AFV performance and cost analysis, are discussed in detail in the following sections of this report.

1. Use of Alternative Fuel Vehicles in BRT Service – Literature Review

In 2019, more than 55% of public transit buses in the United States ran on alternative fuels or employed hybrid technologies (AFDC 2021). Transit agencies across the country often switch their fleets to alternative fuel vehicles (AFVs) because these technologies help reduce harmful emissions and can provide long-term reductions in fleet operating and maintenance costs.

Funding made available through the federal economic stimulus effort known as the American Recovery and Reinvestment Act of 2009 (ARRA) has aided growth in the acquisition of alternative fuel transit vehicles. Some transit agencies received funding through the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) grant program (part of ARRA), while others used regular transit capital funds. The dramatic increase in the number of battery-electric transit bus purchases in recent years was supported by the Federal Transit Administration's (FTA) Low or No Emission (Lo-No) grant program that provides funding for the acquisition of zero-emission and low-emission transit vehicles. The

Infrastructure and Investment Jobs Act (IIJA), Public Law 117-58, enacted November 15, 2021 (also known as the "Bipartisan Infrastructure Law") enacted by Congress in November of 2021, provides $5.6 billion to the FTA's Lo-No program to transition to zero-emission buses in the next 5 years, through 2026 (FTA, 2021). This funding is more than 10 times greater than was allocated to Lo-No program during the past 5 years. Such dramatic increase in funding will likely accelerate purchases of battery-electric buses. Rapid developments in alternative fuel technologies recently, particularly the dramatic improvements in battery technologies, have also contributed to the accelerated growth in public transit's adoption of alternative fuel and hybrid technologies.

The adoption, however, does not always go smoothly. Higher reliance on alternative fuels and propulsion technologies has increased both capital and operating costs for some fixed route operators and has created challenges for widespread adoption of advanced transit technologies. Additionally, the variety of advanced technologies available often makes it difficult for transit agencies to choose the one that will best fit their needs in the long run.

Examples of AFVs in BRT

BRT providers were among the first to embrace alternative fuels and advanced propulsion technologies. Multiple BRT transit systems, both urban and rural, currently operate alternative fuel vehicles in their fleets. For example, Roaring Fork Transit Authority's (RFTA's) VelociRFTA BRT program was the first rural BRT system in United States that introduced compressed natural gas (CNG) buses into its operations. RFTA's BRT system also faces one of the most severe operating conditions in the country with extreme winter temperatures and an altitude of approximately 8,000 feet. RFTA introduced 22 CNG buses in 2013 that were evaluated over several years and the project was determined a success (Mitchell 2015).

Greater Cleveland Regional Transit Authority (RTA) operates a fleet of 63-foot hybrid-electric buses on its first BRT line, called HealthLine, which opened in 2008. It is estimated that RTA's HealthLine is responsible for more than $9.5 billion in economic development along the route's corridor, resulting in a return of $190 for every transit dollar invested (RTA 2018). San Joaquin Regional Transit District (RTD) has been running battery-electric buses in BRT service since 2017. When this BRT project was implemented in August 2017, it was the first 100% electric BRT route in the United States. (METRO Magazine 2017).

Massachusetts Bay Transportation Authority (MBTA) has been running CNG buses on its Silver Line BRT route. When service began in 2002, 60-foot buses were still on order and MBTA had to use 40-foot low-floor CNG New Flyer buses temporarily. In July 2003, 40-foot buses on the Silver Line were replaced by 60-foot articulated low-floor CNG buses that have continued operating since then. By 2005, MBTA's Silver Line BRT project achieved an increase in ridership, improved operating cost efficiency, attracted new customers to transit, and improved customer satisfaction. These improvements were achieved with relatively modest investment. The total project capital cost was $27 million, or approximately $11 million per alignment mile (Schimek, Darido, and Schneck 2005).

The San Diego Metropolitan System (MTS) operates 220 40-foot CNG buses and 70 60-foot CNG buses in its fleet. Of these vehicles, 101 CNG buses, including 86 60-foot articulated and 15 40-foot buses, are used on several BRT routes, called the "Rapid" system. San Diego's Rapid system continues to grow, with a new 26-mile BRT route (South Bay Rapid) currently being implemented to connect the U.S.-Mexico border to downtown San Diego (METRO Magazine 2018).

In September 2019, Indianapolis Public Transportation Corporation (IndyGo) opened the city's first BRT line (Red Line), which is planned as the first phase of a robust BRT system consisting of three crossing lines. The use of battery-electric 60-foot articulated buses on the Red Line makes it one of the few 100% all-electric BRT systems in the United States (Renn 2019). Red Line is serviced by 13 BYD K11 60-foot articulated battery-electric buses that were developed specifically for rapid transit service. IndyGo plans to increase the number of these electric buses to 31 in the near future (Jensen 2019).

While Indy's Red Line opened recently and there is not enough data yet to evaluate its performance, it clearly demonstrates a growing trend of employing alternative fuel vehicles (especially electric) for BRT service in urban areas.

CTfastrak is Connecticut's first BRT system, centered around a 9.4-mile-long dedicated bus guideway that links central Connecticut communities including Bristol, Cheshire, Hartford, New Britain, Manchester, Newington, Southington, Waterbury, and West Hartford. The system was constructed with the help of FTA's New Starts program funding and opened in March 2015. CTfastrak uses diesel hybrid buses to provide service (CT Transit 2020).

These are just a few notable examples of successful AFV use in BRT service. There are many more examples, both in the United States and overseas.

Benefits of Alternative Fuel Vehicles

High dependence of the transportation sector on petroleum-based fuels contributes significantly to emissions. Petroleum products account for approximately 90% of the total energy used by the U.S. transportation sector. Biofuels, such as ethanol, and biodiesel account for approximately 5% of the total energy consumed by the transportation sector. Natural gas accounts for approximately 3%, while electricity accounts for less than 1%

of the total energy consumed by transportation and nearly all of that is used in public transit (EIA 2020). A large portion of petroleum-based products is produced from imported oil, raising concerns about stable petroleum supplies and national energy security.

Emissions Reductions

With increased domestic petroleum production and the recent trend of the United States becoming a net energy exporter, energy security may become less significant. In addition to reducing dependence on imported energy sources, wide use of alternative fuel vehicles can also provide environmental benefits in terms of emissions reductions.

Natural gas burns much cleaner than gasoline or diesel, emitting less nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2). Although, current emissions regulations have greatly reduced the tailpipe emissions advantage of natural gas vehicles over conventional vehicles. Plug-in electric vehicles (PEVs) that operate solely on electricity have zero tailpipe emissions. However, generating electricity does produce emissions that can be associated with operating electric vehicles (EVs). The environmental benefits of EVs and plug-in hybrid electric vehicles (PHEVs) depend heavily on the source of electricity generation. Electric vehicles operating in regions that use low-polluting sources for electricity generation have significant emissions reduction advantages over conventional vehicles. When electricity generation relies heavily on traditional fossil fuels, electric vehicles may not be able to demonstrate life-cycle emissions benefits.

Unlike oil, natural gas is abundant in the United States and is produced domestically from a variety of sources that can range from conventional extraction to renewable sources. Higher reliance on domestically produced energy sources for transportation reduces the country’s dependence on imported oil and improves energy security.

Operating Costs

Alternative fuel vehicles can provide operating cost savings due to lower fuel and maintenance costs. Since natural gas burns cleaner than diesel and gasoline, engines running on natural gas typically last longer and do not require as many repairs/rebuilds as the ones running on conventional fuels. This is particularly valuable for high-mileage fleets, such as transit vehicles.

Electric vehicles potentially require less maintenance since they have fewer moving parts than conventional vehicles. While internal combustion engines have hundreds of moving parts, an electric motor has only one, the shaft, rotated by an electromagnetic field. Additionally, while conventional vehicles use multispeed transmissions, EVs don’t have traditional gearboxes, but are rather configured as single-speed gear reduction units.

Noise Pollution

Low emissions and low noise pollution are extremely desirable for BRT, especially when BRT lines are in central business districts with high population densities. With a high volume of bus traffic, community acceptance can depend on the use of low polluting and quiet vehicles. Low onboard noise level is also preferred by customers. Battery-electric and hybrid-electric buses typically produce a low level of noise and are often preferred for operating in high-density areas. Electric motors work so quietly that tires often generate the only noise on a moving battery-electric vehicle.

AFV Challenges

Major barriers to AFV adoption include higher upfront vehicle cost, limited fueling infrastructure, longer fueling time, and lower vehicle range (especially for electric vehicles) compared to conventional vehicles. While AFV upfront costs vary, alternative fuel vehicles typically require higher upfront costs to acquire or to retrofit vehicles to run on alternative fuels than traditional internal combustion engine (ICE) vehicles.

Vehicle Acquisition Costs

High upfront acquisition costs present a problem for AFV adoption, even when alternative fuel technologies provide lower life cycle costs than conventional vehicles. Future fuel savings can be uncertain due to unpredictable fuel prices, potential variations in vehicle use, and uncertain vehicle lifetime. Vehicle owners may value upfront costs more than long-term benefits and may not be willing to pay more for better fuel economy. Behavioral economics explains this phenomenon in terms of risk aversion. When faced with a risky bet, a rational risk-averse person values potential loss higher than potential gains and exaggerates the probability of loss. This can result in undervaluing the life cycle cost benefits of AFVs (NRC 2013).

On average, CNG transit buses are 10% more expensive to acquire than comparable diesel buses. The acquisition cost of hybrid-electric buses is 35% higher than diesel transit buses, while battery-electric buses cost 80% more to purchase than comparable diesel buses. Hydrogen fuel cell buses cost more than twice (125% more) to purchase than comparable diesel buses (AFLEET 2020).

Fueling Infrastructure

Despite healthy growth in alternative fueling infrastructure over the past 10 years, both natural gas and EV charging stations are still not as widely available as fueling stations for conventional vehicles. Additionally, fueling infrastructure costs remain significantly higher than fueling infrastructure for diesel transit vehicles.

Transit agencies converting fleets to alternative fuels can invest in a private fueling station or rely on a public fueling facility. Fleets operating electric buses often prefer to own and operate their own electric charging station(s). Due to the high cost of CNG station construction, agencies running natural gas vehicles may prefer using a public station (often with a priority fueling option) or may employ public-private partnerships or other arrangements to construct/operate a CNG station at no (or minimal) out-of-pocket cost.

The cost of building and operating an alternative fueling facility depends on multiple factors including the type of fueling (time-fill vs. fast-fill) or charging (depot charging vs. on-route charging), facility capacity, proximity to fuel (or electric) supply, financing and ownership models, partnerships, and revenue sharing arrangements. Additionally, smaller fleets may be able to use existing public-use alternative fuel stations rather than invest in a private facility. The cost implications of these options differ significantly.

A search of relevant literature indicates that, in 2021, the average cost of a CNG fueling facility ranged from $1 million to $6 million, of on-route fast-charge electric chargers from $350,000 to more than $2 million, and of depot electric chargers from $30,000 to $70,000.

While operations and maintenance costs for electric bus chargers might be relatively low, backup electricity systems (e.g., generators) could add costs. Depending on the scope of the improvements, the cost of electrical infrastructure upgrades and backup generation for a medium-sized electric bus fleet can run in the millions of dollars.

Compressed Natural Gas

The costs of CNG fueling facilities can vary significantly depending on the type of fueling (fast-fill vs. time-fill), station capacity, and proximity to a gas main line. Fast fueling requires powerful compressors and gas storage. Therefore, fast-fill CNG stations usually cost more to construct than time-fill (or slow-fill) stations. Transit agencies can choose to invest in a private fueling station or use a public station. In general, the main sources of external funding available to transit agencies for constructing CNG fueling facilities include alternative fuel grants and Low-No grants.

Transit agencies that run CNG buses may choose to enter into public-private partnerships with fuel providers to construct and operate fueling stations or contract with existing station operators for providing fuel. Under a typical public-private partnership, a private fuel provider builds a CNG station at no out-of-pocket cost to the transit agency. The cost of a public-private CNG station can be $3–$6 million. However, typical terms usually involve a fuel purchase agreement over a period of 15–25 years where the agency is required to buy CNG only from the station or to purchase a specified amount of CNG per year. Given that FTA stipulates useful life of 12 years for heavy-duty transit vehicles, public-private arrangements for fueling infrastructure are practical only when the agency has long-term CNG commitment. If the agreement does not require a specified amount of fuel purchases, it usually includes an obligation by the agency to purchase a certain number of CNG buses or maintain a certain size CNG fleet during the contract period.

In summary, CNG fueling stations cost significantly more than diesel fueling stations. An average 12,000-gallon diesel tank with a dispenser may cost approximately $90,000–$100,000. For comparison, an average fast-fill CNG fueling station can cost $1.5–$2.5 million, depending on the number of pumps, compressor, and storage configuration.

Electric

The cost of electric vehicle charging equipment depends heavily on the type of charging and availability of electrical infrastructure at the charging location. Depot chargers for electric transit buses cost on average $60,000–$65,000 per charger, including equipment and installation. Depot chargers provided by original equipment manufacturers (OEMs) often come with a warranty covering parts, labor, and inspection. Therefore, transit agencies installing new OEM depot chargers may expect to have no maintenance expenses for the chargers during the warranty period, which is usually a few years.

On-route chargers cost significantly more. Based on the reviewed literature, a typical (installed) on-route charger for electric buses can cost from $850,000 to $1 million apiece, including approximately $350,000 for the charger itself (equipment cost), $400,000–$500,000 for installation costs, and $175,000–$200,000 per site for engineering, surveying, and site preparation.

These estimates do not include land acquisition. If installing an on-route charger requires purchasing land or installing transformers/upgrading the electrical system, the total cost of electric charging infrastructure may be higher. Additionally, on-route chargers may cost approximately $4,000 per charger year to maintain, including $1,200 for preventive maintenance and $2,800 for equipment repairs.

Hydrogen

Hydrogen stations can typically have three configurations of fuel delivery/production: 1) stations that use hydrogen delivered as a gas, 2) stations that use hydrogen delivered as a liquid, and 3) stations that make hydrogen onsite from electrolysis of water. All three configurations have slightly different cost implications, with on-site production as the most expensive option. Hydrogen stations for transit buses cost approximately $5 million for a station that can fill up to 25 buses a day at 6-to-10 minutes per bus. Few agencies currently operate hydrogen fuel cell buses in the U.S.

with various station configurations in use. The stations for AC Transit and Stark Area Regional Transit Authority have liquid delivery stations while SunLine Transit station has a large electrolyzer to produce hydrogen onsite (Hydrogen Fuel Cell Partnership 2022). No reliable data for hydrogen station maintenance costs is available in the literature, but it could be assumed to be comparable to CNG stations with the same bus fueling capacity.

Fueling Time and Range

Alternative fuel vehicles typically take longer to fuel than conventional vehicles. Depending on the type of fueling, AFVs can take from 20 minutes to 20 hours to fuel. While there are fast-fueling options for both natural gas and electric vehicles, these options may not always be available and economical to all fleets. Additionally, even the fastest alternative fueling options still take more time, may require advanced planning, and offer less flexibility and convenience compared to what conventional vehicles can enjoy with fueling options. Logistical challenges related to fueling time may be more relevant for larger fleets. For example, it takes approximately 10–12 minutes to fuel a typical CNG transit bus at a fast-fill station. Large CNG fleets (70–100 buses) may need five to six hours to prepare the entire fleet for the day.

AFVs may have lower driving range than conventional vehicles. While natural gas vehicles may have a driving range comparable to gasoline and diesel vehicles, electric vehicles often have a significantly shorter range. Range anxiety—an EV driver's fear of not having enough battery charge to reach a destination—is often cited as one of the major obstacles for EV adoption, including both light-duty and heavy-duty vehicles.

Battery-electric buses are also particularly vulnerable to range degradation in extreme weather conditions since heating and air conditioning systems require a lot of energy. When operating in an extremely hot or extremely cold environment, the performance of electric vehicles suffers, sometimes significantly. Extreme cold is particularly challenging for battery-electric buses. Unlike an internal combustion engine vehicle, where only air conditioning affects fuel efficiency while heat comes "free," heating in an EV drains the battery and reduces vehicle range. The data collected by Minnesota Valley Transportation Authority (MVTA) during a three-week trial of battery-electric buses during the winter in Minnesota indicated that 70% of the vehicle's electricity consumption was attributed to heating the cabin and only 30% to vehicle propulsion (Levy 2019).

2. Survey of BRT Providers

In 2019, more than 55% of public transit buses in

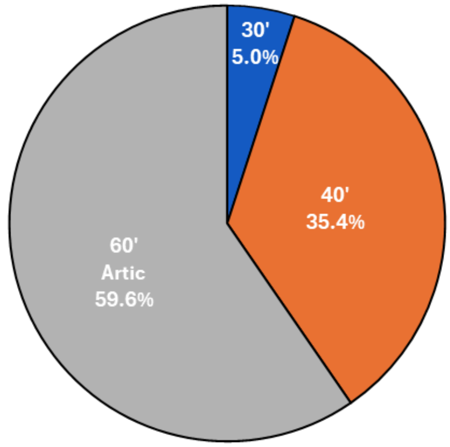
The online survey was initially distributed to BRT providers through the APTA BRT committee in 2020. Several follow-up reminders were also sent through the committee listserv. COVID-19–related challenges faced by transit agencies likely contributed to a low response rate in 2020. In 2021, CUTR researchers used a different approach, reaching out directly to BRT agencies known to operate alternative fuel vehicles in their fleets. In October–November 2021, CUTR directly contacted 29 BRT agencies in the United States requesting them to complete the survey and provide O&M data covering their fleets. Overall, both efforts (through the APTA committee and direct agency contacts) resulted in 14 responses to the online survey, including 12 complete and 2 incomplete submissions. Table 1 lists the responding agencies.

Table 1 ***Agencies Responding to BRT Survey***

Agency Name	City	State
Omnitrans	San Bernardino	CA
AC Transit	Oakland	CA
CT Transit	Newington	CT
IndyGo	Indianapolis	IN
Metro Transit	Minneapolis/St. Paul	MN
City of Albuquerque Transit	Albuquerque	NM
Regional Transportation Commission of Washoe County	Reno	NV
Central Ohio Transit Authority	Columbus	OH
Lane Transit District	Eugene	OR
GRTC Transit System	Richmond	VA
C-TRAN	Vancouver	WA
Sound Transit	Seattle	WA
Spokane Transit Authority	Spokane	WA
Milwaukee County Transit System	Milwaukee	WI

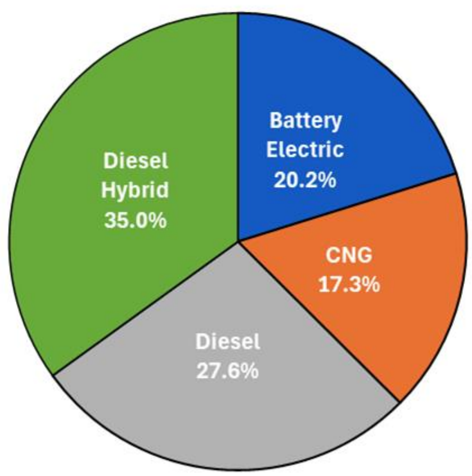
A typical surveyed agency runs one to two BRT lines, using an average of 20 vehicles to provide service. The majority of surveyed agencies reported operating one BRT line and only three reported operating two BRT lines. Larger-size buses seem to be most popular for BRT service. Sixty-foot articulated buses represent almost 60.0% of the BRT vehicles of surveyed agencies, while 40-foot buses represent 35.4%. This finding is not surprising since BRT is often implemented in corridors with high ridership, requiring the use of larger vehicles and having other features similar to light rail or a metro system. Figure 1 summarizes the breakdown of the BRT fleet by vehicle size for surveyed agencies.

Figure 1 *Surveyed BRT Fleet by Vehicle Size*



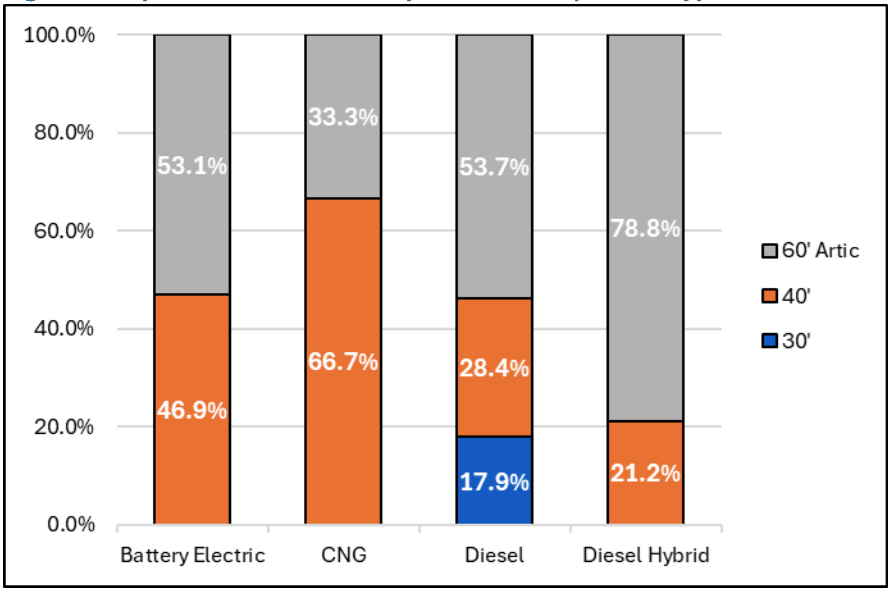
In addition to regular diesel buses, surveyed agencies employ CNG, diesel hybrid, and battery-electric buses in their BRT service. Diesel hybrid is the most popular propulsion type, followed by diesel and battery-electric. CNG vehicles were the least popular among surveyed agencies. Of the total 243 BRT vehicles reported, 35.0% are diesel hybrids, 27.6% are diesel vehicles, 20.2% are battery-electric buses, and 17.3% are CNG vehicles. Figure 2 summarizes the breakdown of vehicle propulsion types for the reported BRT fleets.

Figure 2 *Propulsion Types of Reported BRT Fleets*



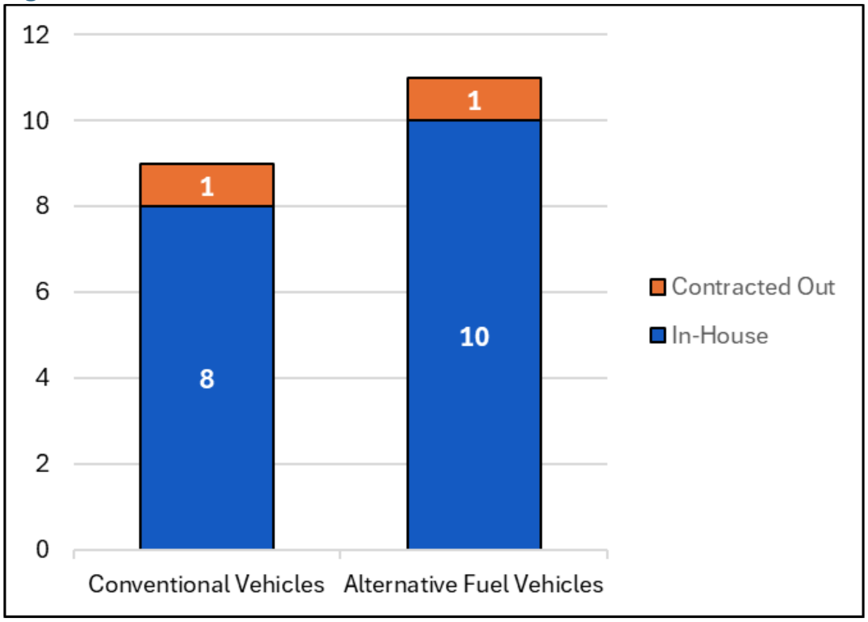
Practically all vehicles of all propulsion types reported are either 40-foot buses or 60-foot articulated buses. Larger articulated vehicles are the most numerous sizes of vehicles for diesel, diesel hybrid, and battery-electric BRT vehicles reported. Sixty-foot articulated buses represent almost 80.0% of diesel hybrid buses and more than 53.0% of diesel and battery-electric buses. At the same time, two-thirds of reported CNG buses are 40 feet in length. The reported diesel BRT fleet includes a relatively small number (18.0%) of 30-foot buses. No other propulsion type includes vehicles of this length. Figure 3 provides the comparison of vehicle length for BRT vehicles of different propulsion types.

Figure 3 *Reported BRT Vehicles by Size and Propulsion Type*



The majority of surveyed agencies perform vehicle maintenance in-house for both conventional and alternative fuel vehicles in their fleet. In fact, only one surveyed agency reported contracting out maintenance for both conventional and alternative fuel vehicles. The survey did not identify noticeable differences in maintenance approaches between conventional diesel and alternative fuel vehicles, except for the use of different mechanic job classifications. The survey indicated that when maintenance is performed in-house, it applies to both diesel and alternative fuel vehicles. Similarly, when agencies prefer to contract out vehicle maintenance, it applies to all types of vehicles in the fleet. Figure 4 summarizes the vehicle maintenance practices of the surveyed BRT agencies.

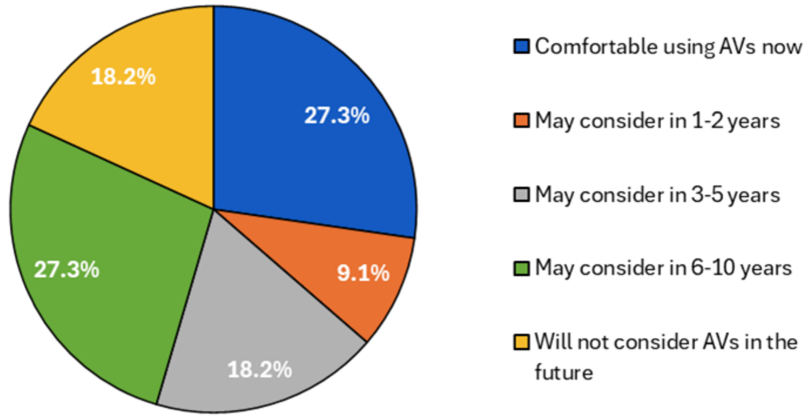
Figure 4 *BRT Vehicle Maintenance Practices*



The survey asked questions regarding the agencies' comfort level using autonomous vehicles in BRT service currently and in the future. The topic of transit vehicle automation has captured the attention of the public and led to discussions in the transit industry in recent years. While most of the AV demonstration pilot projects to date involved smaller low-speed vehicles, continued development in automation technology provides the potential for automation of traditional transit vehicles, as well as BRT service. Surveying transit agencies regarding their opinions about transit service automation is an important step in understanding the prospect for AV implementation and its associated challenges.

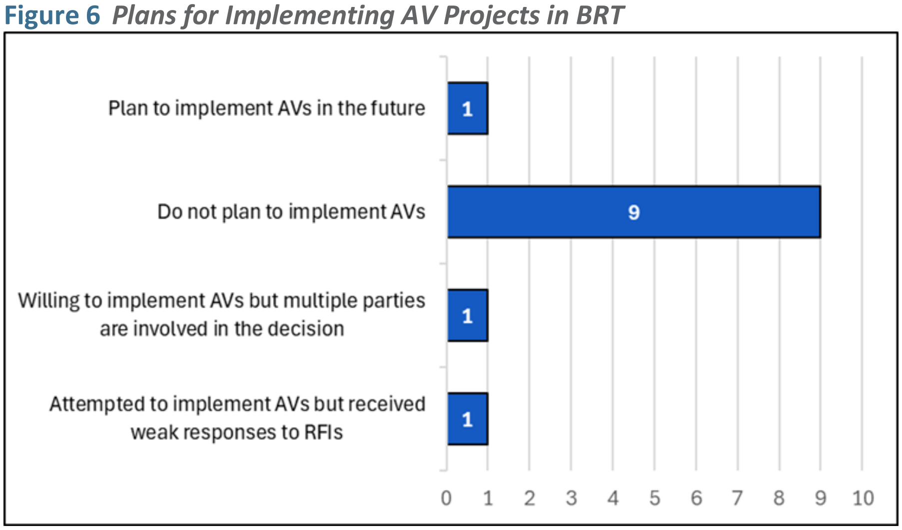
None of the surveyed transit agencies currently use autonomous vehicles in their BRT service, although three (27.3% of responders) reported that they would be comfortable using AVs in BRT service now. One surveyed agency indicated that it may consider using AVs in BRT in one to two years. Two agencies (18.2% of responders) stated that they may consider AVs in 3–5 years, while three agencies (27.3%) may consider using AVs in BRT in 6–10 years. At the same time, two surveyed agencies stated that they are uncomfortable using AVs now and will not consider using them within the next 10 years. Overall, more than 45.0% of surveyed providers reported not being comfortable using AVs in BRT service in the next five years. Figure 5 summarizes the attitudes of the surveyed providers regarding the use of autonomous vehicles in BRT service.

Figure 5 *Attitudes Regarding the Use of AVs in BRT Service*



The majority of surveyed transit agencies (75.0%) reported not planning to implement AV technologies in BRT service in the next one to three years. One agency reported such plans. Another agency indicated a willingness to implement AVs in the future but stated that multiple parties are involved in making this decision. Yet, another agency reported a previous attempt to implement an AV project that received weak responses to the request for information (RFI). Figure 6 summarizes the agency responses regarding their plans for implementing AV technologies in BRT.

Figure 6 *Plans for Implementing AV Projects in BRT*

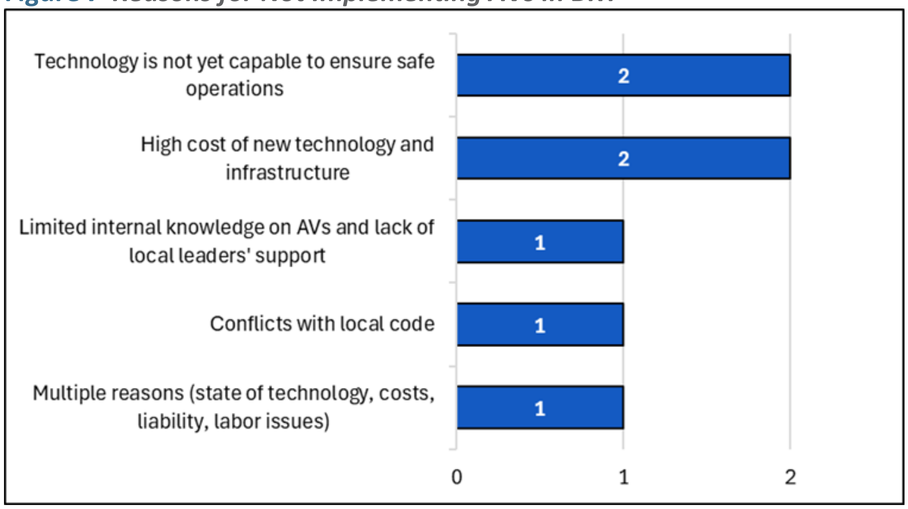


The agencies that indicated willingness to implement AV technologies in BRT listed two potential AV projects they may consider, including Level-4 automation of 40-foot electric buses and braking and steering assist for station docking control. Two of the surveyed agencies listed improvement in safety as the primary reason for plans to implement AV technologies, while one mentioned overcoming driver shortage as the primary reason. Surveyed agencies that are considering implementing AV technologies in

BRT service are expecting these technologies to improve precision docking, reduce damage to the platform due to vehicle collision, and reduce collisions with other vehicles when BRT vehicles change lanes to approach the center platform.

The primary reasons for not implementing AV technologies in BRT include the following statements: technology is not yet capable to ensure safe operations (two agencies); the high cost of new technology and infrastructure (two agencies); limited internal knowledge about AVs and a lack of local leaders' support (one agency); conflicts with local code (one agency); and other reasons. Figure 7 summarizes the primary reasons for the surveyed agencies not choosing to implement AV technologies in BRT.

Figure 7 *Reasons for Not Implementing AVs in BRT*



3. AFV Operating Costs Analysis

Eleven transit agencies provided detailed O&M cost data for their BRT fleets, covering a total of 274 vehicles of various propulsion types and sizes. The current section presents a comparative cost analysis based on the data received from these agencies. While these data may not be fully representative of the entire BRT fleet in the country, it is diverse enough to provide valuable insight into the costs and benefits of various propulsion technologies and fuels that may be used in BRT service. Caution needs to be exercised while interpreting the results, recognizing a relatively small data sample of BRT vehicles that was available for this study. Table 2 lists the agencies that provided their fleet data.

Table 2 *Agencies Responding to BRT Survey*

Agency Name	City	State
AC Transit	Oakland	CA
Omnitrans	San Bernardino	CA
San Diego Metropolitan Transit System	San Diego	CA
LYNX	Orlando	FL
IndyGo	Indianapolis	IN
Metro Transit	Minneapolis/St. Paul	MN
City of Albuquerque Transit	Albuquerque	NM
Capital District Transportation Authority	Albany	NY
Central Ohio Transit Authority	Columbus	OH
GRTC Transit System	Richmond	VA
C-TRAN	Vancouver	WA

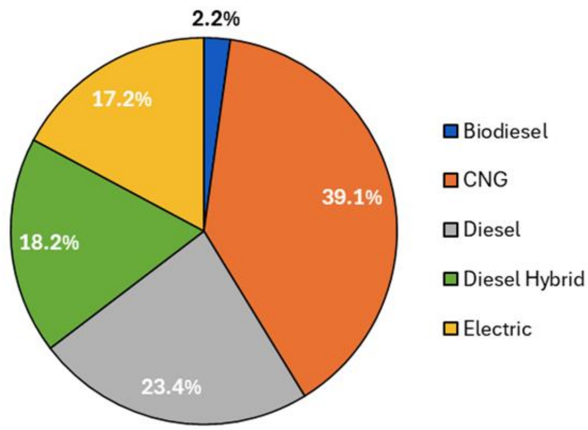
The data assembled from responding BRT agencies covers a fleet of 274 vehicles, including conventional diesel vehicles as well as biodiesel, CNG, diesel hybrid, and battery-electric buses. Most of the BRT vehicles in the sample are 40-foot buses or 60-foot articulated vehicles. Table 3 provides a summary of the propulsion types and vehicle sizes for the surveyed BRT fleets.

Table 3 *Propulsion Types and Vehicle Sizes for BRT Sample*

Power Plant	Length	Number of Buses
Biodiesel	60’ Articulated	6
CNG	40’	28
	60’ Articulated	79
Diesel	40’	23
	60’ Articulated	41
Diesel Hybrid	35’	8
	40’	15
	60’ Articulated	27
Electric	35’	8
	60’ Articulated	39
Total Fleet		***274***

More than 39.0% (107 vehicles) of the reported BRT vehicles are CNG and approximately 23.0% (64 vehicles) are conventional diesel vehicles. Diesel hybrid and battery-electric vehicles represent 18.2% (50 vehicles) and 17.2% (47 vehicles), respectively. Biodiesel vehicles account for slightly over 2.0% (6 vehicles) of the reported BRT vehicles. Figure 8 demonstrates the mix of vehicle propulsion types for the reported BRT vehicles.

Figure 8 ***BRT Fleet Vehicle Propulsion***



Sixty-foot articulated buses seem to be the most popular size for all types of the reported BRT vehicles. Almost two-thirds of reported CNG vehicles, 64.1% of diesel vehicles, and 83.0% of battery-electric vehicles in the sample are 60 feet in length. Additionally, all reported biodiesel vehicles and 54.0% of diesel hybrid vehicles are 60-foot buses. Other size vehicles in the data sample included 35-foot and 40-foot vehicles. Figure 9 summarizes the breakdown of BRT vehicles with different propulsion types by vehicle size.

Figure 9 ***Surveyed BRT Fleet by Propulsion Type and Vehicle Size***

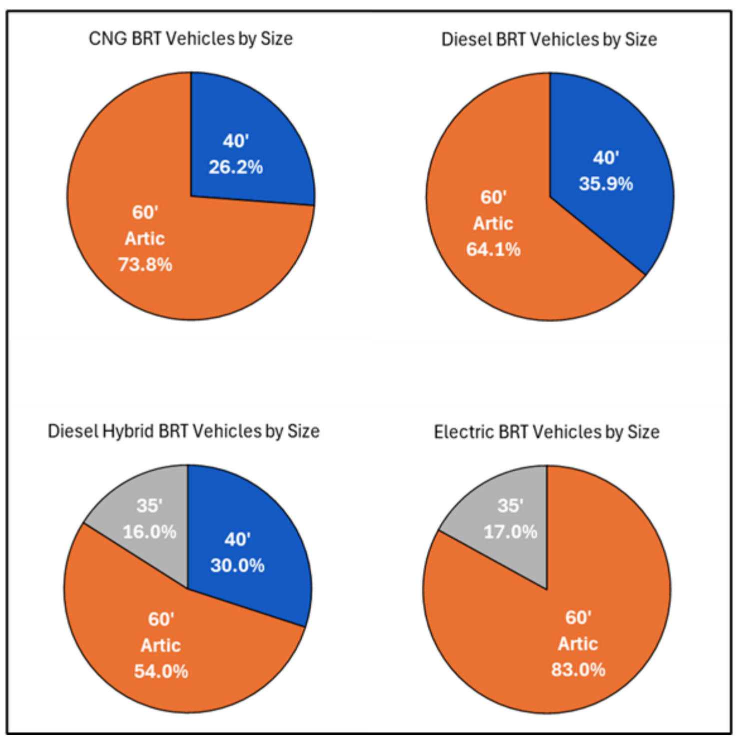


Table 4 presents a detailed cost and performance comparison of the surveyed BRT fleets. For comparison purposes, reported vehicle acquisition costs have been adjusted using the Consumer Price Index (CPI) reported by the U.S. Bureau of Labor Statistics and are presented in constant 2021 dollars. Fuel cost per mile is calculated based on the nationwide average prices for fuel in July of 2022 reported by the U.S. Department of Energy (DOE). Given that diesel is the most common fuel/propulsion type for transit vehicles around the country, all the comparisons in the current report focus on comparing other propulsion types/fuels to diesel vehicles.

Table 4 *Cost and Performance Comparison of Surveyed BRT Vehicles*

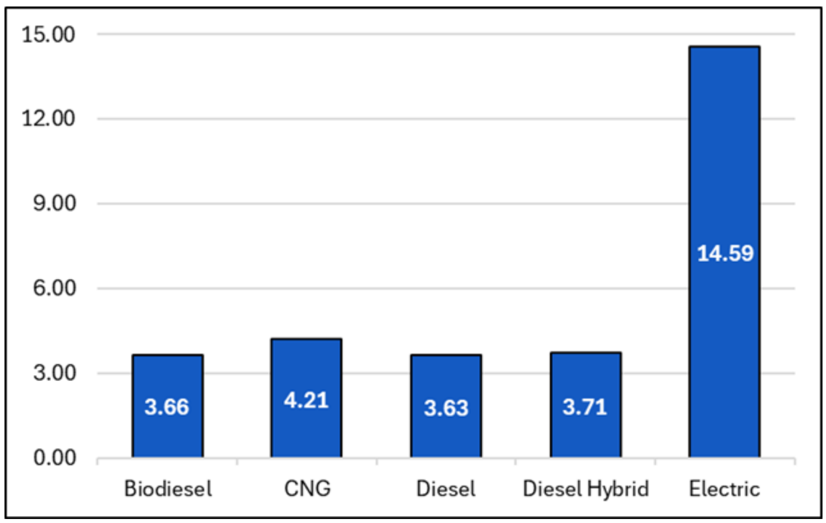
Power Plant	Length	Number of Buses	Bus Age	Acquisition Cost*	MPG	Scheduled Parts Cost per Mile	Un-scheduled Parts per Mile	Scheduled Labor Cost per Mile	Un-scheduled Labor Cost per Mile	Total All Costs per Mile	Fuel Cost per Mile**	Operating Cost per Mile
Biodiesel	60’ ARTIC	6	2.5	$876,912	3.66	$0.024	$0.174	$0.350	$0.571	$1.119	$1.458	$2.577
CNG	40’	28	3.8	$593,654	3.88	$0.058	$0.160	$0.049	$0.084	$0.313	$0.711	$1.023
	60’ ARTIC	79	6.4	$1,042,278	4.06	$0.144	$0.198	$0.146	$0.125	$0.613	$0.725	$1.338
Diesel	40’	23	1.6	$574,095	5.71	$0.108	$0.082	$0.026	$0.070	$0.287	$0.987	$1.274
	60’ ARTIC	41	2.6	$987,708	3.65	$0.097	$0.414	$0.188	$0.489	$1.188	$1.544	$2.732
Diesel Hybrid	35’	8	7.7	$758,059	4.65	$0.022	$0.310	$0.065	$0.336	$0.733	$1.214	$1.947
	40’	15	11.0	$701,433	5.41	$0.113	$0.177	$0.038	$0.097	$0.425	$1.043	$1.468
	60’ ARTIC	27	3.8	$1,212,964	3.69	$0.044	$0.272	$0.287	$0.937	$1.541	$1.528	$3.069
Electric	35’	8	0.9	$764,329	15.25	$0.001	$0.185	$0.029	$0.518	$0.732	$0.422	$1.154
	60’ ARTIC	39	2.4	$1,314,001	14.43	$0.031	$0.055	$0.108	$0.260	$0.434	$0.446	$0.881
Total:		**274**	**4.4**	**$984,303**	**4.32**	**$0.118**	**$0.205**	**$0.122**	**$0.176**	**$0.609**		

* Acquisition costs are adjusted to CPI and are presented in constant 2021 dollars
** Calculated based on nationwide average prices of fuel reported by U.S. DOE

The data show that 60-foot CNG buses demonstrate higher fuel mileage than comparable diesel buses, slightly higher acquisition cost, significantly lower parts cost per mile, significantly lower labor cost per mile, and lower fuel cost per mile. Based on the current data sample, 60-foot CNG buses have 11.2% higher fuel mileage, 49.0% higher scheduled parts cost per mile, 52.1% lower unscheduled parts cost per mile, 22.2% lower scheduled labor cost per mile, 74.5% lower unscheduled labor cost per mile, and 53.1% lower fuel cost per mile than comparable diesel buses. At the same time, 60-foot CNG buses are comparable in price to similar diesel buses (CNG vehicles are 5.5% more expensive to acquire than comparable diesel buses).

Sixty-foot electric buses demonstrate an even larger advantage over diesel vehicles in terms of fuel mileage, parts cost per mile, labor cost per mile, and fuel cost per mile. Yet, 60-foot battery-electric buses are significantly more expensive to acquire than comparable diesel vehicles. Based on the collected data, 60-foot battery-electric buses have fuel mileage almost four times higher than comparable 60-foot diesel buses. Additionally, 60-foot battery-electric buses demonstrate 68.2% lower scheduled parts cost per mile, 86.7% lower unscheduled parts cost per mile, 42.4% lower scheduled labor cost per mile, 46.9% lower unscheduled labor cost per mile, and 71.1% lower fuel cost per mile compared to 60-foot diesel buses. Articulated battery-electric buses are 33.0% more expensive to purchase than comparable diesel vehicles. Vehicle age may be one of the contributing factors for electric BRT vehicles performing better than CNG. Sixty-foot battery-electric buses are noticeably younger than comparable CNG vehicles (average age of 2.4 years for battery-electric buses compared to 6.4 years for CNG buses). Figure 10 provides the comparison of fuel mileage between 60-foot BRT vehicles of different propulsion types. Fuel mileage for battery-electric buses is calculated based on diesel gallon equivalent conversion (1 diesel gallon equivalent = 40.26 kWh).

Figure 10 *Comparison of Fuel Mileage (MPG Equivalent) – 60-foot BRT Buses*



It is noteworthy that the fuel mileage of articulated battery-electric buses presented in Figure 10 represents fuel mileage for vehicle propulsion only. Some 60-foot BRT buses reported in this data sample operate in an extremely cold climate and use diesel-powered heaters. Accounting for (diesel) fuel used for heating decreases the overall fuel mileage of these buses to 12.3 miles per gallon equivalent, which is still significantly higher than buses of any other propulsion type in this sample. Since only a few vehicles in this sample use external diesel-powered heaters, only the energy/fuel used for vehicle propulsion was considered for miles per gallon (MPG) calculation in this analysis for consistency of the comparison.

Figures 11 and 12 compare parts cost and labor cost for 60-foot BRT buses of different propulsion types.

Figure 11 *Parts Cost per Mile – 60-foot BRT Buses*

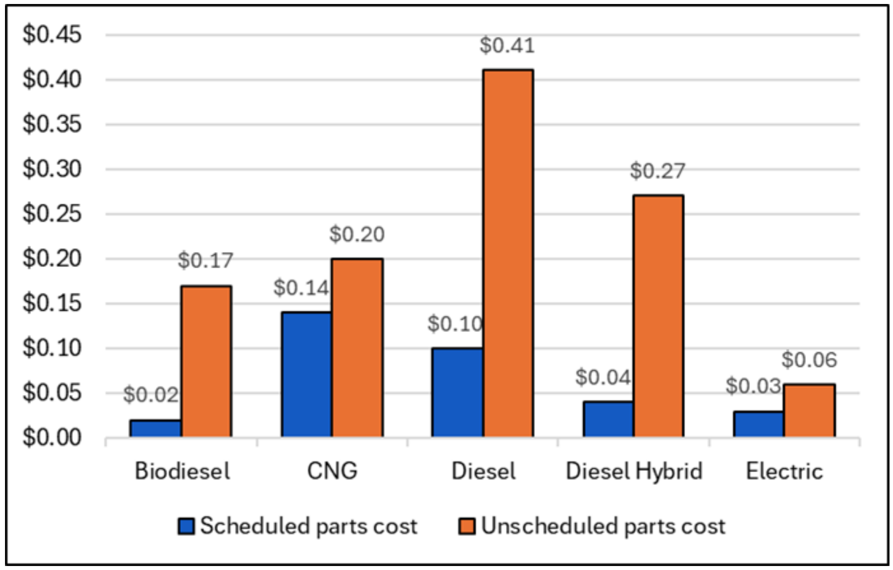
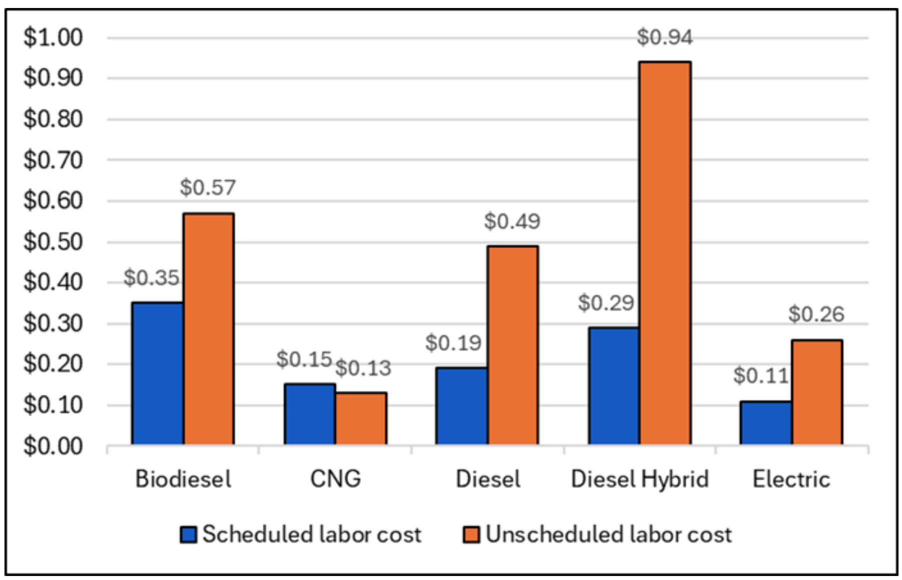
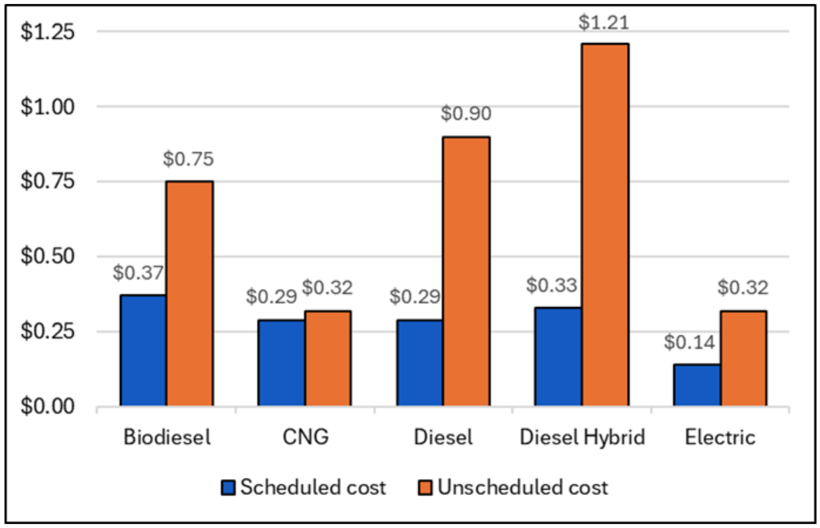


Figure 12 *Labor Cost per Mile – 60-foot BRT Buses*



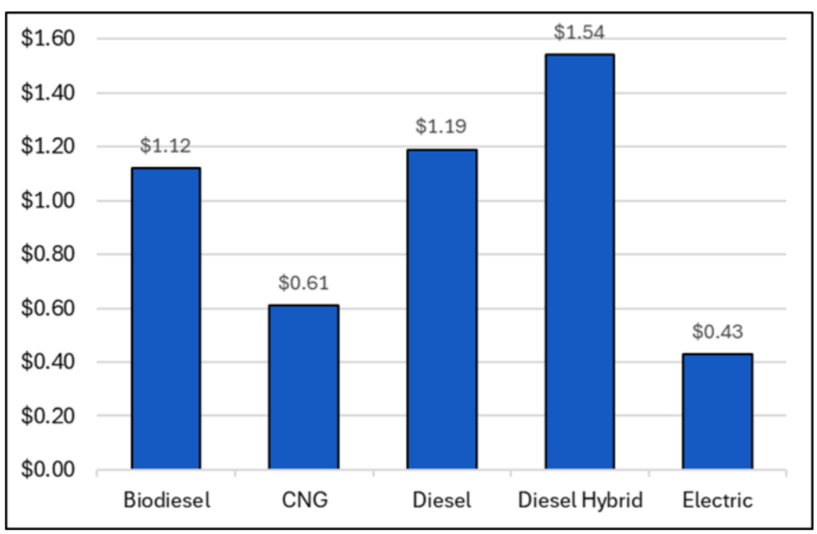
The data show that the largest difference between scheduled and unscheduled costs is observed for 60-foot diesel hybrid buses, while the smallest difference is for CNG buses. Transit agencies can be sensitive to unscheduled costs because they represent unbudgeted expenses. Thus, large unscheduled expenses may be more problematic for transit operators than large scheduled costs. Figure 13 summarizes the comparison of total scheduled and total unscheduled costs per mile for 60-foot BRT buses.

Figure 13 *Scheduled and Unscheduled Costs per Mile – 60-foot BRT Buses*



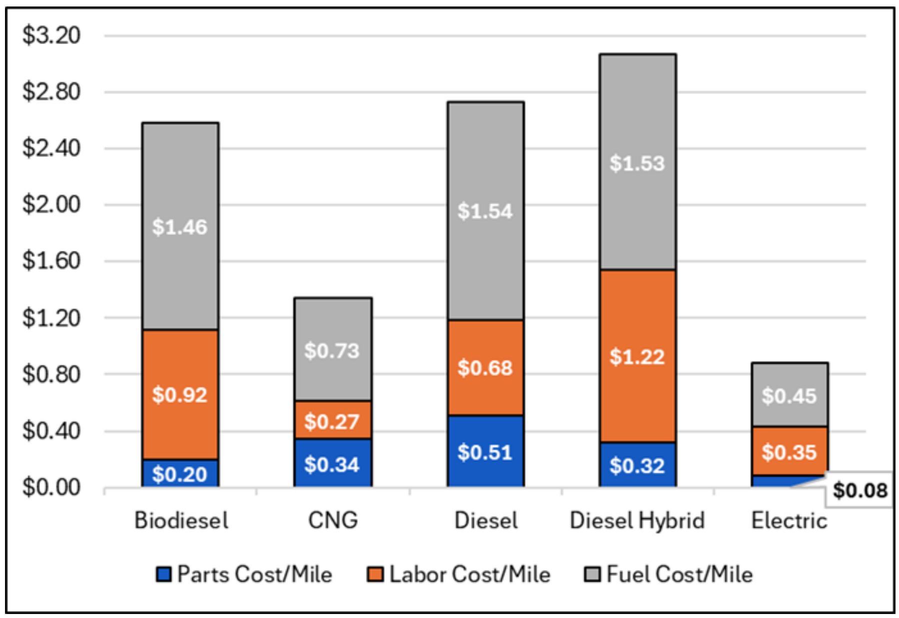
Articulated battery-electric buses demonstrate the lowest overall vehicle costs per mile, followed by CNG and biodiesel. Diesel hybrid BRT buses in this data sample show the highest overall costs per mile. The data show that 60-foot articulated battery-electric buses have 63.5% lower overall costs per mile than comparable diesel buses ($0.434/mile for battery-electric vs. $1.188/mile for diesel). Sixty-foot CNG buses show 48.4% lower overall costs per mile compared to diesel vehicles of the same size ($0.613/mile for CNG vs. $1.188/mile for diesel). At the same time, articulated diesel hybrid buses show 29.7% higher overall costs per mile compared to conventional diesel buses of the same size ($1.541/mile for diesel hybrid vs. $1.188/mile for diesel). Figure 14 summarizes the comparison of total costs per mile between different propulsion types of 60-foot buses.

Figure 14 *Total Costs per Mile – 60-foot BRT Buses*



For many agencies, fuel is a major part of overall operating costs. The current analysis does not directly track how much different transit agencies spend on fuel, and fuel purchase schemes vary from agency to agency. Some agencies buy at current (market) prices, while others have long-term contracts at a fixed price (or a fixed markup). To eliminate differences in fuel purchase contracting among the BRT providers, this analysis uses the nationwide average price of fuel to calculate fuel costs. The U.S. Department of Energy reported the following nationwide average prices in July of 2022 (Q3 of 2022): $5.64 per gallon for diesel, $0.16 per kilowatt-hour (kWh) for electricity, $2.76 per diesel gallon equivalent for CNG, and $5.34 per gallon for B-20 biodiesel blend. Figure 15 shows the comparison of operating costs per mile for 60-foot BRT buses of different propulsion types, including parts, labor, and fuel costs and excluding operator expense.

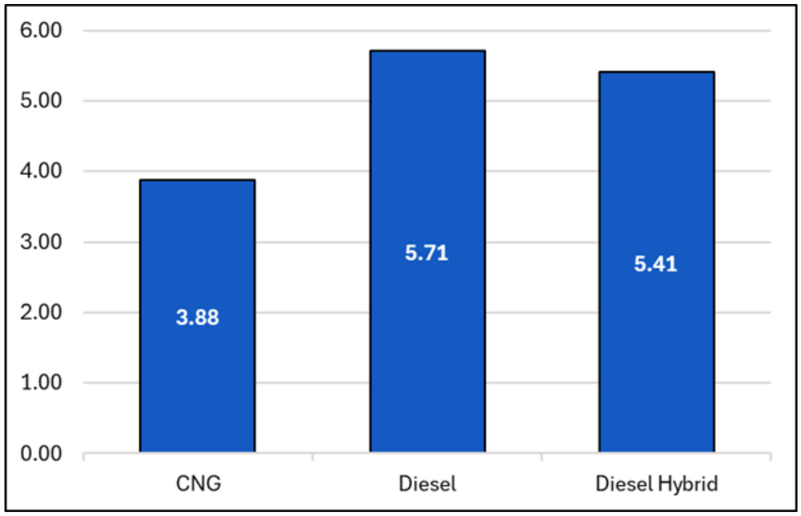
Figure 15 *Operating Costs per Mile – 60-foot BRT Buses*



The data demonstrate that 60-foot battery-electric buses have the lowest parts cost per mile, fuel cost per mile, and the overall operating costs per mile compared to similar vehicles of other propulsion types. Total operating costs of 60-foot articulated battery-electric buses are 60.4% lower than those costs for comparable diesel BRT buses. Sixty-foot CNG vehicles in the current data sample have the lowest labor cost per mile and the second lowest overall operating costs per mile, which is still 51% lower than overall operating costs per mile of comparable diesel vehicles. Diesel hybrid buses demonstrate the highest labor cost per mile (almost twice the labor cost per mile of 60-foot diesel buses) of all reviewed propulsion types and the highest overall operating costs per mile (12.3% higher than operating costs per mile of diesel vehicles) of all 60-foot articulated buses in the data sample.

Forty-foot buses are the second most popular vehicle size for BRT buses in the data sample. At the same time, there are no 40-foot biodiesel or battery-electric buses in the current sample. Therefore, for this vehicle size, the comparison can only be performed between diesel, diesel hybrid, and CNG buses. Figure 16 presents the comparison of fuel mileage of 40-foot BRT buses of different propulsion types.

Figure 16 *Fuel Mileage (MPG Equivalent) – 40-foot BRT Buses*



The data show that 40-foot diesel BRT buses have the highest fuel mileage compared to similar CNG and diesel hybrid vehicles. Forty-foot CNG vehicles demonstrate 32.0% lower fuel mileage, while 40-foot diesel hybrids show 5.3% lower fuel mileage than comparable diesel buses. Figures 17 and 18 present the comparison of parts cost per mile and labor cost per mile, respectively, for 40-foor BRT vehicles.

Figure 17 *Parts Cost per Mile – 40-foot BRT Buses*

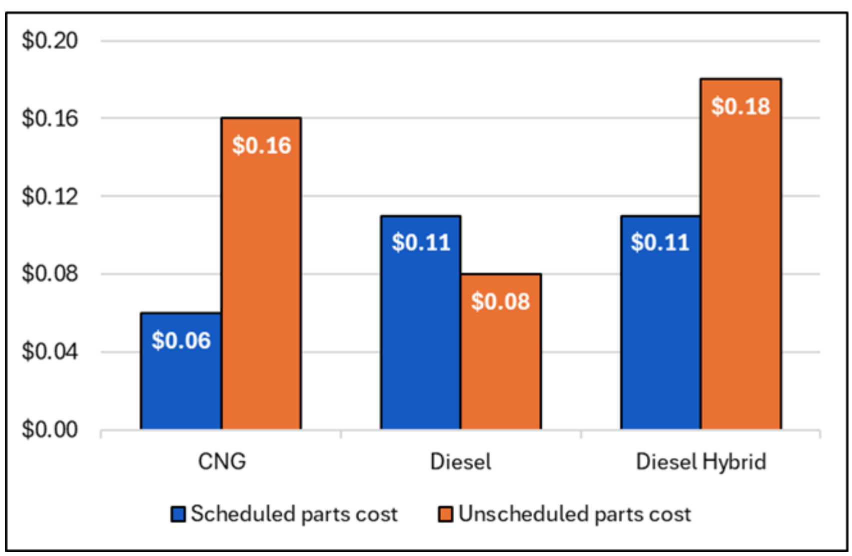
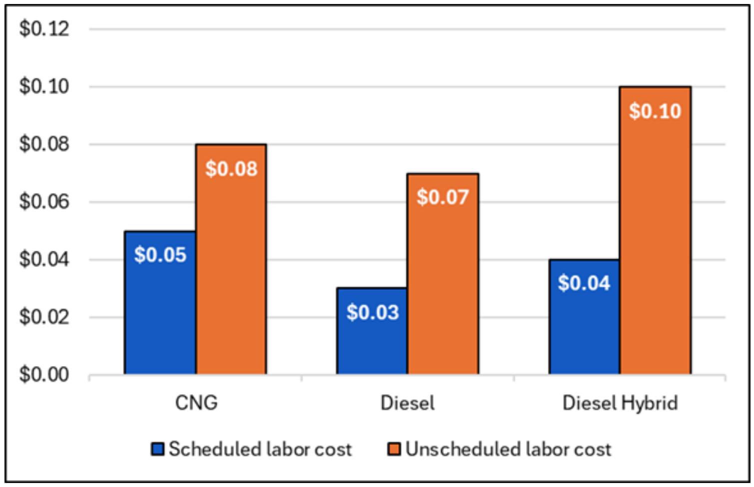


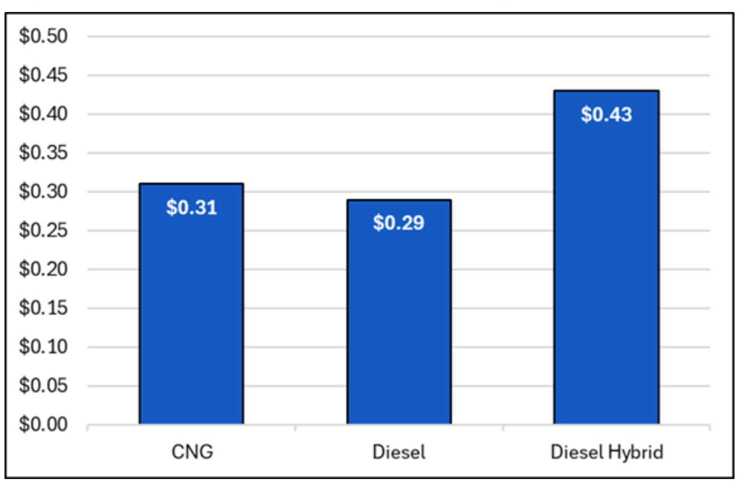
Figure 18 *Labor Cost per Mile – 40-foot BRT Buses*



According to the analysis, 40-foot diesel hybrid BRT buses have the highest scheduled and unscheduled parts cost per mile and the highest unscheduled labor cost per mile among 40-foot vehicles of all propulsion types. At the same time, 40-foot diesel buses demonstrate lower unscheduled parts cost per mile and lower scheduled and unscheduled labor cost per mile than CNG and diesel hybrid vehicles of the same size.

Forty-foot CNG vehicles show the lowest overall parts cost per mile (8.0% lower than diesel vehicles and 40.3% lower than diesel hybrid vehicles) among all propulsion types of that vehicle size. Yet, 40-foot diesel vehicles demonstrate the lowest overall labor cost per mile (31.4% lower than CNG vehicles and 29.4% lower than diesel hybrid vehicles) among other propulsion types of the same vehicle size. As a result, 40-foot diesel BRT vehicles show the lowest overall vehicle costs per mile (including both parts and labor costs), that is 8.3% lower than CNG and 32.5% lower than diesel hybrid vehicles of the same size. Figure 19 presents the comparison of total vehicle costs for 40-foot BRT buses of different propulsion types.

Figure 19 *All Vehicle Costs per Mile – 40-foot BRT Buses*



In addition to the lowest overall costs per mile, diesel buses demonstrate the lowest total unscheduled and the second lowest scheduled costs per mile compared to other propulsion types. Forty-foot diesel BRT vehicles have total unscheduled costs per mile that are 37.0% lower than CNG vehicles and 44.2% lower than diesel hybrid vehicles. Since transit agencies are often more sensitive to unscheduled costs (since they represent unbudgeted expenses) than scheduled costs, the lower unscheduled cost of 40-foot diesel vehicles represents a clear advantage over other propulsion types. Figure 20 shows the comparison of scheduled and unscheduled costs for 40-foot BRT buses of different propulsion types.

Figure 20 *Scheduled and Unscheduled Costs per Mile – 40-foot BRT Buses*

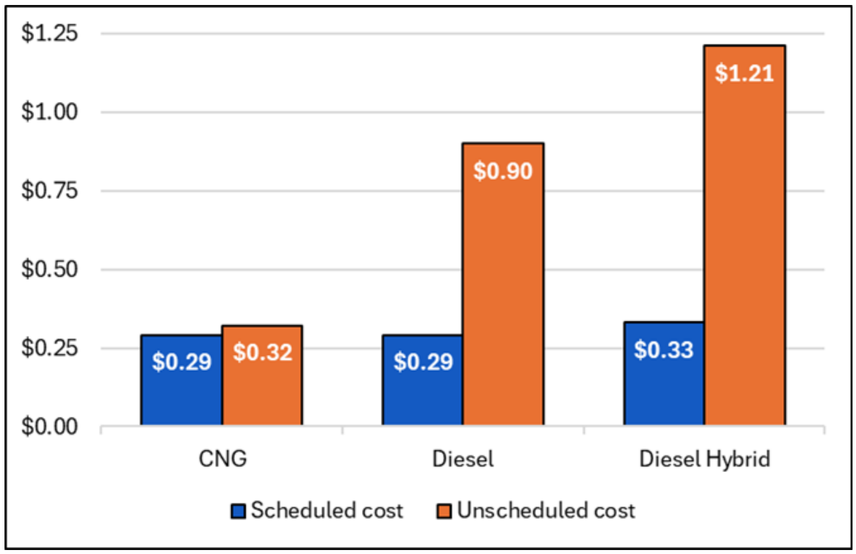
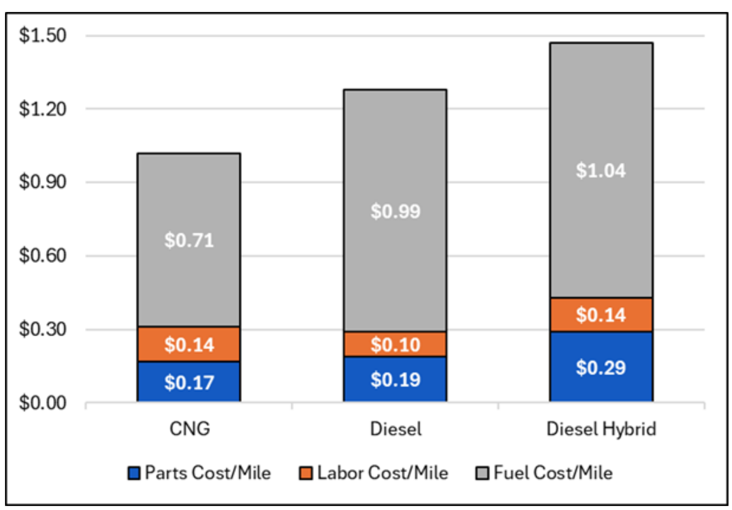


Figure 21 presents the comparison of operating costs per mile for 40-foot BRT buses of different propulsion types, including parts, labor, and fuel costs and excluding operator expense.

Figure 21 *Operating Costs per Mile – 40-foot BRT Buses*

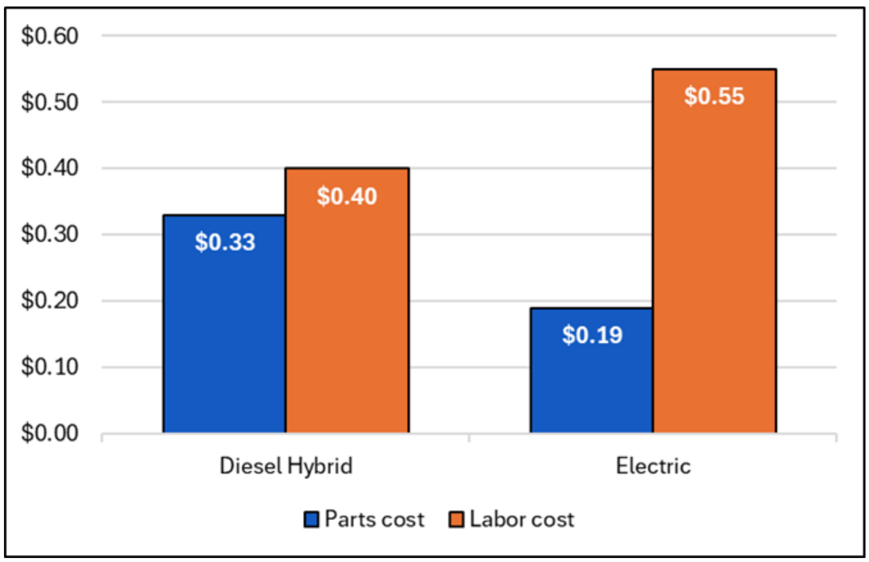


The graph demonstrates that 40-foot CNG buses have the lowest parts cost, lowest fuel cost, and the lowest overall operating cost per mile. Forty-foot diesel hybrid buses demonstrate the highest parts cost of all propulsion types, the highest fuel cost, and the highest overall operating cost per mile. Total operating costs per mile of 40-foot diesel hybrid BRT buses are 15.2% higher than for diesel vehicles and 43.4% than for CNG vehicles of the same size.

Average vehicle age contributes at least partially to the difference in fuel mileage and costs per mile for the compared 40-foot buses. Forty-foot hybrid buses in this data sample are older, with an average age of 11.0 years. For comparison, the average age of 40-foot CNG buses is 3.8 years, while the average age of 40-foot diesel buses is 1.6 years. Newer vehicles typically perform better and cost less to operate than older vehicles.

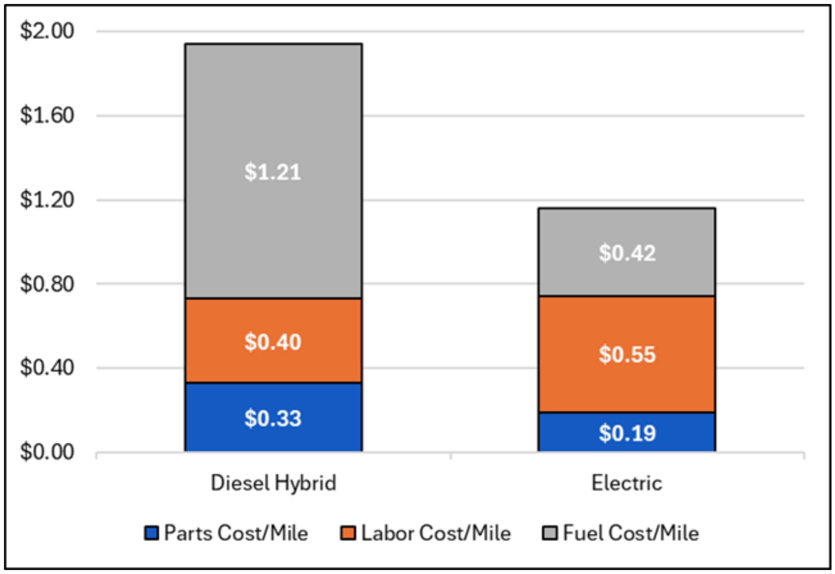
In addition to 40-foot and 60-foot vehicles (that are typical for BRT service), the current sample includes data on 16 35-foot buses, including 8 diesel hybrids and 8 battery-electric buses. Figure 22 compares parts and labor costs of 35-foot diesel hybrid and battery-electric buses.

Figure 22 *Parts and Labor Costs – 35-foot BRT Buses*



The data show that parts cost per mile for 35-foot battery-electric BRT buses is 44.3% lower than parts cost of comparable diesel hybrid buses. At the same time, labor cost per mile of 35-foot battery-electric buses is 36.4% higher than parts cost of diesel hybrids. Additionally, 35-foot battery-electric buses demonstrate fuel mileage that is more than three times higher than fuel mileage of comparable diesel hybrids. Figure 23 compares vehicle operating costs per mile of 35-foot diesel hybrid and 35-foot battery-electric buses, including parts cost, labor cost, and fuel cost per mile.

Figure 23 *Operating Costs per Mile – 35-foot BRT Buses*



The graph demonstrates that 35-foot buses have 44.3% lower parts, 36.5% higher labor cost, and 65.2% lower fuel cost per mile than diesel hybrid BRT buses of the same size. As a result, the overall operating costs of 35-foot battery-electric buses (including parts, labor, and fuel) are 40.7% lower than operating costs per mile of comparable diesel hybrid buses. At the same time, data indicate that 35-foot battery-electric buses have a comparable acquisition cost to 35-foot diesel hybrids.

Table 5 presents a comparison of performance and costs between buses with different power plants at an aggregate level (regardless of vehicle size). For proper comparison, reported vehicle acquisition costs have been adjusted to constant 2021 dollars using CPI.

Table 5 *Aggregate Comparison of Surveyed BRT Vehicles*

Power Plant	Number of Buses	Bus Age	Acquisition Cost*	MPG	Scheduled Parts Cost per Mile	Un-scheduled Parts per Mile	Scheduled Labor Cost per Mile	Un-scheduled Labor Cost per Mile	Total All Costs per Mile	Fuel Cost per Mile**	Operating Cost per Mile
Biodiesel	6	2.5	$876,912	3.66	$0.024	$0.174	$0.350	$0.571	$1.119	$1.458	$2.577
CNG	107	5.7	$970,690	4.03	$0.135	$0.194	$0.135	$0.120	$0.568	$0.722	$1.290
Diesel	64	2.2	$839,066	4.15	$0.101	$0.304	$0.134	$0.350	$0.888	$1.358	$2.247
Diesel Hybrid	50	6.6	$986,720	5.04	$0.094	$0.204	$0.069	$0.221	$0.589	$1.119	$1.708
Electric	47	2.1	$1,220,440	14.47	$0.030	$0.062	$0.104	$0.274	$0.450	$0.445	$0.895
Total:	***274***	***4.4***	***$984,303***	***4.32***	***$0.118***	***$0.205***	***$0.122***	***$0.176***	***$0.609***		

* Acquisition costs are adjusted to CPI and are presented in constant 2021 dollars
** Calculated based on nationwide average prices of fuel reported by U.S. DOE

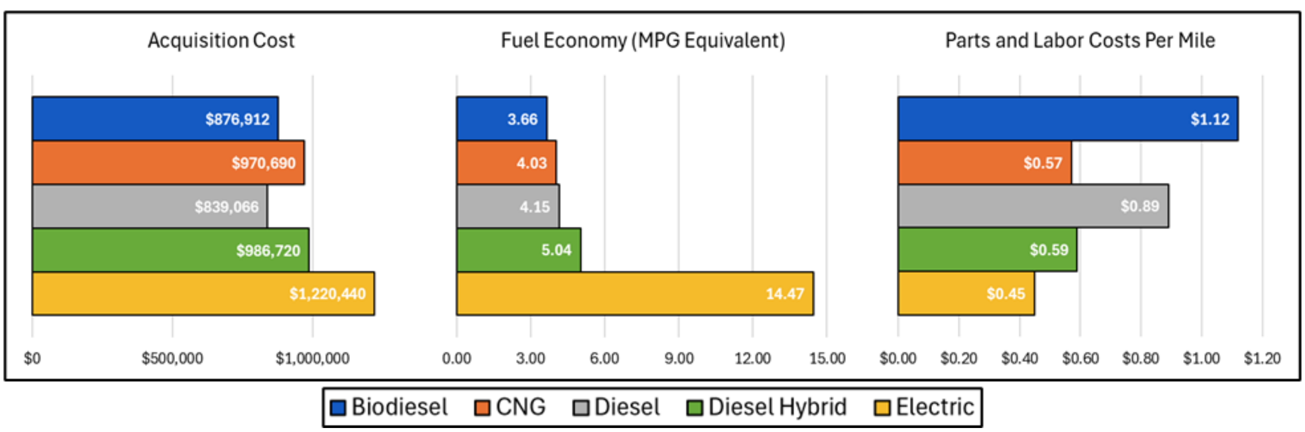
The data show that biodiesel BRT buses regardless of size on average have 11.8% lower fuel economy, 76.6% lower scheduled parts costs, 42.7% lower unscheduled parts costs, but also 161.6% higher scheduled and 63.3% higher unscheduled labor costs than regular diesel buses. Biodiesel buses also cost on average about 4.5% more to acquire than comparable diesel vehicles.

CNG BRT buses regardless of size on average demonstrate 2.8% lower fuel mileage, 33.9% higher scheduled parts cost, 36.2% lower unscheduled parts cost, 1.0% higher scheduled labor cost, and 65.7% lower unscheduled labor cost per mile than diesel BRT buses. CNG buses also have a 15.7% higher acquisition cost than diesel vehicles.

Diesel hybrid buses in this data sample regardless of size on average demonstrate 21.4% better fuel mileage, 6.7% lower scheduled parts cost, 32.7% lower unscheduled parts cost, 48.3% lower scheduled labor cost, and 36.8% lower unscheduled labor cost per mile compared to diesel buses. Diesel hybrid buses also have a 17.6% higher acquisition cost than diesel vehicles.

Battery-electric buses on average demonstrate 248.5% better fuel economy and 69.8% lower scheduled parts cost, 79.5% lower unscheduled parts cost, 22.4% lower scheduled labor cost, and 21.6% lower unscheduled labor cost per mile than diesel buses. The data also indicate that battery-electric buses cost 45.5% more to purchase than diesel vehicles. Figure 24 shows the comparison between buses of all sizes with different power plants.

Figure 24 *Comparison of Buses with Different Power Plants – All Vehicle Sizes*



The graph demonstrates that battery-electric buses of all sizes have the lowest total parts and labor costs and the highest overall fuel mileage of all propulsion types. Biodiesel vehicles, on the other hand, have the lowest fuel economy and the highest parts and labor costs of all reviewed propulsion types. Biodiesel BRT buses of all vehicle sizes demonstrate total parts and labor costs that are 26.0% higher than diesel vehicles. At the same time, diesel hybrid buses demonstrate 33.7% lower total costs, CNG buses have 36.1% lower total costs, and battery-electric buses have 49.3% lower total costs per mile than diesel vehicles.

Figures 25 and 26 present a more detailed comparison of parts and labor costs, respectively, for vehicles of different propulsion types.

Figure 25 *Parts Cost Per Mile – All Vehicle Sizes*

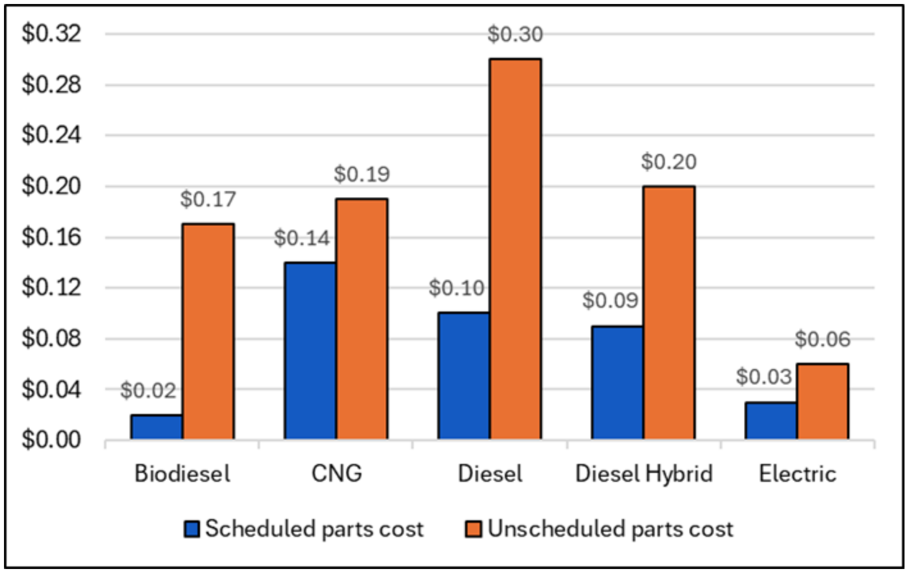
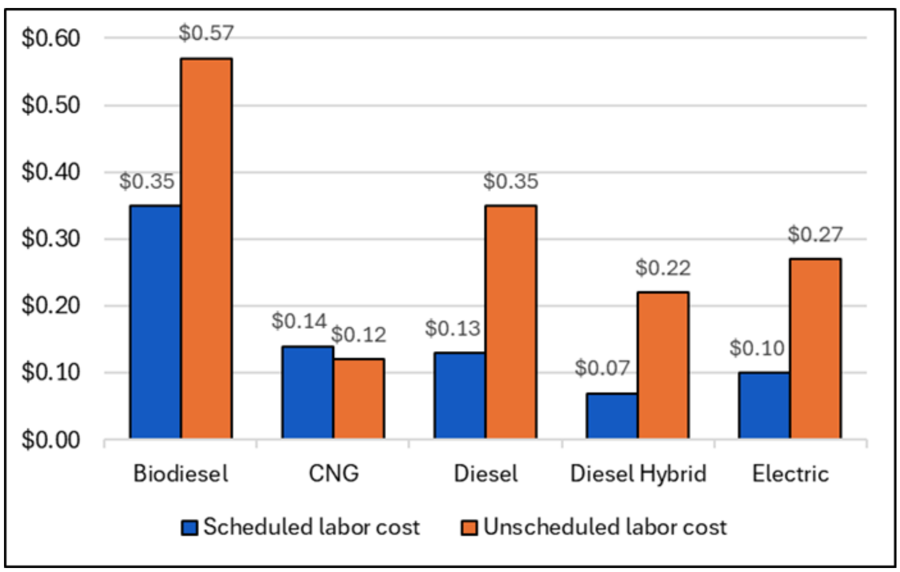
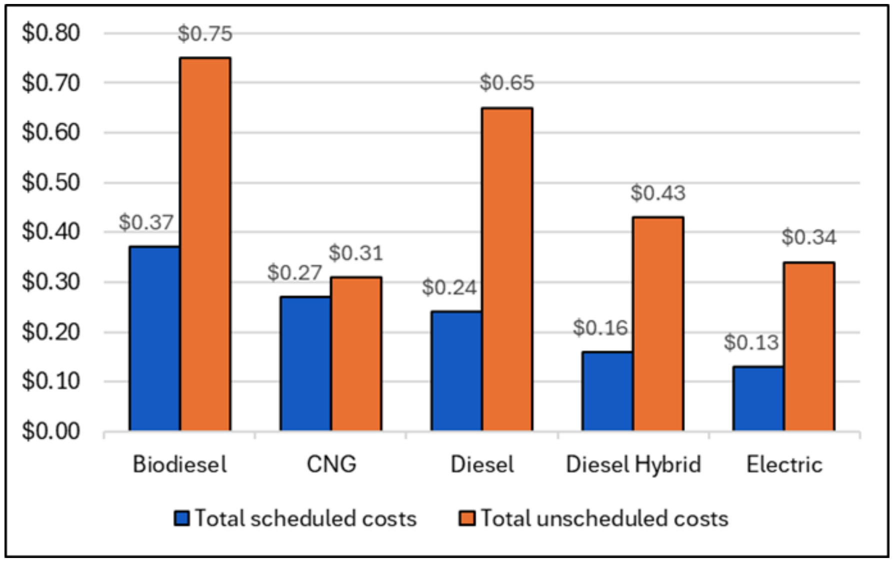


Figure 26 *Labor Cost per Mile – All Vehicle Sizes*



Diesel vehicles demonstrate the highest parts cost per mile of all propulsion types (and the second highest labor cost), while battery-electric vehicles demonstrate the lowest parts cost per mile, followed by biodiesel and diesel hybrid buses. At the same time, biodiesel vehicles also show the highest labor cost per mile compared to vehicles of all propulsion types, while CNG vehicles show the lowest labor cost per mile, followed by diesel hybrid and electric vehicles. Interestingly, unscheduled costs typically exceed scheduled costs for most propulsion types for both parts and labor, except for CNG vehicles. Unscheduled labor costs of CNG buses are lower than scheduled labor costs. Figure 27 compares total scheduled and unscheduled costs per mile for vehicles of different propulsion types and sizes.

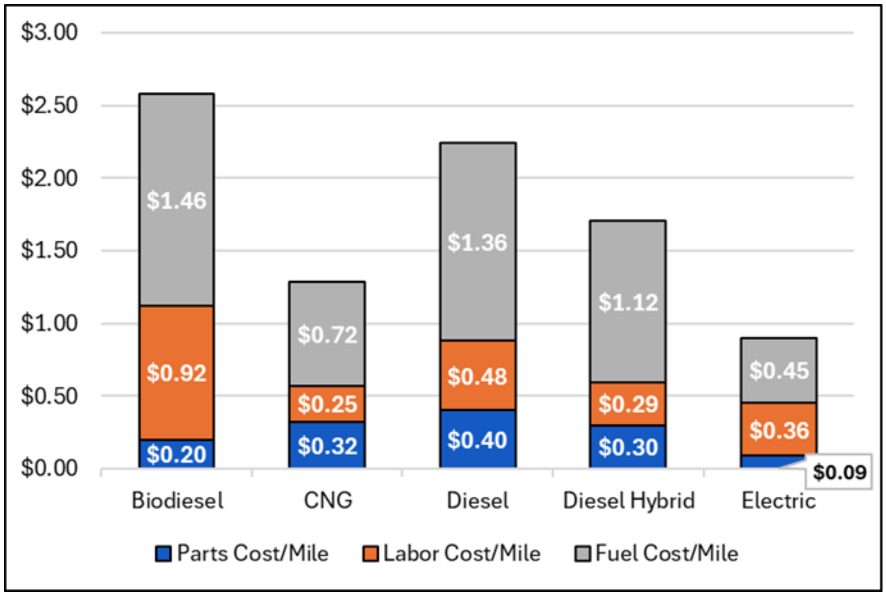
Figure 27 ***Scheduled and Unscheduled Costs per Mile – All Vehicle Sizes***



The data show that biodiesel and diesel BRT vehicles have the highest unscheduled costs of all reviewed propulsion types. CNG vehicles, at the same time, have the lowest unscheduled costs per mile and the lowest ratio of unscheduled to scheduled costs of all propulsion types in the data sample. While battery-electric vehicles of all sizes have the lowest scheduled costs of all reviewed propulsion types, unscheduled costs exceed scheduled costs for battery-electric buses by more than 153%. For comparison, unscheduled costs of CNG vehicles exceed scheduled costs by 16%. Agencies are likely to be more sensitive to large unscheduled costs, rather than large scheduled costs, since unscheduled costs represent unbudgeted expenses.

Figure 28 summarizes total operating costs, including parts, labor, and fuel costs per mile, for biodiesel, CNG, diesel, diesel hybrid, and battery-electric vehicles of all sizes.

Figure 28 *Operating Costs per Mile – All Vehicle Sizes*



The data show that CNG vehicles of all sizes demonstrate the lowest labor cost and the second lowest overall operating cost per mile compared to vehicles of other propulsion types. Biodiesel vehicles, on the other hand, show the highest labor cost, highest fuel cost, and highest overall operating cost per mile of all compared propulsion types. Battery-electric buses of all sizes demonstrate the lowest parts cost, lowest fuel cost, and lowest overall operating cost per mile of all vehicle propulsion types in the data sample.

These results should be interpreted with caution since some cost differential may be attributed to vehicle age rather than performance. For example, the average age of battery-electric buses is 2.1 years, biodiesel vehicles is 2.5 years, and of diesel is 2.2 years. For comparison, the average age of CNG vehicles is 5.7 years, while the average age of diesel hybrids is 6.6 years. Finally, the performance and operating cost estimates for various types of vehicles used for the comparison are based on a limited number of data points, limiting the robustness of the analysis.

4. AFVs and Resilience

There are several notable case studies where alternative fuels were able to provide critical transportation needs after natural disasters, when conventional fuels were not available or were in short supply. These examples include the use of CNG minibuses in Atlantic City and CNG bi-fuel pickup trucks in New York and New Jersey area after Hurricane Sandy, CNG transit buses in Houston after Hurricane Harvey, and other examples from around the country. Some of these case studies are discussed in more detail below.

Hurricane Sandy (2012)

Port Authority of New York and New Jersey – CNG Bi-fuel Pickups

After Hurricane Sandy (2012), the Port Authority of New York and New Jersey used a fleet of bi-fuel CNG Ford F-350 work trucks to deliver critical supplies and service key transportation facilities, including airports, tunnels, and bridges. The ability to operate on two different fuels increased vehicle usefulness in the case of fuel shortage and extended vehicle range during normal operations (iREV 2016a). While there were shortages of gasoline and diesel after the hurricane, the supply of CNG was not impacted by the storm and CNG vehicles operated without interruption.

Atlantic City – CNG Jitneys

After Hurricane Sandy (2012), Atlantic City, New Jersey, relied on a fleet of 190 CNG minibuses, called Jitneys, to provide public transportation, assist with evacuation and recovery efforts, transport medical patients, and help with other essential functions (iREV 2016a). While the supply chain disruptions caused gasoline shortages and compromised recovery efforts, the CNG supply was uninterrupted by the storm. These Jitneys proved valuable to the city both during emergencies and normal operations. In addition to being powered by alternative fuel, the vehicles were included in Atlantic City's Emergency Plan, which allowed for fast coordination and deployment during emergencies. Interestingly, Atlantic City converted its fleet of minibuses to CNG mainly for economic and environmental reasons. But this decision also proved to bring unexpected natural disaster resilience benefits.

Hurricane Harvey (2017)

Houston – CNG Transit Buses

Hurricane Harvey hit Houston, Texas, in August 2017, causing massive flooding and road blockage, disrupting fuel deliveries, and leading to the shortage of conventional fuels (gasoline and diesel). At the same time, the underground natural gas pipeline network was not affected by the storm and allowed for an uninterrupted supply of CNG. As a result, Metropolitan Transit Authority of Harris County (METRO) was able to provide transit service using CNG buses without interruptions. Before, during, and after Hurricane Harvey, METRO transported approximately 10,000 people to emergency shelters and assisted the Red Cross in transporting vital supplies (AFDC 2019). CNG was also used by other fleets assisting with vital services during and after Hurricane Harvey, including Houston Distributing trucks, Waste Corporation refuse trucks, AT&T service vehicles, and many other fleets.

These examples mainly include compressed natural gas. Being transported over a pipeline, the CNG supply is less affected by a storm than conventional fuels. However, other alternative fuels can also be useful for improving an area's preparedness for natural disasters. Emergency resilience benefits come mostly from fuel diversification and the diversification of fuel delivery channels, rather than from any particular fuel (traditional or alternative).

Plug-in electric vehicles with the capability to export power can offer significant benefits during disaster relief efforts. Battery-electric transit vehicles, while having certain challenges during power outages, have a great potential for providing exportable power to critical facilities such as hospitals, shelters, and nursing homes. There are several cases of electric vehicles supplying critical disaster relief as mobile power sources. One example includes the use of an electric utility truck as a power source during the California wildfires in the fall of 2015. During large wildfires in the Sierra Nevada Mountains (Calaveras County) that caused power outages and evacuations, PG&E employed one of its plug-in hybrid electric trucks with exportable power capabilities to power a shelter for two days until power was restored (iREV 2016b).

While most examples found in the literature involve utility trucks or other medium-duty vehicles, battery-electric transit vehicles have an even greater potential due to larger-size batteries that enable them to be a valuable resource in the case of power outages and/or fuel supply interruptions.

5. Emissions and Externality Costs

Transit agencies continue to be under pressure to reduce operating costs and to run a more sustainable and environmentally friendly fleet in the urban environment. One of the approaches agencies take to reduce the harmful air pollutants and greenhouse gas (GHG) emissions associated with transit operations is employing alternative fuel vehicles in their fleets. Different propulsion technologies and fuels provide different environmental benefits and may require different capital and infrastructure investment. The variety of advanced technologies available often makes it difficult for transit agencies to choose the one that will best fit their needs. Finally, relatively low diesel prices often erode the fuel cost advantage of alternative fuel vehicles, reducing the economic incentive at least in the short term.

The analysis presented in this section gives a side-by-side comparison of criteria pollutants, GHG emissions, and the total cost of ownership of transit vehicles with different propulsion types and fuels represented in the BRT data sample collected for this study. The analysis was performed using the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool developed by Argonne National Laboratory.

Since 60-foot articulated buses are the most common vehicle size in the collected BRT sample, the comparison was performed between vehicles of this size, including biodiesel, CNG, diesel, diesel hybrid, and battery-electric buses. The analysis evaluates the implications of a single bus acquisition, comparing all propulsion types to the diesel vehicle as a basis for comparison.

Assumptions

Some of the assumptions for the analysis are listed below:

- Annual vehicle mileage for transit bus: 45,000 miles
- Average fuel economy:
  - Diesel bus 3.65
  - Battery-electric bus 14.43
  - Diesel hybrid bus 3.69
  - Biodiesel (B-20) bus 3.66
  - CNG bus 4.06
- Maintenance and repair costs:
  - Diesel bus $1.188/mile
  - Battery-electric bus $0.434/mile
  - Diesel hybrid bus $1.541/mile
  - Biodiesel (B-20) bus $1.119/mile
  - CNG bus $0.613/mile
- Fuel costs:
  - Diesel $5.64/gallon
  - Electricity $0.16/kwh
  - Biodiesel $5.34/gallon
  - CNG bus $2.76/DGE
- Vehicle useful life: 12 years
- Vehicle is purchased with cash (no financing, no grants)
- Natural gas feedstock source:
  - Conventional gas 66%
  - Shale gas 34%
- Source of electricity: Average U.S. mix

Results of the Analysis

Table 6 summarizes the simple payback calculation for an electric, diesel hybrid, biodiesel, and CNG 60-foot bus compared to a similar diesel vehicle

Table 6 ***Simple Payback Comparison – Buses with Different Propulsions***

	Diesel	Electric	Diesel Hybrid	Biodiesel	CNG
Acquisition Cost	$987,708	$1,314,001	$1,212,964	$876,912	$1,042,278
Annual Operating Costs	$123,791	$38,465	$138,914	$117,829	$62,892
Incremental Acquisition Costs		$326,293	$225,256	-$110,796	$54,571
Annual Operating Savings		$85,326	-$15,123	$5,962	$60,899
Simple Payback (Years)		3.8	N/A	-18.6	0.9

The analysis shows that a 60-foot CNG bus provides the payback on investment in less than a year and a battery-electric bus in 3.8 years compared to a similar diesel bus. In terms of the simple payback analysis, a biodiesel bus is already more beneficial than diesel as indicated by a negative payback period. Diesel hybrid bus, on the other hand, does not provide any payback compared to diesel bus due to higher annual operating costs and acquisition cost of a 60-foot biodiesel bus.

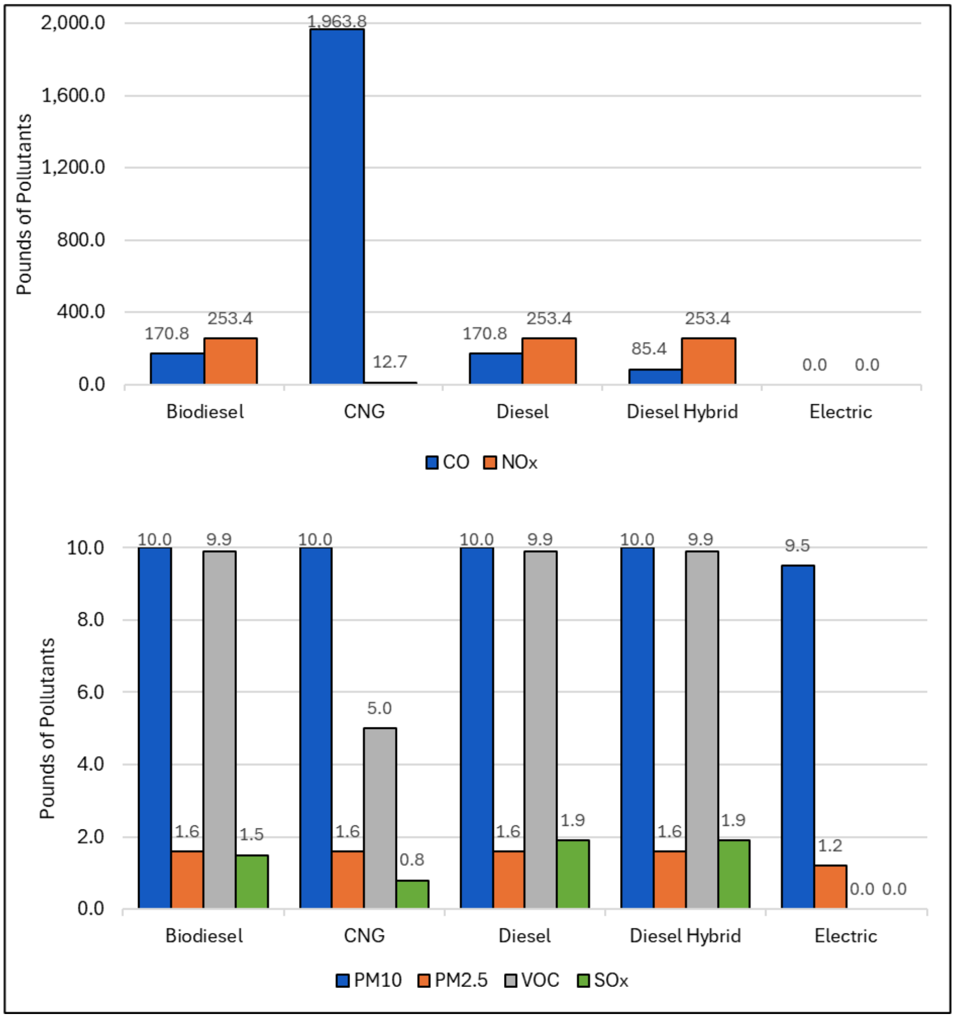
Carbon footprint and air pollution are important factors in comparing various bus propulsion types and fuels. Alternative fuels can offer significant reductions in criteria pollutants as well as greenhouse gas emissions. Table 7 provides a side-by-side comparison of energy and emissions impacts of 60-foot diesel, battery-electric, diesel hybrid, biodiesel and CNG buses.

Table 7 *Energy Use and Emissions Impact – Different Propulsions*

	Diesel	Electric	Diesel Hybrid	Biodiesel	CNG
Annual wells-to-wheels petroleum use (barrels)	307.1	2.1	303.8	247.5	1.2
Annual wells-to-wheels GHG (short tons)	169.1	58.6	167.3	147.9	119.8
Annual air pollutants (pounds)					
CO	170.8	0.0	85.4	170.8	1,963.8
NO_x	253.4	0.0	253.4	253.4	12.7
PM10	10.0	9.5	10.0	10.0	10.0
PM2.5	1.6	1.2	1.6	1.6	1.6
VOC	9.9	0.0	9.9	9.9	5.0
SO_x	1.9	0.0	1.9	1.5	0.8

The analysis shows that a diesel bus uses the largest amount of petroleum per year (307.1 barrels), while a CNG bus uses the lowest amount (1.2 barrels). Diesel and diesel hybrid buses produce the most amount of greenhouse gases per year (169.1 tons and 167.3 tons, respectively), while a battery-electric bus produces the lowest amount (58.6 tons). Figure 29 presents the comparison of annual air pollutants for buses of different propulsion types.

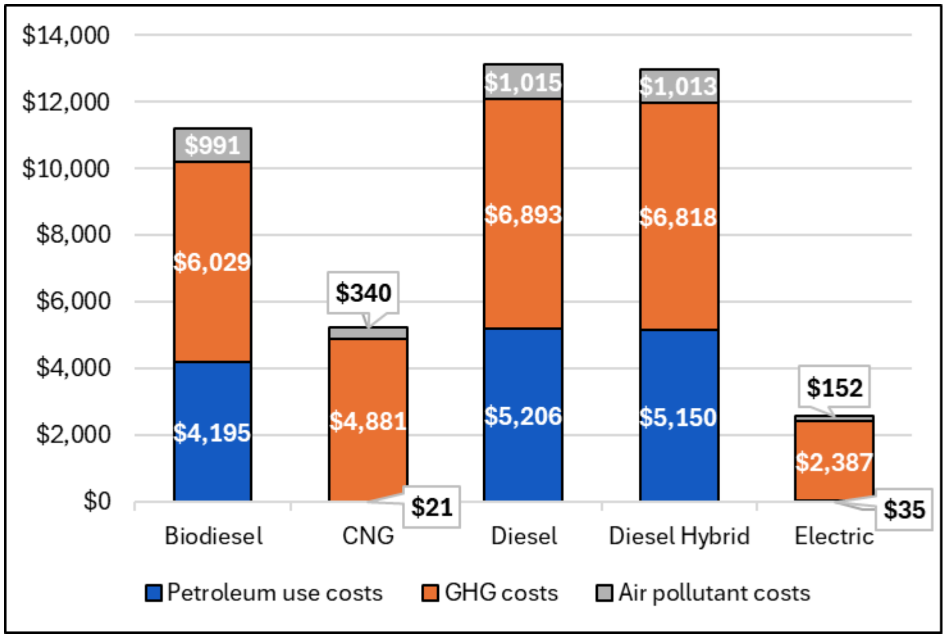
Figure 29 *Annual Air Pollutants – Different Propulsion Types*



The graph demonstrates that diesel hybrid buses show 50.0% lower carbon monoxide (CO) emissions than comparable diesel buses but have similar nitrogen oxide (NO_x) emissions. CNG buses demonstrate 95.0% lower NO_x emissions, but also 11.5 times higher carbon monoxide emissions, than comparable diesel buses. Battery-electric buses show practically zero CO and NO_x emissions, and lower particulate matter emissions compared to diesel vehicles.

The analysis allows attaching a dollar value to the externalities associated with operating transit buses, including petroleum use as well as air pollutant and greenhouse gases emissions. Figure 30 provides the comparison of annual externality costs for transit buses with different propulsion/fuel types.

Figure 30 *Annual Externality Costs – Different Propulsion Types*



The graph shows that biodiesel buses have 19.4% lower annual petroleum use externality costs, 12.5% lower annual GHG costs, 2.4% lower annual air pollutant costs, and 14.5% lower total annual externality costs compared to diesel buses. CNG buses demonstrate 99.6% lower petroleum use externality cost, 29.2% lower GHG costs, 66.5% lower air pollutant costs, and 60.0% lower overall annul externality costs than diesel buses. Diesel and diesel hybrid buses have similar annual externality costs, while battery-electric and CNG buses demonstrate the lowest overall annual externality costs among all propulsion types.

Incorporating externalities into the analysis permits a better understanding of the true social costs involved in operating various types of transit vehicles. Accounting for external costs reduces the payback of electric buses from 3.8 to 3.4 years and of CNG vehicles from 0.9 to 0.8 years.

Table 8 summarizes the lifetime cost of ownership for transit buses with different propulsion types, accounting for vehicle depreciation, fuel costs, diesel exhaust fluid costs, maintenance and repair expenses, insurance, and license and registration costs.

Table 8 *Lifetime Cost of Ownership – Buses with Different Propulsions*

	Diesel	Electric	Diesel Hybrid	Biodiesel	CNG
Depreciation	$709,575	$943,986	$871,401	$629,979	$748,779
Fuel	$950,156	$236,842	$939,857	$911,144	$436,810
Diesel Exhaust Fluid	$9,858	$0	$9,751	$9,831	$0
Maintenance and Repair	$851,021	$308,852	$1,103,892	$801,593	$439,121
Insurance	$258,945	$331,956	$309,348	$234,154	$271,156
License and Registration	$8,300	$8,300	$8,300	$8,300	$8,300
Total Cost of Ownership	**$2,787,856**	**$1,829,935**	**$3,242,548**	**$2,595,001**	**$1,904,166**

Of the reviewed vehicle propulsion types, diesel hybrid buses demonstrate the highest lifetime cost of ownership ($3,242,548), while battery-electric buses have the lowest ($1,904,166). Diesel buses show the second highest cost of ownership (after diesel hybrid buses) over the life of the vehicle.

Figure 31 summarizes the lifetime emission of criteria pollutants (in pounds), including CO, NO_x, PM10, PM2.5, volatile organic compounds (VOC), and sulfur oxides (SO_x) for transit vehicles with different propulsion types/fuels.

During the life of the vehicle, a CNG bus is expected to emit 22,932 pounds of carbon monoxide (11.5 times more than a similar diesel vehicle), 143 pounds of NO_x (95% less than a comparable diesel bus), 120 pounds of PM10 (same as a diesel bus), and 19 pounds of PM2.5 (same as a diesel bus). At the same time, during the life of the vehicle, a battery-electric bus is expected to emit practically zero CO and NO_x, 114 pounds of PM10 (5% less than a diesel bus), and 14 pounds of PM2.5 (26.3% less than a diesel bus).

Figure 32 summarizes the lifetime externality costs for buses of different propulsion types, accounting for petroleum use externalities, GHG costs, and air pollution costs.

The data show that diesel buses have the highest total externality costs over the life of the vehicle ($177,478), followed by diesel hybrid buses ($175,681) and biodiesel buses ($151,719). Of all propulsion types, electric and CNG buses demonstrate the lowest total externality costs ($34,930 for electric and $71,094 for CNG). Greenhouse gas emissions costs represent the largest share of all externality costs, while air pollutant costs represent the smallest share among all externality costs.

Figure 31 *Comparison of Lifetime Air Pollutants – Different Propulsion Types*

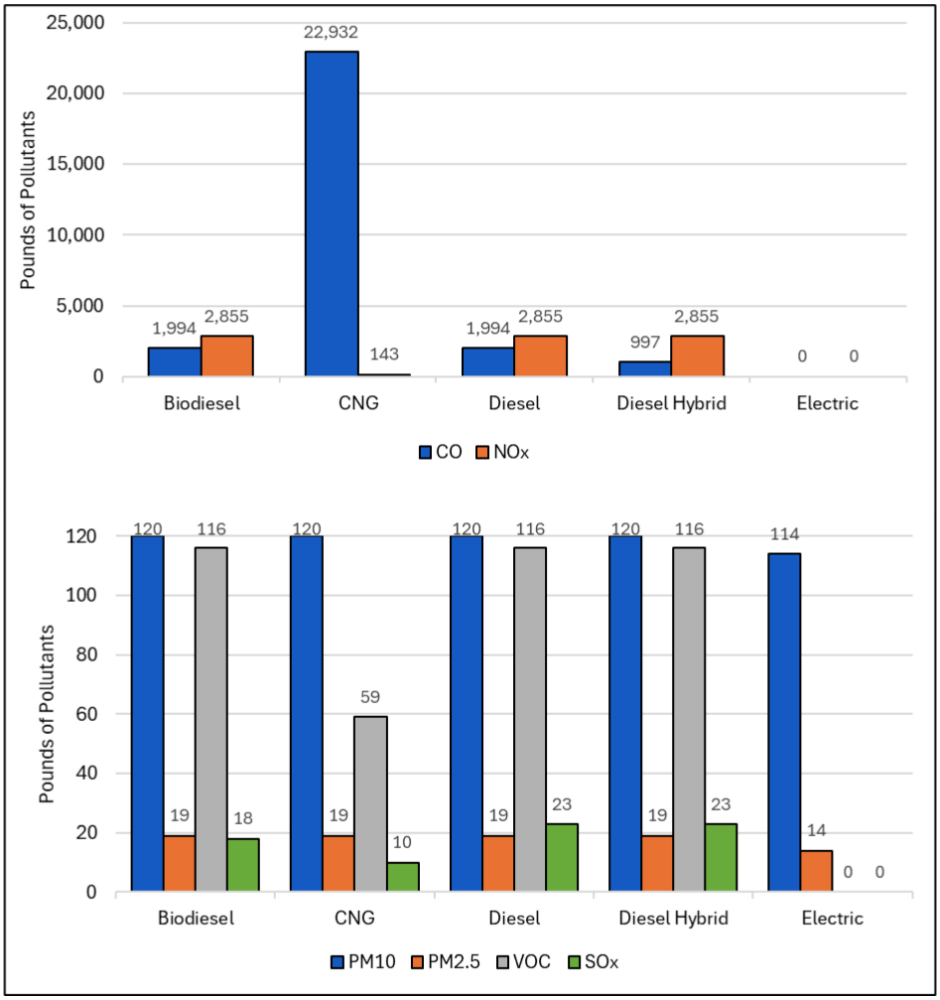
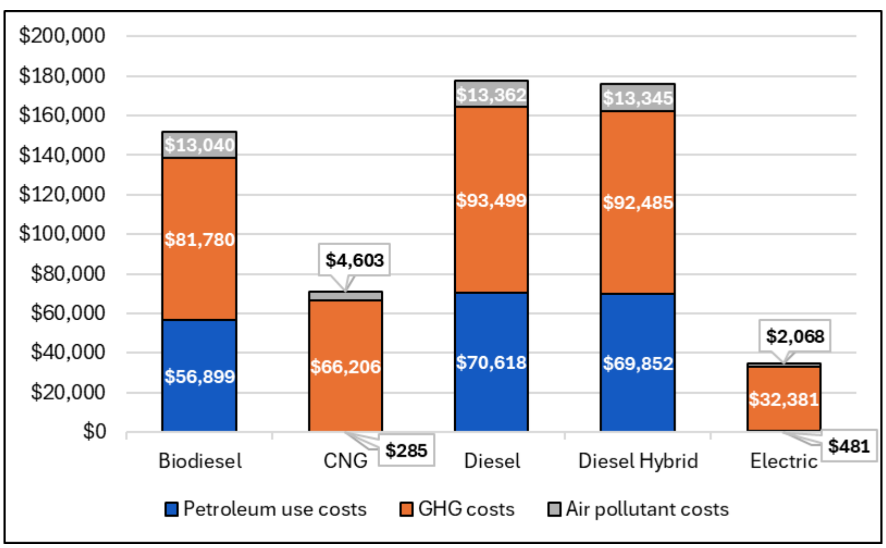
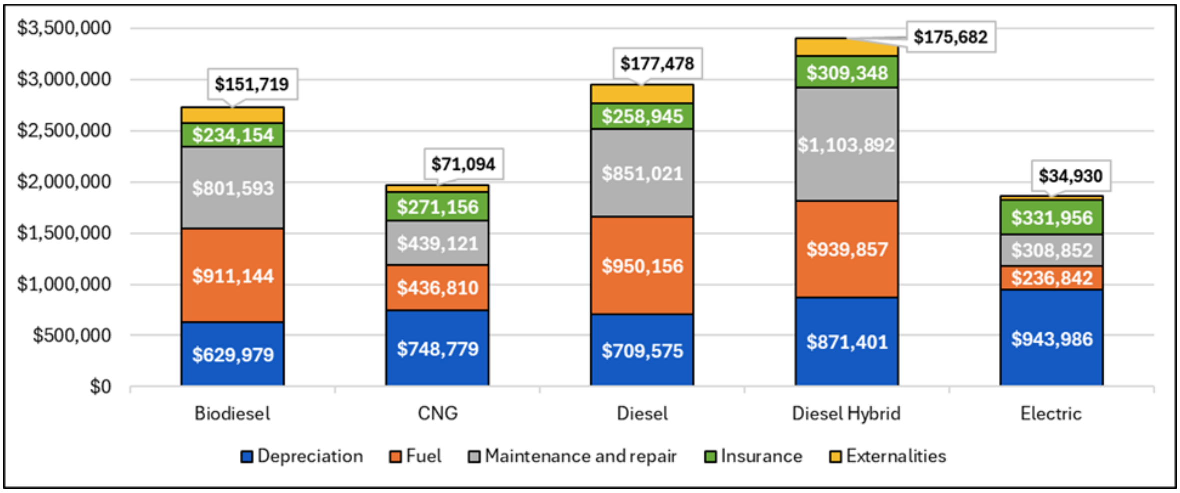


Figure 32 *Comparison of Lifetime Externality Costs*



Combining total externality costs with lifetime cost of ownership allows a comparison of total cost of ownership accounting for social costs of transit buses with different propulsion types, as shown in Figure 33.

Figure 33 *Total Cost of Ownership with Externalities*



Note that in Figure 33, the amounts for diesel exhaust fluid and license/registration are too small to include in the figure; instead, they are included in Table 9 below. The analysis demonstrates that diesel hybrid buses have the highest total cost of ownership when accounting for externalities ($3,418,230) over the life of the vehicle, while battery-electric and CNG buses have the lowest ($1,864,866 for battery-electric and $1,975,260 for CNG). Total cost of ownership (TCO) with externalities for battery-electric buses is 37.1% lower than for diesel buses. Total cost of ownership for CNG buses is 33.4% lower than for diesel, while TCO with externalities for biodiesel vehicles is 7.4% lower than for comparable diesel buses. At the same time, TCO for diesel hybrid buses is 15.3% higher than for diesel buses. Table 9 summarizes the total cost of ownership for transit buses of different propulsion types.

Table 9 *Total Cost of Ownership with Externalities*

	Diesel	Electric	Diesel Hybrid	Biodiesel	CNG
Depreciation	$709,575	$943,986	$871,401	$629,979	$748,779
Fuel	$950,156	$236,842	$939,857	$911,144	$436,810
Diesel Exhaust Fluid	$9,858	$0	$9,751	$9,831	$0
Maintenance and Repair	$851,021	$308,852	$1,103,892	$801,593	$439,121
Insurance	$258,945	$331,956	$309,348	$234,154	$271,156
License and Registration	$8,300	$8,300	$8,300	$8,300	$8,300
Externalities	$177,478	$34,930	$175,682	$151,719	$71,094
TCO with Externalities	**$2,965,334**	**$1,864,866**	**$3,418,230**	**$2,746,720**	**$1,975,260**

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Sub-Appendix 1: Transit Agencies AFV/AV Questionnaire

Survey of BRT Providers

Introduction

The goal of this survey is to inventory different types of alternative fuel vehicles (AFV) and other advanced propulsion technologies, including autonomous technologies, operating in BRT service, as well as compare the performance and operating costs of AFVs with conventional BRT vehicles. The results of this analysis will assist with evaluating operating cost savings resulting from operating various AFVs (including CNG, hybrid electric, and battery-electric vehicles) in BRT service and gauging the adoption of autonomous vehicle technologies by BRT providers. This research is conducted by the National Bus Rapid Transit Institute (NBRTI) in conjunction with American Public Transportation Association (APTA) and Federal Transit Administration (FTA). It is envisioned that the results of this analysis will be published and will be a valuable resource to policy makers and transit professionals.

Please help us collect preliminary data by answering the questions below. Shortly after this survey we will follow up with another, more detailed and targeted, questionnaire covering performance and operating cost data of AFV BRT vehicles.

Questions

General Information

1. Contact Information:
   Contact Person
   Name of the Transit System (organization, entity, agency, company, etc.)
   City/State
   Contact e-mail/phone

2. How many BRT lines do you operate?

Vehicle Fleet Information

3. How many vehicles do you run in BRT service?

4. Number of BRT vehicles of each length:

Length	N of Vehicles
- 30’ buses	
- 35’ buses	

- 40’ buses
- 60’ - Articulated

5. What is the number of **Diesel/Gasoline** vehicles in BRT service by vehicle length?

   Length N of Vehicles

   - 30’
   - 35’
   - 40’
   - 60’-Articulated

6. What is the number of **CNG** vehicles in BRT service by vehicle length?
   Length N of Vehicles

   - 30’
   - 35’
   - 40’
   - 60’-Articulated

7. What is the number of **Propane** vehicles in BRT service by vehicle length?
   Length N of Vehicles

   - 30’
   - 35’
   - 40’
   - 60’-Articulated

8. What is the number of **Hybrid electric** vehicles in BRT service by vehicle length?
   Length N of Vehicles

   - 30’
   - 35’
   - 40’
   - 60’-Articulated

9. What is the number of **Battery-electric** vehicles in BRT service by vehicle length?
   Length N of Vehicles

- 30’
- 35’
- 40’
- 60’-Articulated

10. What is the number of **Other propulsion/fuel** vehicles in BRT service by vehicle length?

    Length | N of Vehicles

    - 30’
    - 35’
    - 40’
    - 60’-Articulated

Vehicle Maintenance Practices

11. Please indicate maintenance practices for alternative fuel vehicles (AFV) in your BRT service

- Maintenance is performed in-house
- Maintenance is contracted out
- Other (please specify)

12. Please indicate maintenance practices for conventional vehicles in your BRT service

- Maintenance is performed in-house
- Maintenance is contracted out
- Other (please specify)

13. Please describe other differences in maintenance approaches for AFV and non-AFV vehicles in BRT service.
14. If AFV vehicles are treated differently in terms of maintenance, please describe the reason.

Autonomous Vehicle (AV) Technologies

15. Please describe your comfort level with using autonomous vehicle (AV) technologies in BRT service

    a. Comfortable using AV now

    b. Somewhat uncomfortable using AV now, but may consider in the future in 1-2 years

c. Somewhat uncomfortable using AV now, but may consider in the future in 3-5 years

d. Somewhat uncomfortable using AV now, but may consider in the future in 6-10 years

e. Uncomfortable using AV now and will not consider using it in the near future (within next 10 years)

16. Do you currently employ AVs for your BRT service?

- Yes
- No

17. Were AV technologies added to BRT vehicles before or after Altoona bus testing?

- Before (There may be testing issues)
- After (No issues)

18. If yes (16), please provide a brief description of automation vehicle technology employed:

- When did AVs go in operation?
- Number of AVs used in service?
- Is this a (temporary) pilot/demonstration project or a permanent implementation?
- Other relevant information

19. If currently using AV technologies for BRT, did this use of AVs improve safety

- Yes
- No
- Don't know (safety data is not available)

20. If the use of AV technologies improved safety, please specify what safety metric improved and by how much?

- Safety metric improved
- Improvement amount

21. Do you plan to implement AV technologies to provide BRT service in the near future (1-3 years)

- Yes
- No

- Other (please explain)

22. If yes, please provide details of your future AV BRT plans

    - Do you have a specific plan or simply a general willingness to employ AV in the future?

    - Please provide a brief concept of the project (if known)

    - When do you plan to implement AV technologies (provide approximate date)?

23. Primary reasons for planning to implement AV technologies in BRT:

    - Improve safety

    - Reduce operating costs

    - Test new technology

    - Other (please specify)

24. If safety improvement is the primary reason for plans to implement AV technologies, please specify what safety metric is expected to improve by using AVs and by how much.

    - Metric expected to be improved

    - Expected amount of improvement

    - Other relevant information

25. Please indicate the primary reasons for not planning to employ AVs for BRT service in the near future:

    - N/A

    - The state of AV technology (technology is not capable yet to ensure safe operation)

    - Liability concerns

    - Negative perception from drivers

    - Not enough support from local leadership/elected officials

    - High cost of new technology and infrastructure

    - Other (please specify)

Sub-Appendix 2: Fleet Operating Cost Data Collection Form

Agency	
Reporting Date	

Vehicle ID	**Length**	**Power Plant**	**Fuel Type**	**Date Placed in Service**	**Date Removed from Service**	**Acquisition Cost**	**Miles to Date**	**Fuel to Date**	**Units of Fuel Used**	**Parts Cost to Date**			**Labor Cost to Date**			**Comments**
										Scheduled Service	**Unscheduled Service**	**Total Parts Costs (scheduled + unscheduled)**	**Scheduled Service**	**Unscheduled Service**	**Total Labor Costs (scheduled + unscheduled)**	
	20', 25', 35', 40', 45', Articulated, etc.	Internal combustion, Hybrid, Plug-in hybrid, Electric, Fuel cell	Diesel, Gasoline, CNG, LNG, LPG, Biodiesel (specify blend), Electricity, Methanol (blend), Ethanol (blend), Hydrogen, Bi-fuel (specify each fuel on separate line)	MM/DD/YYYY	MM/DD/YYYY	Dollars $	Miles driven from date placed in service to date	Expressed in actual units of fuel used	Gallons, kilowatt-hours, cubic feet, tons, lbs., etc.	Dollars $ (from date placed in service to date)	Dollars $ (from date placed in service to date)	Dollars $ (from date placed in service to date)	Dollars $ (from date placed in service to date)	Dollars $ (from date placed in service to date)	Dollars $ (from date placed in service to date)	Optional

Appendix B

Evaluation of Alternative Fuel Vehicles in Bus Rapid Transit Service

EmX BRT vehicle at Lane Transit District in Eugene, Oregon
Photo Credit Victoria Perk

Abstract

Bus rapid transit (BRT) continues to grow in popularity in the United States and around the world. Its relatively low cost, flexibility, and ability to tailor the service and characteristics to each community make it a sound investment. In recent years, there appears to be renewed interest in BRT research and to update earlier BRT research work to include more recent concerns and priorities.

This report contains a detailed analysis of NTD Safety and Security data for BRT systems. From 2014 through 2022, 852 safety and security events occurred for the BRT mode: 77 security events and 775 safety events. Out of 775 safety events, 706 are collisions. Of the 77 security events, 71 are assaults. A total of 6 fatalities and 1,270 injuries resulted from the 852 events.

Current research acknowledges equity implications, accessibility impacts, and impacts to vulnerable persons. This report presented evidence of this shifted focus and noted that the importance of planning and design for BRT systems to be universal and inclusive to all people.

There are also some additional operational issues to consider, such as roundabouts. Researchers are studying the best ways to operate transit vehicles through roundabouts with ease relative to the vehicle size and with minimal delays. One

style of roundabout that seems most promising based on current research has an exclusive bus lane passing through the center island of the roundabout with signals to control passing traffic. With this design, BRT vehicles pass straight through the roundabout, or “throughabout,” with minimal or no delay. As more BRT systems begin operations and others mature, there is still much to learn about inclusive planning and design practices and measures to reduce the frequency and severity of safety and security events

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Executive Summary

Bus rapid transit (BRT) continues to grow in popularity in the United States and around the world. Its relatively low cost, flexibility, and ability to tailor the service and characteristics to each community make it a sound investment. In recent years, there appears to be renewed interest in BRT research and to update earlier BRT research work to include more recent concerns and priorities. NBRTI staff has observed this shift by reviewing and analyzing the literature, available data (including the National Transit Database), and various case studies. As more BRT systems begin operations and others mature, there is still much to learn about inclusive planning and design practices and measures to reduce the frequency and severity of safety and security events.

While transit system safety has been a priority for many years, until recently, it was more difficult to analyze BRT safety over any length of time, as data were generally included with regular bus data. Now that 16 BRT systems are reporting data separately in the National Transit Database (NTD), it has become easier to track BRT statistics over time. In addition, while the focus of BRT research and analysis has often been on efficiency and other monetary considerations such as economic development benefits, more current research has acknowledged equity implications, accessibility impacts, and impacts to vulnerable populations. There are also some additional operational issues to consider. For example, as both roundabouts and BRT systems are increasing, it becomes more likely that larger transit vehicles will need to interact with roundabouts. Key findings from this research are summarized below.

- **Collision rates for BRT –** NTD Safety and Security data from 2014 through 2022 were examined. Overall, while the numbers of events are relatively low for BRT, the collision rates for BRT, as measured per 100,000 vehicle revenue miles (VRM) and vehicle revenue hours (VRH), were found to be somewhat higher than those for motorbus. The same is true for rates of security events, as measured by events per 100,000 VRM and VRH. One reason for this result could simply be the absolute size difference between the two modes; the BRT totals are much smaller than the motorbus totals.

- **Men injured at higher rates –** In addition to just numbers of events, injuries, and fatalities, the NTD Safety and Security database includes gender and age range information for individuals involved in and impacted by these events. It was found that men were injured at higher rates than women, at least for these BRT data for the years studied, 2014 through 2022.

- **Total safety and security events –** Between the years 2014 and 2022, a total of 852 safety and security events occurred for the BRT mode: 77 security events and 775 safety events. Out of 775 safety events, 706 are collisions. Of the 77 security events, 71 were assaults. A total of 6 fatalities and 1,270 injuries resulted from the 852 events that occurred between 2014 and 2022.

- **Inclusive planning for BRT –** This report presents evidence of a shifted focus on equity in the planning and design of BRT investments. In addition, it is shown that anyone who has a safety or security concern related to public transportation could

be considered part of a vulnerable group. Children, women, and the LGBTQIAP+ community may also be vulnerable in certain situations, in addition to the typical vulnerable groups which include older persons, people with disabilities, people with language barriers, people in a minority group, households in poverty, and households with no car. As such, it's important that planning and design for BRT systems and all transportation systems be universal and inclusive to all people.

- **BRTs in roundabouts –** A body of research is growing to study the optimal ways to operate transit vehicles through roundabouts with ease relative to the vehicle size and with minimal delays. One style of roundabout that seems most promising based on current research has an exclusive bus lane passing through the center island of the roundabout with signals to control passing traffic. With this design, the BRT vehicles pass straight through the roundabout, or "throughabout," with minimal or no delay. Two BRT systems, Capital District Transportation Authority and Lane Transit District, which operate the new Purple Line BRT and the Emerald Express EmX, respectively, will be seeing some new roundabouts along their route alignments. The designs for these roundabouts do not have the center bus lane, however.

- **BRT and pedestrian safety –** Regarding pedestrian safety, the Greater Richmond Transit Company's Pulse BRT system has had to deal with a few pedestrian collisions as pedestrians did not realize the bus would be passing through with a green signal while the general traffic was stopped at a red light. As a result, these pedestrians walked directly into the path of the BRT vehicle. In one case, the pedestrian lost their life. These events have spurred community outreach and new mitigation measures both in Richmond and elsewhere to try and eliminate these types of events. One of the common tactics is to paint the bus lanes red to very easily distinguish them from the adjacent general traffic lanes. Hopefully this measure and other mitigation measures will reduce or even eliminate these pedestrian collision events.

Introduction

Bus rapid transit (BRT) continues to grow in popularity in the United States and around the world. Its relatively low cost, flexibility, and ability to tailor the service and its characteristics to each community make it a sound investment. In recent years, there appears to be a resurgence and renewed interest in BRT research and to update earlier BRT research work to include more recent concerns and priorities.

Transit system safety has been a priority for many years. Until recently, it was more difficult to analyze BRT safety over any length of time, as data were generally included with regular bus data. Now that more BRT systems are reporting data separately in the National Transit Database (NTD), it has become easier to track BRT statistics over time. Still, there are many services that operate as BRT but do not meet the Federal Transit Administration (FTA) definition of BRT, and thus are not reported separately. However, this report presents a comprehensive analysis of BRT safety and security data for those 16 BRT systems that are reporting to the NTD.

The first section of this report includes that detailed analysis of NTD Safety and Security data for BRT systems. A few statistics are compared with general motorbus, such as rates of collisions and security events. In addition to just numbers of events, injuries, and fatalities, the NTD Safety and Security database includes gender and age range information for individuals involved in and impacted by these events. That information can be summarized to examine the gender and age distributions for those individuals.

While the focus of BRT research and analysis has often been on efficiency and other monetary considerations such as property value and economic development benefits, more current research has a focus on equity implications, accessibility impacts, and impacts to vulnerable populations. This report will examine some of the latest research and practice related to the consideration of these important issues.

There are also some additional operational issues to consider. For example, the number of roundabouts is increasing as communities realize their significant traffic safety benefits compared to traditional intersections. As both roundabouts and BRT systems are increasing, it becomes more likely that larger transit vehicles will need to traverse roundabouts on their routes. A body of research is growing to study the best ways to have transit vehicles pass through roundabouts with ease relative to the vehicle size and with minimal delays. This report will summarize some of the latest information on BRT systems interacting with roundabouts.

Finally, two brief case examples are presented, one relating to roundabouts and one relating to pedestrian safety.

National Transit Database (NTD) Analysis

One of the first tasks of this work is to explore the data available in the Federal Transit Administration's (FTA) National Transit Database (NTD). Both service data and safety/security data are used in this analysis. The NTD was established by the U.S. Congress to act as a primary source for data and information on U.S. transit systems. Recipients/beneficiaries of grants from the FTA under the Urbanized Area Formula Program (§5307) or Other than Urbanized Area (Rural) Formula Program (§5311) are required to submit data to the NTD (FTA 2022). Approximately 1,000 transit providers in urbanized areas (UZAs) currently report to the NTD through a web-based reporting system

NTD Safety and Security Background

Transit agencies are required to provide detailed information regarding severe safety and security events on the Major Event Report within 30 days and must submit one report for each major event that meets NTD reporting thresholds.
A reportable event is one that meets at least one NTD reporting threshold (listed below) and also:

- Occurs at a transit revenue facility, maintenance facility, or rail yard;
- Occurs on transit right-of-way or infrastructure;
- Occurs during a transit-related maintenance activity; or
- Involves a transit revenue vehicle (FTA 2023).

For non-rail modes, the reporting thresholds are as shown below:

- Fatalities confirmed within 30 days (including suicides);
- Injuries requiring immediate transport for medical attention away from the scene for at least one person;
- Property damage estimated to be greater than or equal to $25,000;
- Collisions that:
    - Meet at least one of the other thresholds;
    - Involve the towing away of any vehicles from the scene;
    - Include attempted suicides, suicides, or homicides that result in injury or fatality from contact with a transit vehicle;
- Evacuation of a transit vehicle or facility for "life-safety" reasons (FTA 2023).

Before delving into the data, it is important to understand the definitions of each of these events. First, according to the NTD, safety incidents are defined as "*a collision, derailment, fire, hazardous material spill, act of nature, evacuation, or Other Safety Occurrence not Otherwise Classified (OSONOC) occurring on transit right-of-way, in a transit revenue facility, in a transit maintenance facility, or involving a transit revenue vehicle and meeting established NTD thresholds*." A collision is "*a vehicle/vessel accident in which there is an impact of a transit vehicle/vessel with another transit vehicle, a non-transit vehicle, an object, a person(s) (suicide/attempted suicide included), an animal, a rail vehicle, a vessel, or a dock*" (FTA NTD Glossary 2023).

A security event is defined in NTD as "*an occurrence of a bomb threat, bombing, arson,* *hijacking, sabotage, cyber security event, assault, robbery, rape, burglary, suicide, attempted suicide (not involving a transit vehicle), larceny, theft, vandalism, homicide, CBR (chemical/biological/radiological) or nuclear release, or other event.*" In addition, a fire is "*uncontrolled combustion made evident by flame that requires suppression by equipment or personnel*" (FTA NTD Glossary 2023).

It is always important to recognize both the strengths and limitations of the NTD data. NTD reporting, including safety and security reporting, has increased in accuracy and quality over the past several years, and the NTD Safety and Security database is readily available to the public (and to researchers). However, there still may be pieces of information that would be helpful but are not captured in the fields of the safety and security reporting forms. In addition, it must be remembered that the NTD are self-reported by the transit agencies, although the safety data submitted to NTD by transit agencies are comprehensively reviewed for clarity and completeness.

NTD Data

This analysis includes a summary of data and event information for the NTD motorbus (MB) and bus rapid transit (RB) modes. A brief description of these two modes is provided below (FTA NTD Glossary 2023).

Motorbus

Motorbus (MB) includes rubber-tired passenger vehicles operating on fixed routes and schedules over typical roadways. Vehicles are powered by diesel, gasoline, batteries, or alternative fuels. Bus rapid transit (BRT) services that do not meet the FTA definition for BRT/RB will have data included in the MB mode.

Bus Rapid Transit

Bus Rapid Transit, or Rapid Bus (RB), began as a separate modal designation beginning with the report year (RY) 2012 NTD reporting cycle. Bus rapid transit comprises fixed route bus systems that operate at least 50 percent of the service on a fixed guideway or runningway. These systems also have defined passenger stations, traffic signal priority or preemption, high-frequency bidirectional services for a substantial part of weekdays and weekend days; low-floor vehicles or level-platform boarding, and separate branding of the service from the other bus service provided by the agency. Agencies generally also use off-board fare collection.
As of RY 2022, there are 16 BRT, or RB, services included in the NTD. The data presented represent these agencies, listed below:

- Alameda-Contra Costa Transit District (AC Transit Rapid)
- Central Florida Regional Transportation Authority (Lynx Lymmo)
- City of Albuquerque Rapid Transit (ART)
- City of Fort Collins Transfort MAX
- Connecticut Department of Transportation (CTtransit – Hartford)
- Greater Richmond Transit Company (Pulse)
- Indianapolis and Marion County Public Transportation (IndyGo BRT)
- Interurban Transit Partnership (Grand Rapids BRT)
- Kansas City Area Transportation Authority (RideKC MAX)

- Lane Transit District Emerald Express (EmX)
- Los Angeles County Metropolitan Transportation Authority (LA Orange Line)
- Massachusetts Bay Transportation Authority (Silver Line)
- New York City Transit MTA (Select Bus Service)
- San Bernardino Omnitrans
- Regional Transportation Commission of Southern Nevada (Las Vegas)
- The Greater Cleveland Regional Transportation Authority (Healthline)

The source of all data presented in this section is NTD Safety and Security data files available online on the NTD website [The National Transit Database (NTD) | FTA (dot.gov)](). In addition, data on unlinked passenger trips (UPT), vehicle revenue miles (VRM), vehicle revenue hours (VRH), and vehicles operated in maximum service (VOMS) are provided via NTD data tables available online (FTA NTD Data 2023).
The years selected for this study are RY 2014 through 2022. Over these years, a total of 852 safety and security events occurred for the BRT mode: 77 security events and 775 safety events. Out of 775 safety events, 706 are collisions. Tables 1 and 2 present a selection of service data as well as safety/security data for the BRT mode as well as the motorbus mode, for comparison. Tables 3 and 4 illustrate the rates of event occurrence for both modes.

NTD Service and Safety/Security Data for BRT and Motorbus

Tables 1 and 2 show unlinked passenger trips (UPT), vehicle revenue miles (VRM), vehicle revenue miles (VRH), vehicles operated in maximum service (VOMS), collisions, and security events for BRT (Table 1) and motorbus (Table 2). Collisions are shown because they are the most common safety event by far (706 of 775 safety events). Table 1 shows that BRT ridership steadily increased from 2014 to 2019, partially due to ridership increases on individual BRT systems and partially due to an increasing number of new BRT systems reporting in the NTD. During this same time, Table 2 shows that UPT for the motorbus mode was steadily declining, as had been the trend for transit ridership as a whole.

The decline in motorbus ridership occurred while miles and hours of motorbus service (VRM and VRH) were increasing. VRM and VRH increased for the BRT mode as well from 2014 to 2021. Vehicles operated in maximum service, VOMS, (also known as peak vehicles) grew for BRT from 2014 to 2020, as service continued to increase during that time. For the motorbus mode, VOMS remained relatively steady through 2020. Of course, the Covid-19 pandemic began affecting transit ridership beginning in 2020. Tables 1 and 2 both show significant declines in UPT beginning in 2020 and finally rebounding slightly starting in 2022. VRM and VRH for BRT only showed declines beginning in 2022, while these measures began declining for motorbus beginning in 2020. VOMS began declining 2021 for BRT and 2020 for motorbus.

Collisions represent the largest share of safety events, and additional data on collisions will be presented later in this section. Table 1 shows that collisions for the BRT mode remained relatively steady over the period examined, reaching a peak of 101 in 2021 even as ridership declined, though BRT service levels increased that year. The number of BRT collisions dropped by one collision in 2020, despite increased levels of VRM and VRH, before climbing again through 2022. Similarly, the number of BRT security events was relatively steady over this period but reached a peak of 21 in 2022.

Table 2 exhibits a similar trend for collisions and security events for the motorbus mode as a whole. The number of collisions did not change significantly over the period examined before dropping in 2020 and then increasing again through 2022. Security events for the motorbus mode declined in 2020 before increasing by approximately 100 in 2021 and again in 2022, reaching a high of 701 events.

Table 1 *BRT Service and Safety/Security NTD Data*

Year	UPT	VRM	VRH	VOMS	Collisions	Security Events
2014	53,876,119	7,866,667	854,294	232	64	4
2015	56,090,735	8,789,282	927,983	259	40	10
2016	63,430,286	9,817,464	1,059,863	302	77	6
2017	63,141,370	9,733,145	1,076,145	288	80	0
2018	63,116,848	10,041,494	1,128,521	301	72	9
2019	64,700,042	10,775,172	1,202,256	351	90	6
2020	38,679,038	11,369,045	1,244,276	381	89	7
2021	38,592,406	11,679,411	1,265,032	319	101	14
2022	44,475,509	11,505,490	1,224,137	307	93	21

Table 2 *Motorbus Service and Safety/Security NTD Data*

Year	UPT	VRM	VRH	VOMS	Collisions	Security Events
2014	4,978,013,738	1,735,659,102	146,387,444	46,701	3,903	521
2015	4,841,204,672	1,765,430,767	149,526,308	47,110	4,878	526
2016	4,641,691,992	1,789,451,027	152,179,487	46,950	4,906	489
2017	4,437,466,466	1,800,230,805	153,845,114	47,182	4,781	484
2018	4,383,505,235	1,822,436,822	155,560,153	47,744	4,963	534
2019	4,346,533,899	1,845,296,440	157,773,657	47,673	5,015	651
2020	2,395,829,236	1,614,295,730	137,479,202	47,239	3,889	511
2021	2,362,161,693	1,665,041,085	141,189,612	43,258	4,451	603
2022	2,839,652,548	1,661,362,638	139,733,045	41,594	4,818	701

It is often more instructive to calculate rates of safety and security events rather than absolute numbers. Table 3 illustrates the rates of collisions and security events relative to VRM and VRH for both BRT and the motorbus mode. Because the numbers of collisions and security events are quite small relative to service levels as measured by VRM and VRH, the rates are per 100,000 VRM and VRH. It should be noted that there were no BRT security events reported in 2017.

Table 3 *Rates of Event Occurrence, Bus Rapid Transit and Motorbus*

Year	Collisions per 100,000 VRM		Security Events per 100,000 VRM		Collisions per 100,000 VRH		Security Events per 100,000 VRH	
	BRT	MB	BRT	MB	BRT	MB	BRT	MB
2014	0.814	0.225	0.051	0.030	7.492	2.666	0.468	0.356
2015	0.455	0.276	0.114	0.030	4.310	3.262	1.078	0.352
2016	0.784	0.274	0.061	0.027	7.265	3.224	0.566	0.321
2017	0.822	0.266	n/a	0.027	7.434	3.108	n/a	0.315
2018	0.717	0.272	0.090	0.029	6.380	3.190	0.798	0.343
2019	0.835	0.272	0.056	0.035	7.486	3.179	0.499	0.413
2020	0.783	0.241	0.062	0.032	7.153	2.829	0.563	0.372
2021	0.865	0.267	0.120	0.036	7.984	3.152	1.107	0.427
2022	0.808	0.290	0.183	0.042	7.597	3.448	1.715	0.502

Table 3 shows that the latest data, for 2022, shows 0.81 collisions per 100,000 BRT VRM and 7.60 collisions per 100,000 BRT VRH. In 2022, there were 0.18 security events per 100,000 BRT VRM and 1.72 security events per 100,000 BRT VRH. These numbers are higher compared to the motorbus mode as a whole. In 2022, 0.29 collisions occurred per 100,000 motorbus VRM, and 3.45 collisions per 100,000 motorbus VRH. Regarding security events, there were 0.04 such events per 100,000 motorbus VRM and 0.50 security events per 100,000 motorbus VRH, as listed in Table 3.

NTD Security Events

Tables 1 and 2 show unlinked passenger trips (UPT), vehicle revenue miles (VRM), vehicle revenue miles (VRH), vehicles operated in maximum service (VOMS), collisions, and security events for BRT (Table 1) and motorbus (Table 2). Collisions are shown because they are the most common safety event by far (706 of 775 safety events). Table 1 shows that BRT ridership steadily increased from 2014 to 2019, partially due to ridership increases on individual BRT systems and partially due to an increasing number of new BRT systems reporting in the NTD. During this same time, Table 2 shows that UPT for the motorbus mode was steadily declining, as had been the trend for transit ridership as a whole

Assaults

As mentioned previously, there were a total of 77 security events on BRT services from 2014 to 2022. Seventy-one of these were assaults, two were homicides, and there was one each in the categories of bomb threat, robbery, attempted suicide, and a suspicious package. Additional information on these events is presented below.

The NTD defines an assault as "*an attack by one person on another without lawful authority or permission*." The NTD further focuses on the definition of an assault on a transit worker: "*a circumstance in which an individual knowingly, without lawful authority or permission, and with intent to endanger the safety of any individual, or with a reckless disregard for the safety of human life, interferes with, disables, or incapacitates a transit worker while the transit worker is performing the duties of the transit worker*" (FTA NTD Glossary 2023). In recent years, there has been an increased emphasis on mitigating assaults on transit workers, and NTD reporting has evolved to address this issue with additional reporting changes beginning in 2023.

Table 4 breaks down the 71 assaults by year. As shown in the table, there were zero assaults in 2017 and an increased number of reported assaults in 2021 and 2022. No fatalities or serious injuries resulted from these assaults. As noted in the NTD definitions, those with serious injuries may or may not have been transported away from the scene for medical attention. For reference, a serious injury is one that:

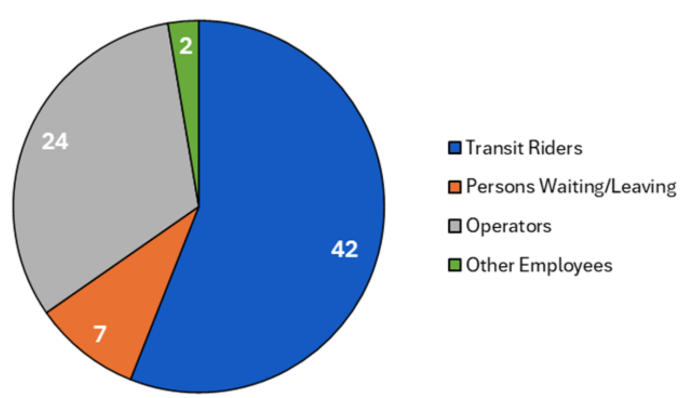
- *"Requires hospitalization for more than 48 hours within 7 days of the event;*
- *Results in a fracture of any bone (except simple fractures of fingers, toes, or nose);*
- *Causes severe hemorrhages, or nerve, muscle, or tendon damage;*
- *Involves an internal organ; or*
- *Involves second-degree burns affecting more than five percent of the body surface"* (FTA NTD Glossary 2023).

Table 4 ***Assaults on BRT Services, by Year***

Year	Number of Assaults
2014	4
2015	9
2016	5
2017	0
2018	9
2019	5
2020	6
2021	14
2022	19

Figure 1 shows the distribution of injuries related to these assaults. The largest group affected by assaults are transit riders on the buses, with 42 injuries over the years from 2014 through 2022. The next largest category is transit operators, with 24 injuries related to assaults during this time. There were seven injuries to persons "waiting or leaving," which refers to people who are waiting to board a transit vehicle or who have just alighted a vehicle yet are still on transit property. Two injuries affected other transit employees.

Figure 1 ***Assaults on BRT Services, by Injury Category 2014–2022***



The NTD safety and security database includes some limited but useful information on those persons impacted by a safety or security event. Individuals are categorized as riders, operators, employees, and so on, and are also categorized by gender and age range. These data can provide insight as to any vulnerable persons that are affected by safety and security events. The gender category is male or female. Age ranges are categorized as children (12 and under), teens (age 13 to 18), adults (age 19 to 60), and seniors (age 61 and above).

Table 5 provides information on the 71 individuals who were victims of assault on BRT services between 2014 and 2022. By far the largest category affected are adult male passengers (26), followed by adult male transit operators inside the vehicle (12). Five adult female transit operators (inside the vehicle) and three adult female operators outside the vehicle were assaulted. There were seven adult female passengers and one senior female passenger affected by assault. Interestingly, the teens who were victims of assault (three female and two male) were involved in fights on board a BRT vehicle.

Table 5 *Persons Impacted by Assaults on BRT Services 2014–2022*

Category	Number of Persons
Passenger Adult Male	26
Operator Adult Male – In Vehicle	12
Passenger Adult Female	7
Wait/Leave Adult Male	6
Operator Adult Female – In Vehicle	5
Operator Adult Female – Outside Vehicle	3
Passenger Teen Female	3
Passenger Teen Male	2
Passenger Male – Age Unknown	2
Passenger Female – Age Unknown	1
Passenger Senior Female	1
Wait/Leave Senior Male	1
Transit Employee Adult Male – In Vehicle	1
Employee Contractor Adult Male	1

Other Security Events

Six additional security events occurred on BRT services between 2014 and 2022. One was a bomb threat on the Lane Transit District's EmX BRT in 2015 that did not result in any injuries. There were two homicides, both in 2022. One occurred on the EmX BRT and resulted from male on male assault. The victim was a senior male. The second homicide occurred on the Cleveland Healthline and resulted from the shooting of an adult male passenger.

A robbery occurred on the AC Transit Rapid in 2022, which was a purse-snatching of an adult female passenger. In 2019, an adult male pedestrian attempted suicide by lying down in front of an EmX BRT vehicle. Finally, a suspicious box was reported onboard an

AC Transit Rapid bus in 2016. It was determined that the box was harmless and there were no injuries associated with that event.

NTD Safety Events

Collisions

Of the 775 reported safety events that occurred on BRT services from 2014 through 2022, 706 are collisions. Collisions with another motor vehicle are, by far, the largest category with 595 events. Remaining collisions are listed in Table 6 below. As the table indicates, there are 99 collisions with a person, 6 collisions with a fixed object, 4 collisions with another transit vehicle, and 2 are unknown as the NTD fields were blank.

Table 6 *BRT Collisions 2014–2022*

Collision With	Number of Collisions
Motor Vehicle	595
Person	99
Fixed Object	6
Transit Vehicle	4
Not Specified	2

Collision types are summarized in Table 7. The most common type of collision is a side impact crash, with 279 between 2014 and 2022. Front collisions (other front collisions, not head-on collisions) are the second most common type of collision for BRT vehicles, with 272 occurring during these years. Head-on collisions and other rear impact collisions comprise 46 collisions each.

A "rear-ended" collision refers to the transit vehicle being rear-ended by another vehicle, whether a passenger vehicle or another transit vehicle. There are 23 rear-ended collisions between 2014 and 2022. "Rear-ending" means that the transit vehicle rear-ended another vehicle (motor vehicle or another transit vehicle). There are 22 rear-ending collisions during the time period examined. Rear-ending collisions are typically considered to be preventable events.

Other types of BRT collisions include sideswipes (14), side to side impacts (2), other front-side impacts (1), and a collision with the roof or top of a transit vehicle (1).

Table 7 *BRT Collisions by Type 2014–2022*

Collision Type	Number of Collisions
Side Impact	279
Other Front Impact	272
Head-On	46
Other Rear Impact	46
Rear-Ended	23
Rear-Ending	22
Sideswipe	14
Side – Side Impact	2
Other Front – Side Impact	1
Roof/Vehicle Top Impact	1

Tables 8 and 9 provide data on fatalities and injuries associated with BRT collisions. Between 2014 and 2022, only four fatalities occurred. Reported injuries from these collisions totaled 1,122 during this time.

Two fatalities resulted for persons waiting or leaving on transit property from 2014 to 2022. Both of these fatalities occurred on the Grand Rapids BRT system. The first was in 2020 and involved an adult male who fell between the platform and the bus as it was pulling away. The victim suffered fatal leg injuries. The second event happened in 2021 when an adult male rose from a seat on the platform and attempted to bang on the side of a bus as it was pulling away from the station. The victim was fatally injured when he lost his footing, slipped off the platform, and became pinned under the rear wheels of the bus.

In 2016, a Cleveland Healthline BRT vehicle was traveling on the interstate when a pedestrian attempted to run across the freeway. The victim, an adult male, ran into the path of the bus, which was traveling at freeway speeds and unable to stop in time. Another fatality occurred in 2020 on the Los Angeles Orange Line BRT when a senior male driver of a light-duty (pick-up) truck made a right-hand turn into the path of a BRT vehicle that had the right-of-way on a green light. The victim turned against the no-right-turn signal and flashing warning lights.

Table 8 *Fatalities Resulting from BRT Collisions 2014–2022*

Collision Type	Number of Collisions
Persons Waiting or Leaving	2
Pedestrian Not in Crossing	1
Occupant of Other Vehicle	1

Table 9 lists the injury types for BRT collisions occurring between 2014 and 2022. There were no serious injuries reported, as defined by NTD. Of the 1,122 total injuries from collisions, 629 injuries occurred to transit riders on board the BRT vehicle, the largest category of injuries. The second largest injury category is occupants of other vehicles that collided with a BRT vehicle, with 276 injuries. Bicyclists incurred 29 injuries in collisions with BRT vehicles.

Pedestrians in crossings incurred 28 injuries from collisions, and pedestrians not in crossings had 21 injuries, as shown in Table 9. Seven people were walking along a roadway or sidewalk when they fell into or otherwise collided with a bus. Interestingly, these injuries were classified under the category for pedestrians walking along tracks, but further investigation revealed that all were walking along roadways or sidewalks. There is no category for pedestrians walking along roadways, so this may be why these particular injuries were classified as walking along tracks. However, there is also an "other" category, and there were nine injuries classified in this way. It appears that some of the "other" injuries were similar to those reported as pedestrians walking along tracks (roadway or sidewalk). Seven individuals were also injured while waiting in or leaving a BRT facility. Finally, three transit employees (not operators) were injured during this time period.

Table 9 *Injuries Resulting from BRT Collisions 2014–2022*

Injury Category	Number of Injuries
Transit Rider	629
Occupant of Other Vehicle	276
Transit Operator	113
Bicyclist	29
Pedestrian in Crossing	28
Pedestrian Not in Crossing	21
Other	9
Pedestrian Walking Along Road	7
Persons Waiting or Leaving	7
Transit Employee	3

Table 10 summarizes the injury categories along with the injured persons' gender and age ranges. In total, there were 1,122 injuries, as mentioned previously. There are 55 categories listed in the table. The largest categories of injuries are to transit riders, followed by occupants of other vehicles and transit operators, respectively. In looking at the age range and gender, it is possible to gain insight into vulnerable groups that may be impacted by these injuries. While the information is not complete, it is possible to see how many women, children, and older persons are being injured in BRT collisions. Interestingly, women tend to comprise the majority of transit ridership (APTA 2017) and, while there is no NTD data available on the gender of riders, Table 11 indicates that most of the injured persons tend to be male.

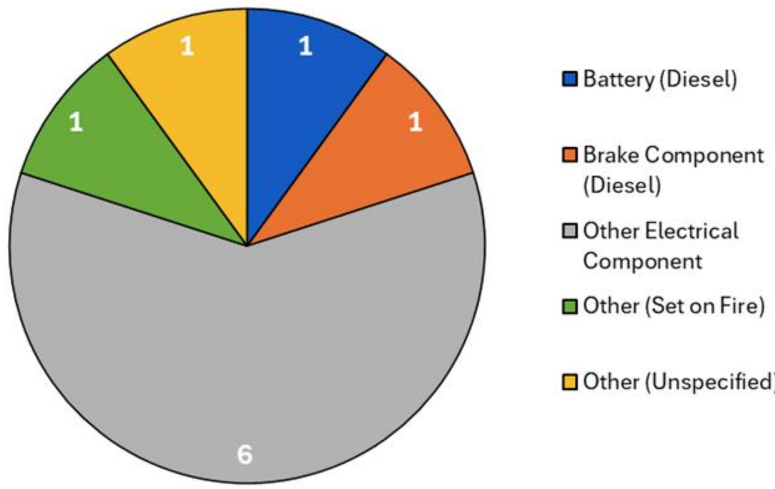
Table 10 *Persons Injured from Collisions on BRT Services 2014–2022*

Category	Number of Persons	Category	Number of Persons
Bicyclist Adult Female	3	Passenger Adult Female	191
Bicyclist Adult Male	18	Passenger Adult Male	178
Bicyclist Senior Male	1	Passenger Senior Female	16
Bicyclist Teen Male	2	Passenger Senior Male	8
Bicyclist Unknown Age Male	2	Passenger Teen Female	2
Bicyclist Unknown	3	Passenger Teen Male	2
Occupant Other Vehicle Adult Female	67	Passenger Child Female	11
Occupant Other Vehicle Adult Male	87	Passenger Child Male	7
Occupant Other Vehicle Senior Female	4	Passenger Unknown Age Female	53
Occupant Other Vehicle Senior Male	8	Passenger Unknown Age Male	63
Occupant Other Vehicle Teen Female	3	Passenger Unknown	37
Occupant Other Vehicle Teen Male	1	Pedestrian in Crossing Adult Female	9
Occupant Other Vehicle Child Female	9	Pedestrian in Crossing Adult Male	10
Occupant Other Vehicle Child Male	12	Pedestrian in Crossing Teen Female	1
Occupant Other Vehicle Unknown Female	10	Pedestrian in Crossing Unknown Age Male	1
Occupant Other Vehicle Unknown Male	27	Pedestrian in Crossing Unknown	6
Occupant Other Vehicle Unknown	37	Pedestrian Not in Crossing Adult Female	7
Operator In Vehicle Female	15	Pedestrian Not in Crossing Adult Male	9
Operator In Vehicle Male	55	Pedestrian Not in Crossing Child Male	1
Operator In Vehicle Unknown	8	Pedestrian Not in Crossing Unknown	5
Operator Outside Vehicle Female	3	Pedestrian Walking Tracks/Road Adult Male	2
Operator Outside Vehicle Male	16	Pedestrian Walking Tracks/Road Unknown	4
Operator Outside Vehicle Unknown	10	Pedestrian Other Adult Female	2
Other Staff Female	2	Pedestrian Other Adult Male	5
Other Staff Male	1	Persons Waiting or Leaving Adult Female	1
Other Adult Female	1	Persons Waiting or Leaving Adult Male	6
Other Unknown	1	Persons Waiting or Leaving Child Female	1
		Persons Waiting or Leaving Unknown Male	1

Fires

Between 2014 and 2022, 10 fires occurred on BRT vehicles, resulting in approximately $450,000 in property damage. Most of the property damage is related to a CNG bus that was set on fire by protestors on Greater Richmond's Pulse BRT system, noted as "Other (Set on Fire)" in Figure 2. Seven of the fires occurred on Silver Line BRT vehicles operated by the Massachusetts Bay Transportation Authority. The remaining two fires occurred on Cleveland Healthline vehicles. In each of the 10 fires, all passengers were evacuated safely and there were no injuries or fatalities. The breakdown of fire types is shown in Figure 2.

Figure 2 ***BRT Fires 2014–2022***

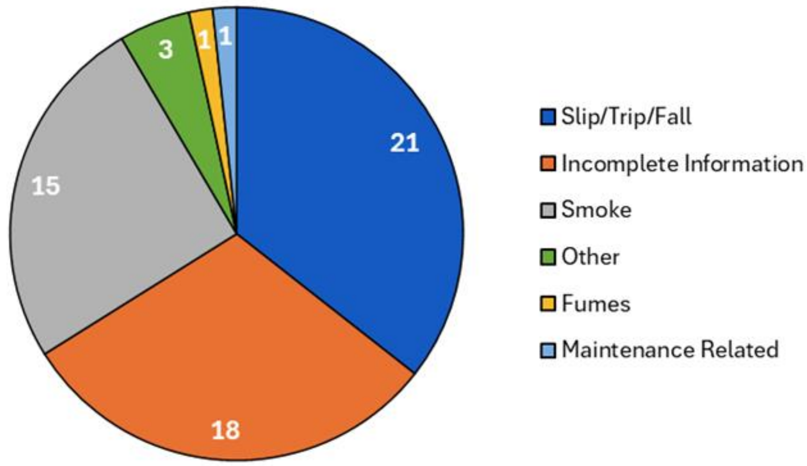


One fire was related to the battery, and another fire involved a brake component. The six fires under the category of "other electrical component" each occurred on different types of BRT vehicles. There was one fire each on a CNG bus, diesel bus, dual fuel bus, electric propulsion bus, hybrid diesel bus, and one of unknown type. One fire did not have any information specified.

<u>Other Safety Events</u>

The remaining 59 other safety events are summarized in Figure 3. The most common type of other safety event is the 21 slips/trips/falls that meet the threshold of a major event. Unfortunately, 18 other events have blank information in the database. There were 15 smoke-related events, 1 related to fumes and 1 related to a maintenance issue. Three other events were due a coolant hose issue, chemical irritation, and an adult female passenger getting her hand stuck in the bus's door as it was closing.

Figure 3 *Other BRT Safety Events 2014–2022*



The other safety events discussed above and shown in Figure 3 resulted in 58 injuries and no fatalities. 57 transit riders were injured, and one transit operator was injured. Table 12 summarizes the person category for each of these injuries. In contrast to injuries from collisions, the majority of injured persons in Table 11 are female.

Table 11 *Injuries Resulting from Other BRT Safety Events 2014–2022*

Injury Category	Number of Injuries
Operator In Vehicle Female	1
Passenger Adult Female	23
Passenger Adult Male	8
Passenger Senior Female	6
Passenger Senior Male	5
Passenger Teen Female	2
Passenger Child Female	2
Passenger Child Male	1
Passenger Unknown Female	5
Passenger Unknown Male	5

Summary

This section analyzed NTD Safety and Security data for BRT systems that meet the FTA definition for the mode. The years included in the analysis were 2014 through 2022. First, service data were presented and used to calculate the rates of safety and security event occurrences, and BRT data were compared to data for the motorbus mode as a whole. In general, rates of event occurrence are greater for BRT than for motorbus services, although the total number of events is much larger for motorbus services due to the increased level of exposure of the services.

The remainder of the section presented data for the various security and safety major events that have been reported from 2014 through 2022. Over these years, a total of

852 safety and security events occurred for the BRT mode: 77 security events and 775 safety events. Out of the 775 safety events, 706 are collisions. Fatality and injury data were also available, as well as gender and age range for those impacted by the events. A total of 6 fatalities and 1,270 injuries resulted from the 852 events that occurred between 2014 and 2022. Examination of gender and age range can provide at least some information regarding any vulnerable populations that are impacted by these events (e.g., women, older persons, children). On the whole, men were injured the most in the events included in this analysis. The next section of this report will review relevant literature related to BRT safety, security, and other pertinent operational issues.

Synthesis of Literature

This section of the report focuses on recent literature regarding BRT planning, design, safety, security, and operational issues such as planning for BRT operations in roundabouts. Although these topics have considerable overlap, this section divides the literature into three content areas: planning and designing for safety of all users includes bicyclists and pedestrians; planning and design for vulnerable users, including those with security concerns; and BRT operations in roundabouts.

Planning and Design for BRT Safety

While the past 20 years have seen a surge in new BRT systems in the United States, the trend is not slowing down. BRT continues to be a viable alternative in any number of settings in the United States and a plethora of new research is available to assist communities with the planning and operating of BRT systems. Current planning and design for new BRT systems (and improvements to existing services) tends to incorporate additional facets of safety and concern for vulnerable users and members of the community compared to what had been available in the past. There is also increased emphasis on ensuring the safety of pedestrians and bicyclists.

Blume et al. surveyed BRT agencies around the United States and Canada and found that these agencies recommend acquiring as high a level of exclusive runningways as possible, and as high a level of transit signal priority treatments as possible. This will not only help the BRT reach likely goals of travel time reduction but can enhance safety as well. They noted that it is also important to obtain BRT stations of adequate size (Blume et al. 2022). Proper sized stations can increase the efficiency of the service but also allow appropriate space for pedestrians (including those with mobility devices) and bicyclists to move through the area.

Another lesson from the work of Blume et al. is that agencies must recognize that the introduction of BRT or other priority bus infrastructure will likely require educating the community about how to travel with and on these systems safely. Ideally, agencies are already considering community needs in the planning process, but it's likely that outreach and education will need to continue while the project is in operation (Blume et al. 2022). This idea was evident in the aftermath of a pedestrian fatality on the Pulse BRT system in Richmond, Virginia, and another close call with a pedestrian being hit. In both cases, the victims saw the stopped regular traffic at a red light but failed to realize that the bus lane had the right-of-way with a green signal. Both women walked directly into the path of the moving BRT vehicle; one was killed and one suffered only minor injuries (O'Brien 2019). While the local government and the transit agency can strive to take measures to lessen the likelihood of this type of event, the community needs to be educated on the purpose of the bus lanes and how they work. In Richmond, as will be discussed later in this report, one of the measures they implemented was painting the bus lane bright red. Many other agencies have painted or otherwise designed the bus lane to appear different from the regular lanes of traffic (Streets Cred 2019).

While striving to understand and address the needs of the community in which the service will operate, or already operates, Blume et al. reminds agencies that it's important to have solid community leadership and strong relationships with local entities, and that it can take several years to forge those relationships. Ideally, all stakeholders in the community will feel a sense of “ownership” of the BRT system as part of the community (Blume et al. 2022). This sense of the transit agency recognizing that it can be a leader in its community and help to foster changed perceptions and increased safety was also explored by Perk et al. (2019).

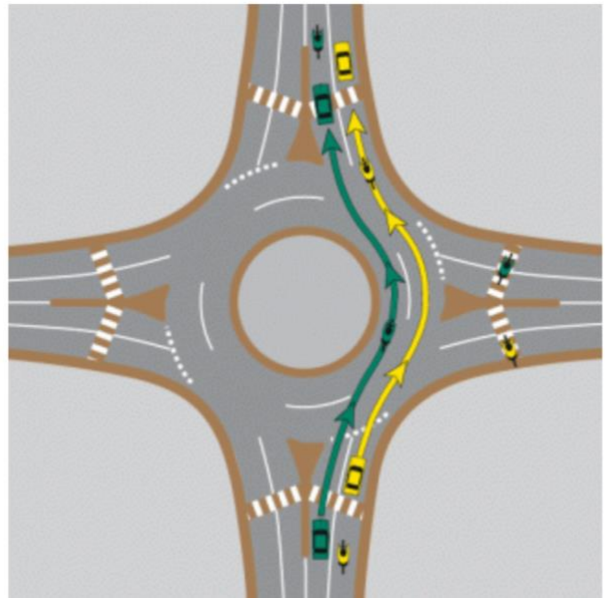
Hudson et al. recently collaborated on TCRP Synthesis 169 which focuses on bicycle and pedestrian safety in BRT and other high-priority bus corridors. They found that varying design and mitigation elements will have differing safety impacts. In compiling literature, as with this effort, there were fewer examples of specific safety studies in the United States compared to other countries around the world. Further, many studies in the United States focus primarily on crash reduction rather than also taking into consideration active travelers along a corridor (Hudson et al. 2023). However, any literature search will reveal many different guides and best practices for planning and designing BRT systems. One such resource is the BRT Planning Guide provided by the Institute for Transportation Development and Policy (ITDP 2017).

Several solid lessons learned are provided by Hudson et al. Some are typical good practices that have been written about before, but still need to be reiterated. A few of the lessons learned serve as a reminder that BRT systems are typically very customized to the local environment in which they operate. Because of this customization, it is not easy to find a one-size-fits-all solution to most planning and design challenges. To be sure, many design elements are typically decided on a case-by-case basis. Hudson et al., continues to remind agencies that early and productive partnerships are key, solutions need to be from an innovative and updated source, safety efforts need to be very proactive, and accessibility is a multifaceted issue, covering platform design, level boarding, accessible pedestrian signaling, curb ramps, station messaging, leading pedestrian intervals, and others (Hudson et al. 2023).

One specific recommendation from Hudson et al. is to consider a center-running bus-only lane as those designs will result in fewer conflicts with bicyclists and pedestrians. However, the station design must consider high quality and safe crossings for riders to access the system (Hudson et al. 2023). They also indicate that additional research will be needed going forward on strategies for managing general traffic turning movements along BRT corridors, to improve safety and reduce collisions. Additional guidance is needed for the implementation of BRT service in partially exclusive or shared runningways as well.

While there will be a further discussion on roundabouts later in this report, Washington State Department of Transportation provides information about the safety of roundabouts for pedestrians and bicyclists. Modern roundabouts are designed to be safer than typical intersections for bicyclists and pedestrians, including those who use mobility assistance devices. One reason that the roundabouts can be safer is because traffic is typically moving 15 to 20 miles per hour slower than otherwise. This slowing of traffic contributes to safety for other users. Further, crosswalks are typically set farther back from the flow of vehicle traffic, giving pedestrians more space and allowing for more reaction time from vehicle drivers (WSDOT). Figure 4 depicts a roundabout with crosswalks.

Figure 4 *Figure 4. Example of a Roundabout with Set-Back Crosswalks*



Source WSDOT, https://wsdot.wa.gov/travel/traffic-safety-methods/roundabouts

Planning and Design for BRT Safety

According to the U.S. Census Bureau, potentially vulnerable populations include:

- Households in poverty;
- Households without cars;
- People with disabilities;
- People aged 65+;
- People in a minority group; and
- People with language barriers (U.S. Census 2018).

In addition, some may consider other groups to be part of a vulnerable population such as children, members of the LGBTQIAP+ community, and women, particularly when traveling or using public transportation. Anyone in these groups can be considered a vulnerable group if they have concerns about their safety when moving in public spaces.

Blume et al. surveyed systems where BRT operates and found that many agencies are using measures of service accessibility, for example, as one way to evaluate the impacts of BRT in a community in addition to traditional measures. Measures such as a household's opportunity to access BRT may be important to a community's goals (Blume et al. 2022). This may be of particular concern for those who do not have access to affordable housing, or when the implementation of new infrastructure impacts the availability of affordable housing. In addition, Hudson et al. found from surveying BRT agencies as part of TCRP Synthesis 169 that approximately half of the BRT facilities and routes represented by responding agencies had replaced an existing transit service (Hudson et al. 2023). In some cases, the new BRT service can enhance accessibility for vulnerable populations; however, in other cases it may reduce accessibility by reducing the number of transit stops along a corridor, or by crowding out affordable housing from the area.

Rickert developed *Technical and Operational Challenges to Inclusive Bus Rapid Transit: A Guide for Practitioners* to bring to light accessibility issues that can make it difficult for BRT systems in less wealthy nations to serve vulnerable populations. He argues that those are the populations who would most benefit from inclusive design elements (Rickert 2010). He laments that although BRT systems in theory lend themselves to an accessible design, in practice there are too many examples of systems being inaccessible to a significant range of potential riders who either cannot reach the stations or cannot easily board the vehicles or traverse the system due to a host of operational or technical issues. Rickert has a desire for his guide to focus on the issues that have caused many BRT systems around the world to fall short of the potential to serve all people.

Picking up on Rickert's objectives, McKone writes in support of his ideas and provides a brief summary of some key accessibility challenges with BRT and the solutions offered by Rickert. These are listed below:

- There is a need to consider hidden disabilities in design practices. Rickert stated that for every wheelchair user, there are up to four additional individuals using canes or some other mobility aid (McKone 2010). In addition, there are myriad hidden disabilities such as sensory issues, deafness, heart conditions, etc.
- The conventional notion that paratransit can act as a catch-all for people with disabilities assumes that those with disabilities have separate and distinct travel patterns from the rest of the population, or that they are concentrated in one area. Of course, this notion is untrue and further provides the case for universal design.
- Some potential passengers are limited by crossings and pedestrian bridges. Fatigue or mobility aids can make traversing them a challenge. Rickert points out that such crossings and bridges are supposedly implemented for pedestrian safety, but the truth is that they remove people from the roadways to improve the flow of traffic (Rickert 2010). The ideal solution, according to Rickert, is crossings at ground level controlled by traffic signals.
- Bus platform gaps are a significant issue, and the most preferable solution is eliminating the gap with some type of device. Some BRT systems in the United States have used mechanical guide wheels to close the bus platform gap (Pessaro et al. 2016).
- Accessibility to a BRT corridor is impacted when a community does not have other adequate transit or feeder services, or proper sidewalks and stations. Ideally, BRT system stakeholders can help influence positive changes in these areas (McKone 2010).

Bates et al. share a similar sentiment to Rickert and McKone. They write that new transit services such as BRT are promoted as increasing property values and attracting economic development, but as the areas becomes more attractive to those investments, the supply of affordable housing in the area will decrease (Bates et al. 2017; Perk et al. 2017). Then, the vulnerable populations who rely on transit the most are forced to move farther away from areas of economic activity to afford housing. For many years, BRT research focused on the mode's added value to the community in the form of development and property values. Now, many are focusing their research on these equity implications and perhaps unintended consequences of high-quality transit investment. Specifically, Bates et al. say the challenge in planning for BRT is to question whether a new investment will have significant neighborhood gentrification impacts. In addition, planners should ask, “how this project can alleviate housing vulnerability and lack of access” (Bates et al. 2017). Other questions to ask include:

- How does the new service differentially affect vulnerable groups or other populations of concern?
- How does the new service impact residents of neighborhoods with varying risk of gentrification?
- How does the new service impact these populations differently depending on which neighborhood they live in? (Bates et al. 2017).

It was mentioned previously that most studies of BRT safety in the United States focus on traffic safety. The City of Albuquerque wanted to learn how the construction of a new BRT service would affect traffic safety, but also specifically for road users from vulnerable populations such as pedestrians. Bia et al. analyzed collision, fatality, and serious injury data for all road users and pedestrians at three points in time before and after the implementation of the Albuquerque Rapid Transit (ART) BRT system. They found significant benefits after the implementation of ART, with fatal and serious injury collisions decreasing nearly 65 percent along the ART corridor (compared with a 6 percent decline on control segments) (Bia et al. 2022). They found that individual drivers’ risk of a fatality or serious injury decreased significantly. Their findings suggest that ART did have a major role in making the corridor safer.

A few agencies have created indices or equity analysis when planning for BRT or simply transportation planning in general. Headwater Economics worked with the Denver Regional Transit District (RTD) to develop the RTD BRT Equity Analysis tool to visually assess the impacts to vulnerable populations from potential new BRT corridors (Headwater Economics 2022). Similarly, the Baltimore Metropolitan Council (BMC) has developed a Vulnerable Population Index (VPI). The index focuses on broad, regional impacts related to existing and proposed transportation facilities and systems. The VPI accounts for how effective the project is in moving people and goods, whether the project operates in an environmentally sustainable way, and on a more community-based level, how does the project affect the region’s most vulnerable populations. For example, will the project limit the ability of some people to take advantage of the benefits of the transportation system or to access certain opportunities or destinations? Further, do people have the opportunity to adequately voice their concerns related to proposed investments? (BMC 2018).

Some users of a transit system become vulnerable when they are concerned about their security either while on board a transit vehicle or when traveling to or from a transit station. Soto et. al. studied the perception of security and the fear of crime on the BRT systems in Barranquilla, Colombia. They collected data from 500 transit users and used a hybrid choice model to include location-based fear of crime the perception of public transit risk. The authors found that the relationship between the fear of crime and the perception of security in public transit is indirect and highly statistically significant (Soto et al. 2022). Unsurprisingly, being a female rider was the strongest predictor of the fear of crime.

A large body of growing research focuses on gender differences in the perception of safety and security on public transit, and more generally, women’s experiences and fears when traveling alone in any public space. Perk et al. stated that many women simply learn to accept that public spaces, particularly at night, are not places where they can feel safe and that women are indeed concerned with harassment, etc., in public spaces, and experience feelings of physical and emotional insecurity. Regarding transportation, some of the major issues include a lack of safe pedestrian access to transit services and personal safety on transit vehicles or shared use services (such as Uber or Lyft). It does not matter whether these safety concerns are real or perceived; they still significantly influence women's travel choices. Much of the personal safety/security concerns that women have involve harassment. Harassment in public spaces, as well as specifically on public transit, has evolved into a significant public policy issue (Perk et al. 2020). The heightened safety and security concerns of women can limit their mobility when they choose, for example, to not travel after dark, to not travel/walk alone, not use public transit, or not travel on specific routes.

Research suggests that transit agencies can benefit from focusing attention on women's security by gaining ridership because, when women feel unsafe on transit, they will likely not take the trip. Due to the limited resources of most public transit agencies, actions to improve safety and security will mostly focus on all passengers and workers. Yet, additional focus on the unique needs of women traveling in public spaces can have a return in higher ridership. Transit agencies are in a unique position as public entities to act as community leaders in addressing gender-based harassment and security concerns, not only by addressing events on their services, but by engaging with their local communities to address these issues on a larger, societal scale (Perk et al. 2020). Figure 5 shows three examples from an anti-harassment campaign at Chicago Transit Authority.

Figure 5 *Anti-Harassment Campaign Images from Chicago Transit Authority (CTA)*

Source WSDOT, https://www.transitchicago.com/speakup/

BRT Operations in Roundabouts

Research suggests that roundabouts are safer than the conventional stop sign or traffic signal controlled intersection. The Insurance Institute for Highway Safety (IIHS) found that injury crashes declined by 75 percent at intersections with roundabouts that used to have traditional traffic control devices. Further the IIHS and the Federal Highway Administration (FHWA) have found that roundabouts generally result in 37 percent fewer collisions, 90 percent fewer fatalities, and a 40 percent decline in pedestrian collisions (WSDOT). It's likely that the safety of roundabouts is due to lower travel speeds in the roundabout, the continuous flow of traffic, and one-way travel. Roundabouts can also be less expensive to maintain than a signalized intersection, and they can possibly take up less space if using a single lane to enter.

Because of these benefits, roundabouts are becoming more popular in many places throughout the United States and around the world. With an increasing number of roundabouts, it becomes more likely that transit buses will need to traverse these traffic calming devices. What happens when high frequency services such as BRT need to interact with a roundabout? First, modern roundabouts are designed to accommodate larger vehicles such as buses, trucks, and emergency vehicles (WSDOT). In addition, the Institute for Transportation and Development Policy (ITDP) devotes an entire section of its BRT Planning Guide to BRT operations in roundabouts (ITDP 2017). According to ITDP, intersections with roundabouts can either be relatively straightforward for BRT vehicles to traverse, or they can hinder the movement of BRT service if the BRT vehicle must cross several lanes of mixed traffic in a congested roundabout to continue along its route. There are some solutions to the challenges introduced by roundabouts. Five possibilities for accommodating BRT vehicles through a roundabout include:

- Mixed traffic operations;
- Mixed traffic operations with signalized waiting areas;
- Exclusive lane along the inside of a roundabout;
- Exclusive busway through the center of the roundabout;
- Grade separation.

ITDP expands upon each of these possible solutions in its BRT Planning Guide (ITDP 2017). Each solution has its own set of advantages and disadvantages, and the preferred solution will depend on the specific operating conditions of a given BRT system.

However, there have been a few studies conducted outside the United States on the center lane solution. Hafsteinsdottir et al. used a case study in Reykjavik and a simulation model to develop an evaluation method to compare various design solutions of roundabouts with BRT services. One solution is sometimes called a "throughabout," where exclusive bus lanes traverse the center island of the roundabout, giving the buses full priority (Hafsteinsdottir et al. 2022). The results of the authors' analysis found that the "throughabouts" with signals for conflicting traffic was the optimal design solution for roundabouts with BRT. Figure 6 shows an image of a roundabout with a center bus lane, or a "throughabout."

Figure 6 ***Roundabout with a Center Bus Lane: "Throughabout"***

Source WSDOT, https://theweekin.co.uk/news/one-of-the-ring-roads-busiest-roundabouts-could-be-turned-into-a-throughabout/

Another study analyzes the layout of a roundabout that purports to give full priority to the BRT vehicle with no delays at smaller and medium sized roundabouts. It's referred to as the Continuous Median Lane Roundabout (CMLR) and is specifically designed for BRTs or high-priority bus services that operate in an exclusive median lane. In the CMLR, conflicts between buses and other vehicles are controlled with give way-signs. The authors show that microsimulations show near zero delay for BRT buses in this scenario (Aakre and Aakre 2017).

Gitelman and Korchatov also studied a signalized multi-lane roundabout with a bidirectional BRT exclusive lane running through the center. The example, in Israel, proved to be confusing for drivers at first. They observed risky driver behaviors and red-light violations from drivers of other vehicles and concluded that additional research is needed on the design of such a system (Gitelman and Korchatov 2021).

Case Examples

This section includes a few case examples related to the material in this report. First, examples of BRT systems and roundabouts are presented for two transit systems in the United States (Lane Transit District's Emerald Express BRT, the EmX, and Capital District Transportation Authority's BRT Purple Line). Second, a closer look at a pair of pedestrian collisions with a BRT vehicle on the Greater Richmond Transit Company's Pulse BRT system.

Roundabout Implementation

While a few of the studies presented in the previous section focused on BRT and roundabouts outside the United States, there are several examples of roundabout implementation domestically. Capital District Transportation Authority (CDTA) in Albany, New York, is collaborating with its regional partners to lead the effort to construct a new roundabout at the Crossgates Mall that will provide access to and from the I-87 Northway as part of its Purple Line Project. The Purple Line is CDTA's third bus rapid transit line, and it will operate along Washington and Western Avenues. It will connect to the existing Red and Blue Lines, providing increased access across the region (CDTA 2023). Figure 7 shows an image of the proposed new roundabout. This roundabout will not have the center lane running through the island.

Figure 7 ***Capital District Transportation Authority's Proposed Roundabout for the Purple Line BRT"***

Source [**https://www.cdta.org/news/purple-line-moves-forward**](https://www.cdta.org/news/purple-line-moves-forward)

Lane Transit District's Emerald Express (EmX) BRT service connects Eugene and Springfield, Oregon. The City of Eugene plans to redesign the Franklin Corridor, along which the EmX operates, to make it safer and more accessible. The new design also includes a new EmX BRT lane that will enable to service to operate at higher frequencies. The redevelopment of the Franklin Corridor has been through a few iterations over the past few years. Initially some businesses along the corridor opposed the plans with concerns that the new design would hinder access to their stores. The preferred design shown in Figure 8 has at least one fewer roundabout than initially planned. While the EmX does operate partially in an exclusive at-grade guideway, the roundabouts in this plan do not have center bus lanes. It is not yet clear how the EmX will navigate through the redeveloped corridor.

The redesign is currently in the engineering phase. Construction is hoped to begin in 2026 with completion in 2028. The project is still in need of some additional funding for completion but will begin with building the roundabouts at some intersections. The City has promised to minimize impacts on passage through the corridor to maintain access to area businesses (Aronson 2023).

Figure 8 *City of Eugene Franklin Boulevard Transformation Preferred Conceptual Design*

Source **https://www.eugene-or.gov/3830/Franklin-Boulevard-Transformation**

BRT and Pedestrian Safety

The Greater Richmond Transit Company (GRTC) operates the Pulse BRT system, which runs on an exclusive center lane for part of its alignment. The BRT system is relatively new, having opened in 2018. As with many types of new transportation projects, the new operation likely took some getting used to by the general public, both drivers and pedestrians. In October 2019, it had the unfortunate experience of having a fatal pedestrian collision in the bus lane. Approximately a year earlier, another pedestrian had a similar encounter but was only slightly injured (O'Brien 2019). These events highlight the need for continuing public education about how the bus lanes operate and that they are on a different signal than the rest of the traffic. In both cases, the pedestrian was crossing between traffic stopped at a red light. However, when they reached the bus lane, they kept walking across and directly into the path of a moving Pulse BRT vehicle. In both cases, the BRT vehicle had a green signal and the right-of-way.

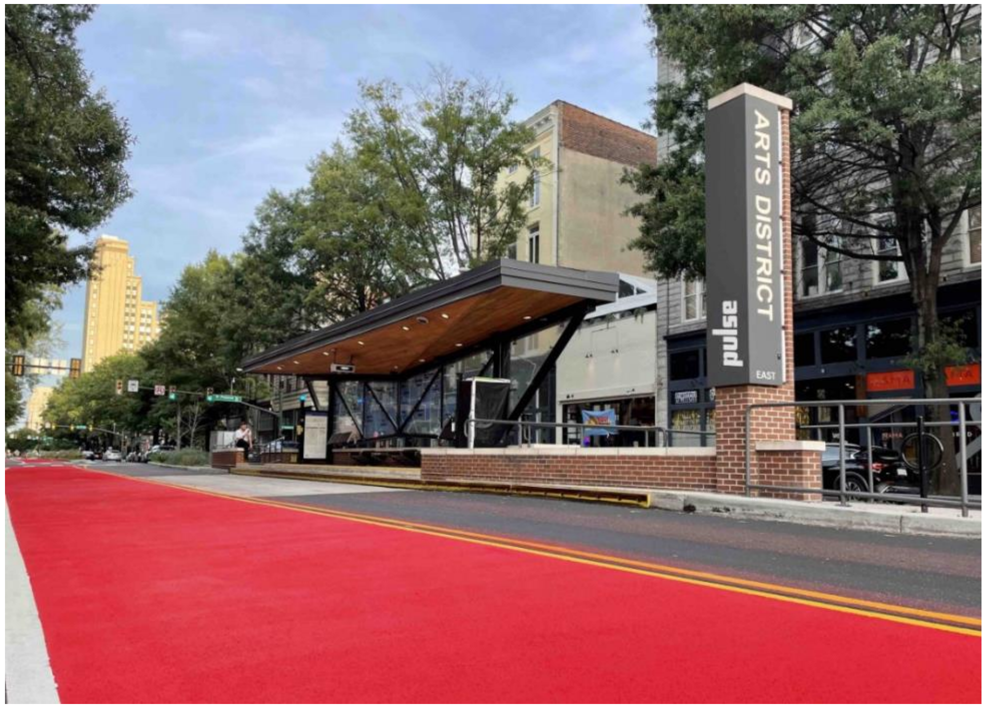
The pedestrian who sustained only minor injuries stated, "*There was a pretty big back up, there was congestion. But I looked and I noticed it was a red light. I looked both ways," she said. "The last minute, I looked over to the left and I was in the Pulse lane and the bus hit me. I couldn't see the bus*." (O'Brien 2019).

She decided to come forward and share her story after hearing about the story of the other pedestrian who was struck and killed. She wants to let others know that this type of event has happened before and to warn others to use extra caution when crossing. She was in a crosswalk, but it wasn't signalized.

City leaders hoped that a growing momentum surrounding Richmond's pedestrian safety would actually translate into substantive design changes and mitigation measures. One official stated, "*The lesson of this tragedy shouldn't be that buses are unsafe or that buses and pedestrians are in conflict with one another. The takeaway needs to be that our streets are unsafe, and we need to design them better to make sure people on foot aren't put in dangerous situations.*" Another official stated, "*Mobility safety is a shared responsibility*," (Gordon 2019).

One change that GRTC implemented was to paint the Pulse BRT lane bright red (Gordon 2022). This is something that several other BRT systems have done, as well, to make the exclusive land stand out from the adjacent regular mixed traffic lanes. Figure 9 displays the result.

Figure 9 ***Fresh Red Paint in Front of a Pulse Bus Rapid Transit Station***



Source **Wyatt Gordon, https://ggwash.org/view/85417/richmonds-pulse-bus-rapid-transit-gets-the-red-carpet-treatment**

The bright red lanes used in several locations have proven to have real safety benefits. According to officials in San Francisco, their red lanes reduced transit delays, increased reliability by 25 percent, decreased collisions by 16 percent, and reduced injury collisions by 24 percent (Brasuell 2022). Beginning in 2020 federal transportation officials from FHWA removed bureaucratic barriers to making it easier for local officials to paint their bus lanes (Short 2019).

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Appendix C

NBRTI Advisory Board

The NBRTI Advisory Board (AB) last met by web conference in March 2011, and is no longer active. The mission of the AB was to provide guidance for the NBRTI research agenda and to validate the support of the transit industry for the Institute's activities. NBRTI paid for member travel to meetings as needed, but took advantage of opportunities to meet at APTA, ITE, and TRB conferences to fulfill the following functions:

- Provide new research program ideas
- Validate existing research areas and help in the finalization of detailed scopes of work
- Advise on the process and selection of demonstration projects
- Provide guidance and industry buy-in for research documents
- Review research reports
- Help in transferring the information developed by FTA/NBRTI through presentations

The makeup of the Advisory Board is detailed below.
Representatives:

- Dennis Hinebaugh, NBRTI Director and Board Chair
- Helen Tann, FTA-TRI Representative
- Venkat Pindiprolu, FTA-TRI Representative
- Walt Kulyk, FTA-TRI Representative

Members:

- Joseph Calabrese, GM, Greater Cleveland Regional Transit Authority
- Alan Danaher, Parsons Brinkerhoff
- Rex Gephart, Los Angeles County Metropolitan Transportation Authority
- Cliff Henke, Parsons Brinkerhoff
- Jeff Hiott, American Public Transportation Association (APTA)
- Peter Koonce, Kittelson and Associates
- Herb Levinson, Private Consultant
- Ted Orosz, Director of Bus Route Planning, New York City Transit
- Frank Spielberg, Vanasse Hangen Brustlin
- Bill Vincent, Director of BRT Policy Center, Breakthrough Technologies
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Acronyms and Abbreviations

AFV	Alternative Fuel Vehicle
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
BLIMP	Bus Lane with Intermittent Priority
CBRT	Characteristics of Bus Rapid Transit
BRT	Bus Rapid Transit
CNG	Compressed Natural Gas
CUTR	Center for Urban Transportation Research
DAS	Driver Assist System
EMx	Emerald Express
FTA	Federal Transit Administration
GHG	Greenhouse Gas
GIS	Geographic Information Systems
HART	Hillsborough Area Regional Transit
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LRT	Light Rail Transit
LTD	Lane Transit District
MDT	Miami-Dade Transit
MVTA	Minnesota Valley Transit Authority
NBRTI	National Bus Rapid Transit Institute
NTD	National Transit Database
NTI	National Transit Institute
TCRP	Transit Coooperative Research Program
TOD	Transit Oriented Development
TRB	Transportation Research Board
TSP	Transit Signal Priority
UPA	Urban Partnership Agreement
USF	University of South Florida
VAA	Vehicle Assist and Automation

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