CUTR
CENTER for URBAN TRANSPORTATION RESEARCH

# Ongoing Evaluation of Alternatively Fueled Buses

## Final Report

## May 2016

**PROJECT NO.**
FDOT BDV25-943-37

**PREPARED FOR**
Florida Department of Transportation

FDOT

Center for Urban Transportation Research
University of South Florida
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# Ongoing Evaluation of Alternatively Fueled Buses

**FDOT BDV25-943-37**

Prepared for:

**Florida Department of Transportation**
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# Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

# 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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16. Abstract


*The goal of this project is to continue collecting and reporting data on the performance and costs of alternatively fueled public transit vehicles in Florida in a consistent manner. Over the course of this project, researchers sent repeated data requests to all fixed route transit agencies in the state. Additionally, the project provided for site visits to all fixed route and a few rural transit agencies to facilitate and encourage participation. Researchers also attempted to engage three large non-Florida agencies, but no data was obtained from these agencies.*

*Despite the challenges in data collection and low response rate, enough data was collected to represent the majority of the Florida fixed route fleet and perform a valid cost analysis. Researchers requested data for both fixed route and paratransit vehicles. However, due to the low response rate and inconsistent reporting for the demand response vehicles, the extent and reliability of the paratransit fleet analysis is limited and should be interpreted with caution. As more data is collected, the reliability of the analysis will improve.*


| 17. Key Word | 18. Distribution Statement |
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| *Alternative fuel vehicles, fixed route buses, diesel, hybrid electric, compressed natural gas (CNG), battery electric, biodiesel, paratransit buses, demand response, Advanced Transit Energy Portal* | *No restrictions* |

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# Executive Summary

Florida transit agencies have been dealing with volatile fuel prices and changes in regulations regarding diesel engines and fuel. In addition, emphasis on reducing the overall consumption of fossil fuels has increased, as well as reducing carbon emissions by transit agencies. Florida transit agencies and funding entities continue to be under pressure to reduce operating costs and to run a more sustainable and environmentally friendly fleet in the urban environment. A popular strategy to pursue these goals has been the acquisition of alternatively fueled buses. Pressure on agencies to procure and on FDOT to fund alternatively fueled buses has escalated with the enormous push toward compressed natural gas as a domestically produced urban fleet fuel. Some Florida agencies are receiving funding through the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) grant program, while others are using regular transit capital funds. Typically, the Florida Department of Transportation (FDOT) funds 50 percent of the non-federal share of bus capital acquisition.

However, higher reliance on alternative fuels has increased both capital and operating costs for some fixed route operators, and has created challenges for the widespread adoption of advanced transit technologies. Additionally, current low diesel prices erode the fuel cost advantage of alternative fuel vehicles, reducing the economic incentive for investing in these technologies at least in the short term.

FDOT is interested in collecting and analyzing up-to-date field data on the performance of alternative fuel vehicles to evaluate the benefits and investment costs associated with advanced transit technologies, and to compare their performance to traditionally fueled vehicles. The Department engaged the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) in 2009, 2012, and again in 2013 to establish a reporting system for the collection of transit fleet performance and cost data. FDOT is interested in continuing regular data collection, monitoring, and evaluating field data on the performance and operating costs of alternative fuel transit vehicles that are currently in use in Florida and nationwide.

CUTR sent data submission requests to all fixed route transit agencies in Florida requesting their assistance in collecting the data. Agencies were given several options to submit data, including e-mail to the project's principal investigator (PI) or co-principal investigator (Co-PI) or uploading data through the Advanced Transit Energy Portal (ATEP) website, which is funded by another CUTR project. To facilitate data collection, CUTR researchers implemented a wide outreach campaign with site visits to 25 fixed route transit agencies in Florida and 3 rural agencies in the state. Additionally, CUTR also visited 2 non-Florida transit agencies. Researchers attempted to collect data covering both fixed route and demand response vehicles. Unfortunately, regardless of continued efforts to maintain regular data reporting, the response rate to data requests was less than ideal.

Despite difficulties with data collection, CUTR obtained relevant operations and cost data for fixed route buses from 13 Florida transit agencies reporting during 2015. However, the reporting was not always regular and consistent, with only four agencies providing fleet data every quarter of 2015.

The data analysis for fixed route buses revealed that the vast majority of Florida transit buses (over 78.0 percent of the reported fleet) are regular diesel buses, while 14.5 percent are diesel hybrids, 5.4 percent are biodiesel (running on B-20 blend), and gasoline, electric, and CNG buses account for 0.9, 0.2, and 0.1 percent, respectively. Seventy-three percent of the diesel fleet sample is comprised of 40-foot buses, while 12.5 percent are 35-foot buses. Twenty-nine-foot, 30-foot, and 32-foot buses represent 3.7, 1.6, and 4.8 percent, respectively. Diesel vehicles of other sizes do not exceed 1.0 percent of the fleet in their size categories. Larger 60-foot articulated buses account for 0.5 percent of the diesel fleet sample. Additionally, size was not reported for 1.7 percent of diesel vehicles.

Similar to the diesel fleet, 40-foot buses represent the majority of the reported diesel hybrid vehicles, over 47.0 percent. Thirty-five-foot and 60-foot buses account for 24.5 percent and 23.9 percent of reported diesel hybrids, respectively. All electric buses in this dataset are 35 feet in length, while all CNG vehicles are 29 feet long. Most of the gasoline vehicles in this data sample are either 16 feet (47.4 percent) or 25 feet (42.1 percent) in length. The vast majority (91.6 percent) of biodiesel vehicles are 40 feet in length, while 8.4 percent are 35-foot buses.

The data show that diesel hybrid buses have a significantly higher acquisition cost compared to diesel buses. At the same time, hybrid buses provide better fuel economy and lower parts and labor costs per mile than diesel buses. For example, current data indicate that a 40-foot diesel hybrid bus demonstrates 32.0 percent better fuel economy than a 40-foot diesel bus (4.78 mpg for diesel hybrid vs. 3.62 mpg for regular diesel). In addition, 40-foot diesel hybrid buses have 67.9 percent lower parts cost per mile than diesel buses of the same size ($0.212/mile for diesel hybrid vs. $0.661/mile for diesel) and 67.6 percent lower labor cost per mile ($0.160/mile for diesel hybrid vs. $0.494/mile for diesel).

The current sample contains data on four 35-foot battery electric buses running on batteries recharged from the electric grid. Based on the data provided, while battery electric buses demonstrate over 262.0 percent better fuel economy and 47.6 percent lower parts cost per mile than comparable diesel buses, they have significantly higher labor cost per mile (483.6 percent). The data sample includes three compressed natural gas (CNG) buses, which are 29 feet in length and have 13.8 percent lower fuel mileage than comparable diesel buses. CNG vehicles also demonstrate 51.0 percent lower parts cost per mile, 117.8 percent higher labor cost per mile, and 22.3 percent higher acquisition cost than 29-foot diesel vehicles.

Aggregate comparison of the performance and costs of fixed route fleets in Florida reveals that diesel hybrid buses, regardless of size, on average have 27.5 percent better fuel economy, 69.0 percent lower parts cost per mile, and 68.1 percent lower labor cost per mile than regular diesel buses. At the same time, diesel hybrid buses on average cost about 73.6 percent more to acquire than comparable diesel vehicles. Electric buses demonstrate an impressive 298.2 percent better fuel economy and 81.7 percent lower parts cost per mile, but 110.8 percent higher labor cost per mile, than comparable diesel buses. In addition, electric buses cost 241.5 percent more to acquire than comparable diesel vehicles. The differential in performance and cost may be attributed at least partially to the average age of the vehicles. An average hybrid bus in this analysis is 3.0 years old, compared to 9.0 years for an average diesel bus. Newer vehicles typically perform better and cost less to operate than older vehicles.

Slightly different results are observed when weighted averages are used to calculate miles per gallon and cost per mile in order to account for potential differences in miles driven by the various buses in the data sample. The use of weighted averages slightly changes the analysis results, most notably for 40-foot buses, decreasing the differential in fuel efficiency and costs per mile between diesel and diesel hybrid vehicles. Forty-foot hybrid buses demonstrate 30.0 percent better fuel mileage than comparable diesel buses when accounting for mileage driven (compared to 32.0 percent when miles driven are not considered). Additionally, when weighted averages are used, 40-foot hybrid buses have 35.4 percent lower parts cost per mile (compared to 67.9 percent when simple averages are used) and 20.6 percent lower labor costs per mile (compared to 67.6 percent when simple averages are used) than diesel buses of the same size.

The observed results may indicate that a relatively large number of hybrid buses in the dataset are earlier-generation vehicles with lower fuel efficiency, which have been in use for some time and have logged a lot of mileage. The dataset also contains a large number of older, high-mileage diesel buses that perform exceptionally well.

CUTR collected a limited data sample on paratransit vehicles covering 218 demand response vehicles. Of the reported paratransit fleet, 59.6 percent (130 vehicles) are gasoline, 38.5 percent (84 vehicles) are diesel, and 1.8 percent (4 vehicles) are CNG. The analysis indicates that CNG paratransit vehicles demonstrate significantly higher costs per mile (792.3 percent higher parts and 771.5 percent higher labor costs per mile) than comparable diesel vehicles. CNG paratransit vehicles also cost 31.6 percent more to purchase than comparable diesel vehicles. Gasoline paratransit vehicles, on the other hand, demonstrate 2.2 percent lower parts cost and 23.4 percent lower labor cost per mile. Gasoline vehicles also cost 11.9 percent less to purchase than diesel vehicles.

The comparison of 23-foot and 25-foot vehicles (the most common sizes) with different propulsion types shows that gasoline performs best for smaller vehicles, while diesel is more cost efficient than gasoline or CNG for larger vehicles. A 23-foot gasoline paratransit vehicle in the current sample has 13.3 percent lower fuel mileage, but provides 56.2 percent lower parts cost and 48.3 percent lower labor cost per mile than a comparable diesel vehicle. Additionally, a 23-foot gasoline vehicle costs 13.7 percent less to acquire than a diesel vehicle of the same size.

During the course of the project, the PI and Co-PI met with maintenance managers and the senior staff of 25 fixed route transit agencies, 3 rural transit agencies in Florida, and 2 non-Florida agencies to discuss the project, demonstrate the data collection tool, and connect with the staff responsible for data collection and submission. These discussions also provided an opportunity for agencies to voice concerns regarding the data collection process and offer recommendations on how to improve it. The most common concern expressed was a lack of resources to collect and report requested data on a regular basis.

In some cases, smaller agencies do not use maintenance management software, have only handwritten records, and lack the resources (staff) to track vehicle mileage, fuel use, and costs. Gathering historic information about the fleet to report life-to-date figures requires tremendous effort for such agencies and is a main obstacle to participating in the data collection under this project. It was suggested that FDOT consider purchasing and providing management software to all the agencies, which would also allow reporting data in a consistent format.

Other recommendations included standardizing data reporting for different purposes to avoid providing the same data multiple times for different agencies/purposes. Another suggestion was to improve the accuracy of the assessment by using emission year to compare vehicles and by accounting for electrified accessories installed onboard. Finally, organizing a daylong seminar/training would allow all the agencies to share their experiences, successes, and challenges with data collection.

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# List of Abbreviations and Acronyms

| | |
|---|---|
| ARRA | American Recovery and Reinvestment Act of 2009 |
| ATEP | Advanced Transit Energy Portal |
| BCT | Broward County Transit |
| BLS | U.S. Bureau of Labor Statistics |
| BRT | Bus Rapid Transit |
| CAT | Collier Area Transit |
| CNG | Compressed Natural Gas |
| Co-PI | Co-principal Investigator |
| CPI | Consumer Price Index |
| CT | Council on Aging of St. Lucie County |
| DGE | Diesel Gallon Equivalents |
| CUTR | Center for Urban Transportation Research |
| ECAT | Escambia County Area Transit |
| FDOT | Florida Department of Transportation |
| GoLine | Indian River Transit |
| HART | Hillsborough Area Regional Transit |
| JTA | Jacksonville Transportation Authority |
| kWh | Kilowatt-hours |
| LA Metro | Los Angeles County Metropolitan Transportation Authority |
| LAMTD | Lakeland Area Mass Transit District |
| LCBOCC | Lake County Connection |
| LeeTran | Lee County Transit |
| LYNX | Central Florida Regional Transportation Authority |
| MARTA | Metropolitan Atlanta Rapid Transit Authority |
| MCAT | Manatee County Area Transit |
| MDT | Miami Dade Transit |
| MPG | Miles per Gallon |
| NCTR | National Center for Transit Research |
| NYCT | MTA New York City Transit |
| OCT | Okaloosa County Transit |
| PalmTran | Palm Beach Transit |
| PI | Principal Investigator |
| PCPT | Pasco County Public Transportation |
| PSTA | Pinellas Suncoast Transit Authority |
| RTS | Gainesville Regional Transit System |
| San Diego MTS | San Diego Metropolitan Transit System |
| SCAT | Sarasota County Area Transit |
| SCAT | Space Coast Area Transit |
| StarMetro | City of Tallahassee Transit |
| Sunshine Bus | St. Johns County Transit Service |
| SunTran | Ocala/Marion County Public Transit |
| The Bus | Hernando County Transit |
| TIGGER | Transit Investments for Greenhouse Gas and Energy Reduction |
| USF | University of South Florida |
| VOTRAN | Volusia County Public Transit System |
| WHAT | Polk County Transit |
| WMATA | Washington Metropolitan Area Transit Authority |

# Chapter 1
# Introduction

## Background

Florida transit agencies and funding entities continue to be under pressure to reduce operating costs and to run a more sustainable, environmentally friendly fleet in the urban environment. 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 Florida agencies are receiving funding through the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) grant program (part of ARRA), while others are using regular transit capital funds. Typically, the Florida Department of Transportation (FDOT) funds 50 percent of the non-federal share of bus acquisition. Pressure on agencies to procure and on FDOT to fund alternatively fueled buses has escalated with the enormous push toward compressed natural gas as a domestically produced urban fleet fuel.

However, 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 the widespread adoption of advanced transit technologies. Additionally, the wide variety of advanced technologies currently available often makes it difficult for transit agencies to choose the alternative fuel that will best fit their needs. Finally, low diesel prices erode the fuel cost advantage of alternative fuel vehicles, reducing the economic incentive at least in the short term. Both transit agencies and FDOT can benefit from current data on the performance of alternative fuel transit vehicles, which will assist in evaluating the advantages and limitations of different propulsion technologies, as well as comparing alternatively fueled to traditionally fueled transit vehicles.

FDOT engaged the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) in 2009, 2012, and again in 2013 to establish a reporting system for collecting transit fleet performance and cost data. The Department is interested in continuing regular data collection, monitoring, and evaluating field data on the performance and operating costs of alternative fuel transit vehicles currently used in Florida and nationwide. These data are intended to assist decision makers considering investment in alternative fuel transit technologies, especially against the current reality of low diesel prices.

The Center for Urban Transportation Research, established in 1998, is nationally recognized and serves as an important resource for policy makers, transportation professionals, the education system, and the public. With an emphasis on developing innovative, implementable solutions to transportation problems, CUTR provides high quality, objective transportation expertise in the form of technical support, policy analysis, and research support that translates directly into benefits to its project sponsors.

## Project Goals

The main objective of this project is to continue regular collection of maintenance, parts, and energy usage data on heavy-duty urban transit fleets in Florida, as well as to attempt collecting similar data from fleets outside of Florida to facilitate ongoing life cycle cost analysis of vehicles of varying propulsion types. The actual field data, collected and reported, will assist policy makers in deciding on maintenance resources and vehicle acquisitions.

Additionally, the current project aims to create a statistically reliable database of transit fleet operations and maintenance costs. This database will aid in assessing investment in energy efficient public transportation vehicles by providing policy makers with recent and reliable data on fuel and maintenance savings resulting from the use of alternatively fueled buses. The project will facilitate regular data submissions by transit agencies both in and outside of Florida, and continue promoting agency participation in the information exchange through the established Advanced Transit Energy Portal (ATEP).

While the project provides for the evaluation of performance and costs of alternative fuel buses, the primary goal of this effort is to establish a process for the ongoing performance assessment of alternative fuel transit fleets. It is understood that as more data is accumulated, the current assessment of cost efficiency and performance may change. The current analysis is intended to provide decision support resources to policy makers regarding the operation of alternative fuel buses, rather than give definitive recommendations regarding the application of a particular propulsion technology.

In addition to the above goals, the project calls for assisting the FDOT Office of Public Transportation in evaluating various issues and projects related to the performance of alternative fuel vehicles, as well as emission reduction and fuel efficiency strategies. The project manager may initiate this activity by special request, which may involve coordination with appropriate FDOT district and transit agency personnel.

# Chapter 2
# Research Approach

During the course of the project, CUTR continued collecting data from fixed route transit service providers on the performance of alternative fuel vehicles in their fleets using a reporting tool established under previous projects. The data collection template was modified slightly to accommodate comments and suggestions from the agencies. The data collected included agency name, service type, unit number, vehicle description, vehicle length, power plant, fuel type, duty cycle, date placed in service, date removed from service, acquisition cost, warranty status, life-to-date mileage, life-to-date fuel usage (expressed in actual units of fuel used), life-to-date parts costs, and life-to-date labor costs. Researchers assembled the data collection tool in the form of a brief spreadsheet for ease of reporting. To facilitate data collection, agencies were also offered the option to report data in any other format that was more convenient to them.

CUTR sent requests to all fixed route transit agencies in Florida for their assistance in collecting the data. Researchers asked agencies to report on their entire fleet, both alternative and traditionally fueled, and to report on a quarterly basis. Agencies were given the options to submit their data by e-mail to the principal investigator (PI) or co-principal investigator (Co-PI) or to upload their data through the Advanced Transit Energy Portal (ATEP) website, funded by another CUTR project. Regular reminders were sent in coordination with the project manager. CUTR staff also maintained contact with the agencies, addressing their questions and concerns regarding the collection and submission of data.

Despite these efforts and the support of the FDOT project manager, response to data requests was less than ideal. During the calendar year 2015, 13 of the 27 Florida fixed route transit agencies provided relevant maintenance and cost data for their fleets. These agencies included the following:

1. Bay County Transportation Planning Organization (Panama City)
2. Central Florida Regional Transportation Authority (LYNX, Orlando)
3. Indian River Transit (GoLine, Vero Beach)
4. Jacksonville Transportation Authority (JTA)
5. Lake County Connection (Tavares)
6. Lee County Transit (LeeTran)
7. Miami Dade Transit (MDT)
8. PalmTran (Palm Beach)
9. Pasco County Public Transportation (PCPT)
10. Pinellas Suncoast Transit Authority (PSTA)
11. Regional Transit System (RTS, Gainesville)
12. Sarasota County Area Transit (SCAT)
13. StarMetro (Tallahassee)

Only four of the responding agencies reported their quarterly data consistently (i.e., every quarter) throughout the year. Nevertheless, having regular reporting by a few larger transit agencies in the state with a significant number of vehicles made it possible to assemble the dataset covering the majority of the Florida fixed route fleet.

Researchers used the collected data to analyze the costs involved in operating alternative fuel vehicles in the Florida transit fleet. The project manager received the analysis results in the form of quarterly summary reports that compared field performance and costs across different transit propulsion technologies. After submission to the project manager, the quarterly analysis results were posted on the ATEP website to provide value to the agencies.

CUTR researchers also attempted to collect operating and cost data for the demand response vehicles operating in Florida. The same reporting tool used for data collection of the fixed route fleet was used for demand response vehicles. Requests were sent to all fixed route agencies directly operating or contracting out paratransit service.

The data for paratransit vehicles was less available than for fixed route fleets and was not reported consistently. During 2015, CUTR collected data for 218 demand response vehicles in the state. Of these vehicles, only 44 were reported relatively consistently and with the complete cost and performance data that was requested. The data for the remaining 174 paratransit vehicles had gaps in it, which prevented the same level of analysis as for the fixed route fleet. Since the overall analysis of the paratransit fleet presented in the current report is limited in detail, it should be interpreted with caution.

Separate from the operating cost data collection and analysis, researchers were also available to assist the project manager in assessing special issues related to alternative fuels, advanced propulsion technologies, emissions reduction, and fuel efficiency strategies that stem from grant requests made by transit agencies to FDOT. Over the duration of the current contract, no such requests for special projects and evaluations were received from the project manager.

# Chapter 3
# Cost Comparison Analysis

CUTR researchers made repeated attempts to collect performance and cost data for both fixed route and paratransit vehicle fleets. Recognizing the difference between the two types of service, researchers performed the data collection separately for fixed route buses and paratransit buses. Consequently, the costs were also reported separately for these two types of transit service.

Since cost data for the paratransit fleet was limited, the analysis presented in the current report focuses primarily on the fixed route fleet. The analysis of the paratransit fleet should be interpreted with caution due to the limitations of the data on which it is based.

During 2015, some agencies reported their data consistently every quarter, while others reported only in certain quarters. To perform the current analysis and to overcome the limitations of inconsistent reporting, researchers assembled the dataset covering all the vehicles reported in 2015, regardless of whether the vehicles were reported each quarter. Since the agencies were asked to provide fleet statistics on a to-date basis, the latest quarter in which the agency reported data was used for the annual analysis. The 13 agencies listed in Chapter 2 provided operation and maintenance cost data on their fleets for at least one quarter during 2015. The data assembled from these agencies covers 2,190 fixed route buses and 218 demand response vehicles. The summary statistics presented in this document are based on the cost data that was reported sometime during 2015, although not necessarily for each quarter of the calendar year.

## Fixed Route Fleet

Table 3-1 presents a summary of physical characteristics of the fixed route transit fleet.

**Table 3-1. Fixed Route Fleet Summary**

| Power Plant | Length | Number of Buses |
|---|---|---|
| **Biodiesel** | 35’ | 10 |
| | 40’ | 109 |
| **CNG** | 29’ | 3 |
| **Diesel** | Unknown | 29 |
| | 20’ | 1 |
| | 23’ | 1 |
| | 25’ | 3 |
| | 27’ | 4 |
| | 28’ | 4 |
| | 29’ | 64 |
| | 30’ | 27 |
| | 31’ | 15 |
| | 32’ | 83 |
| | 35’ | 216 |
| **Diesel (cont.)** | 40’ | 1,260 |
| | 45’ | 12 |
| | 60’ Articulated | 8 |
| **Diesel Hybrid** | 29’ | 12 |
| | 31’ | 1 |
| | 35’ | 78 |
| | 40’ | 151 |
| | 60’ Articulated | 76 |
| **Electric** | 35’ | 4 |
| **Gasoline** | 15’ | 1 |
| | 16’ | 9 |
| | 23’ | 1 |
| | 25’ | 8 |
| ***Total Fleet*** | | ***2,190*** |

Over 78.0 percent (1,727 buses) of the reported fixed route fleet consists of regular diesel buses, 14.5 percent (318 buses) are diesel hybrids, 5.4 percent (119 buses) are biodiesel (running on B-20 blend), while gasoline, electric, and CNG buses account for 0.9 percent, 0.2 percent, and 0.1 percent, respectively. Due to a small number of gasoline, electric, and CNG buses in the dataset, as well as gaps in the biodiesel vehicle data, the analysis focuses primarily on the comparison between diesel and diesel hybrid buses. Comparison of diesel buses to CNG and electric vehicles has limited reliability. Figure 3-1 presents a comparison of the diesel, diesel hybrid, and gasoline fixed route fleets by vehicle size.

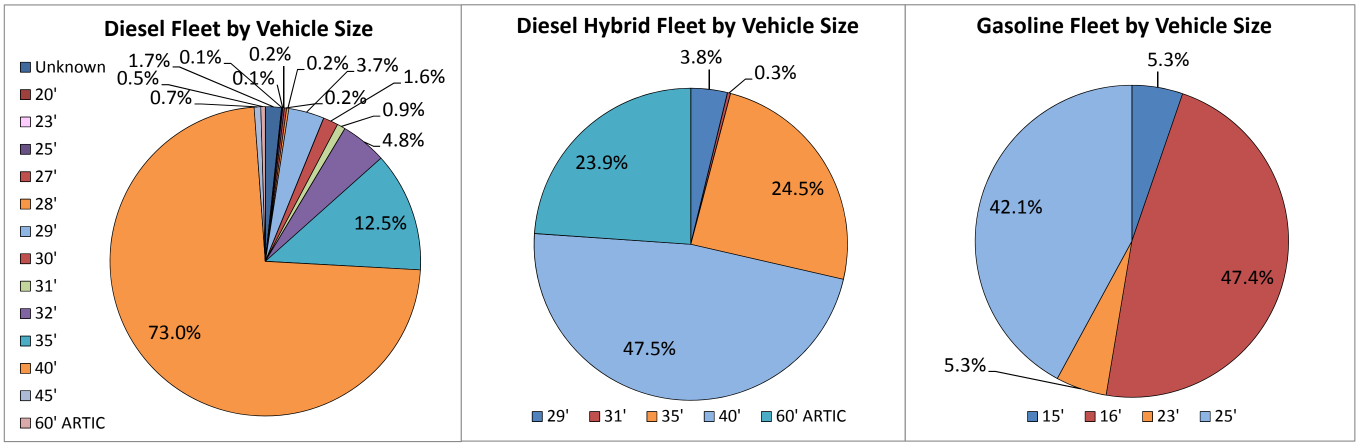


**Figure 3-1. Fleet composition by vehicle size – diesel, diesel hybrid, and gasoline.**

Seventy-three percent of the diesel fleet sample is comprised of 40-foot buses, while 12.5 percent are 35-foot buses. Twenty-nine-foot, 30-foot, and 32-foot buses represent 3.7 percent, 1.6 percent, and 4.8 percent, respectively. Diesel vehicles of other sizes do not exceed 1.0 percent of the fleet in their size categories. Larger 60-foot articulated buses account for 0.5 percent of the diesel fleet sample. Additionally, the size of 1.7 percent of diesel vehicles was not reported.

Similar to the diesel fleet, 40-foot buses represent the majority of the reported diesel hybrid vehicles, over 47.0 percent. Thirty-five-foot and 60-foot buses account for 24.5 percent and 23.9 percent of reported diesel hybrid vehicles, respectively.

All electric buses in this dataset are 35 feet in length, while all CNG vehicles are 29 feet long. Most of the gasoline vehicles in this data sample are either 16 feet (47.4 percent) or 25 feet (42.1 percent) in length. The vast majority (91.6 percent) of biodiesel vehicles are 40 feet in length, while 8.4 percent are 35-foot buses.

Table 3-2 presents a detailed cost and performance comparison of transit buses. 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 (BLS), and are presented in constant 2015 dollars.

**Table 3-2. Cost and Performance Comparison of Fixed Route Fleet**

| Power Plant | Length | Number of Buses | Average Age (Years) | Average Acquisition Cost | Fuel Mileage (MPG) | Parts Cost per Mile | Labor Cost per Mile | Fuel Cost per Mile* | Total Operating Cost per Mile |
|---|---|---|---|---|---|---|---|---|---|
| **Biodiesel** | 35’ | 10 | 3.9 | | | $0.104 | $0.100 | | |
| | 40’ | 109 | 8.5 | | | $0.266 | $0.352 | | |
| **CNG** | 29’ | 3 | 0.5 | $413,998 | 4.01 | $0.079 | $0.289 | $0.515 | $0.883 |
| **Diesel** | Unknown | 29 | 5.7 | $341,119 | 5.73 | | | $0.416 | $0.836 |
| | 20’ | 1 | | | | | | | |
| | 23’ | 1 | 4.1 | $154,415 | 7.23 | $0.209 | $0.297 | $0.322 | $0.828 |
| | 25’ | 3 | 6.4 | $86,235 | | $0.076 | $0.090 | | |
| | 27’ | 4 | 9.3 | $115,661 | | $0.080 | $0.051 | | |
| | 28’ | 4 | 2.9 | $91,569 | 10.45 | $0.117 | | $0.226 | $0.343 |
| | 29’ | 64 | 5.9 | $338,482 | 4.65 | $0.160 | $0.133 | $0.542 | $0.829 |
| | 30’ | 27 | 7.4 | $280,058 | 5.50 | $0.257 | $0.271 | $0.512 | $0.982 |
| | 31’ | 15 | 6.6 | $169,865 | 7.83 | $0.296 | $0.219 | $0.302 | $0.642 |
| | 32’ | 83 | 8.1 | $321,528 | 3.85 | $1.025 | $0.725 | $0.607 | $2.358 |
| | 35’ | 216 | 7.4 | $344,802 | 4.19 | $0.206 | $0.161 | $0.560 | $0.924 |
| | 40’ | 1,260 | 9.7 | $367,549 | 3.62 | $0.661 | $0.494 | $0.627 | $1.782 |
| | 45’ | 12 | 9.3 | $582,249 | 3.12 | $0.943 | $0.873 | $0.748 | $2.565 |
| | 60’ Artic | 8 | 3.5 | $683,702 | 2.66 | $1.634 | $0.831 | $0.816 | $3.281 |
| **Diesel Hybrid** | 29’ | 12 | 4.2 | $573,545 | 6.61 | $0.134 | $0.103 | $0.353 | $0.590 |
| | 31’ | 1 | 3.2 | $640,045 | 6.49 | $0.122 | $0.189 | $0.359 | $0.670 |
| | 35’ | 78 | 4.4 | $557,624 | 4.89 | $0.133 | $0.112 | $0.441 | $0.686 |
| | 40' | 151 | 2.6 | $649,903 | 4.78 | $0.212 | $0.160 | $0.482 | $0.855 |
| | 60’Artic | 76 | 2.2 | $950,849 | 3.88 | $0.271 | $0.505 | $0.638 | $1.406 |
| **Electric** | 35’ | 4 | 2.4 | $1,220,914 | 15.21 | $0.108 | $0.940 | $0.301 | $1.349 |
| **Gasoline** | 15’ | 1 | | | | | | | |
| | 16’ | 9 | 11.5 | $78,394 | 5.42 | $0.245 | | $0.471 | $0.715 |
| | 23’ | 1 | 9.3 | $59,007 | | $0.093 | $0.090 | | |
| | 25’ | 8 | 3.1 | $116,466 | 5.88 | $0.063 | $0.098 | $0.400 | $0.560 |
| ***Total Fleet*** | | ***2,190*** | | | | | | | |

** Calculated based on nationwide average prices for fuel (reported by DOE).*

The data show that diesel hybrid buses have a significantly higher acquisition cost compared to diesel buses. At the same time, hybrid buses provide better fuel economy and lower parts and labor costs per mile than diesel buses. For example, current data indicate that a 40-foot diesel hybrid bus demonstrates 32.0 percent better fuel economy than a 40-foot diesel bus (4.78 mpg for diesel hybrid vs. 3.62 mpg for regular diesel). In addition, 40-foot diesel hybrid buses have 67.9 percent lower parts cost per mile than diesel buses of the same size ($0.212/mile for diesel hybrid vs. $0.661/mile for diesel) and 67.6 percent lower labor cost per mile ($0.160/mile for diesel hybrid vs. $0.494/mile for diesel).

The data sample includes three compressed natural gas (CNG) buses, which are 29 feet in length and have 13.8 percent lower fuel mileage than comparable diesel buses. CNG vehicles also demonstrate 51.0 percent lower parts cost per mile, 117.8 percent higher labor cost per mile, and 22.3 percent higher acquisition cost than comparable 29-foot diesel vehicles. Figure 3-2 illustrates the comparison of performance and costs of 40-foot diesel and diesel hybrid buses.

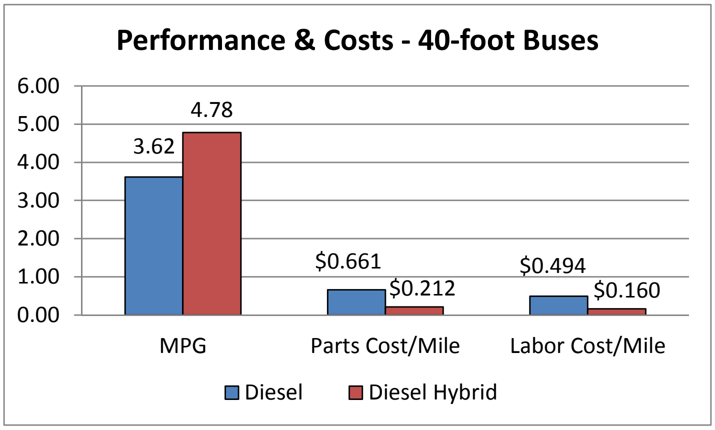


**Figure 3-2. Comparison of performance and costs of 40-foot buses, diesel vs. diesel hybrid.**

Vehicle age often plays an important role in how a vehicle performs. Newer vehicles typically perform better, demonstrating better fuel economy and operating costs per mile. This is true for vehicles of all propulsions. Additionally, the differential in performance between propulsion types may vary for different age vehicles. Figure 3-3 presents the comparison of fuel mileage by vehicle age for 40-foot diesel and diesel hybrid buses.

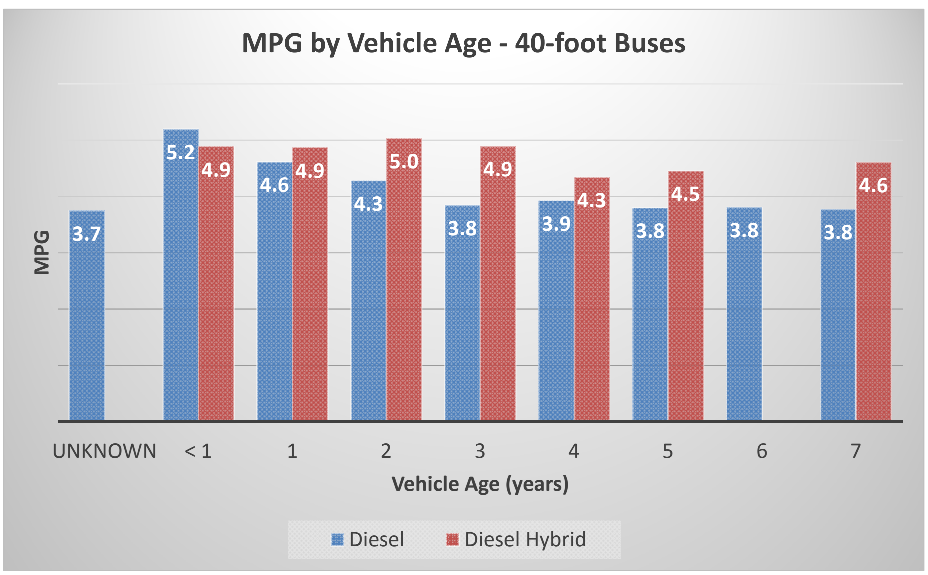


**Figure 3-3. Comparison of fuel mileage by vehicle age – 40-foot buses.**

The data show that the largest differential in fuel mileage between 40-foot diesel and hybrid buses is for three-year-old buses. A three-year-old 40-foot hybrid bus demonstrates 27.2

percent better fuel economy than a diesel bus of the same size and age. The differential between diesel hybrid and diesel buses decreases with the age of the bus. For example, a one-year-old 40-foot diesel hybrid bus demonstrates 5.6 percent better fuel economy than a diesel bus of the same size and model year. This trend may be partially attributed to improvements in clean diesel technology in recent years.

The differential in costs per mile is also dependent on vehicle age and is not always in favor of diesel hybrid technology. Diesel buses that are less than one year old demonstrate exceptionally high costs per mile, and can be viewed as outliers. Sample data show that when disregarding the outliers, 40-foot hybrid buses typically (with some exceptions) have higher parts and labor costs per mile compared to diesel buses of the same size and model year. The data show that 40-foot hybrid buses that are two years old demonstrate 24.2 percent lower parts cost per mile and 24.6 percent lower labor cost per mile than diesel buses of the same size and age. At the same time, four-year-old 40-foot hybrid buses show both significantly higher parts and labor costs per mile than four-year-old 40-foot diesel buses. Figure 3-4 and Figure 3-5 present the comparison of parts cost per mile and labor cost per mile, respectively, between 40-foot diesel and diesel hybrid buses of different ages.

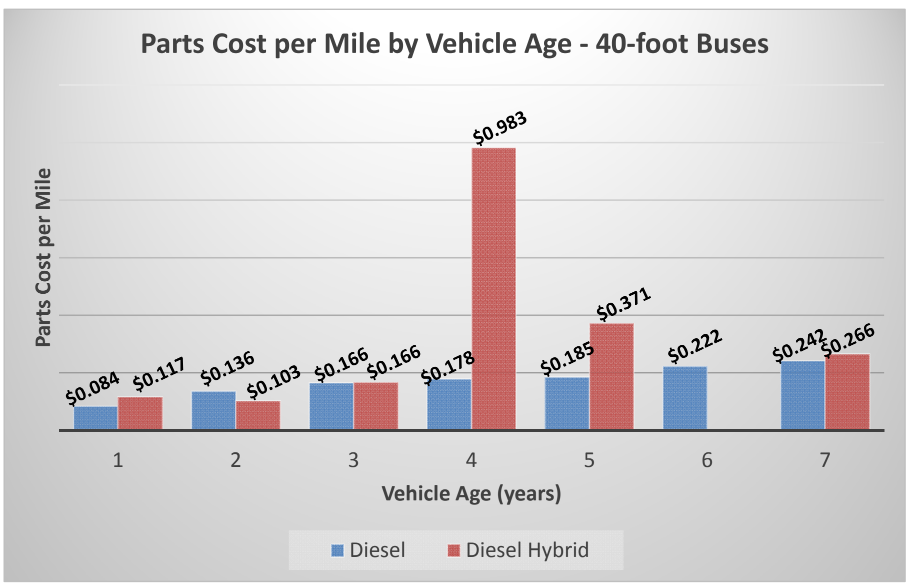


**Figure 3-4. Comparison of parts cost per mile by vehicle propulsion and age – 40-foot buses.**

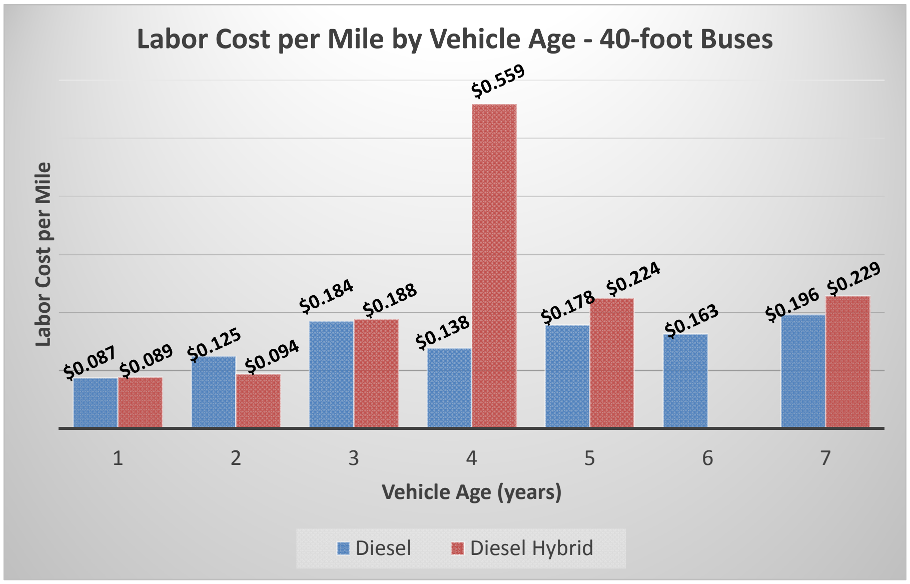


**Figure 3-5. Comparison of labor cost per mile by vehicle propulsion and age – 40-foot buses.**

For many agencies, fuel is the major part of overall operating costs. The current analysis does not directly track how much different agencies spend on fuel. Fuel purchase schemes vary from agency to agency. Some agencies buy at current prices, while others have long-term contracts at a fixed price (or a fixed markup). To eliminate differences in fuel purchase contracting among the agencies, the current analysis uses the nationwide average price of fuel to calculate fuel costs for all agencies. The U.S. Department of Energy reported the following nationwide average prices for the observed period: $2.33 per gallon for diesel, $2.35 per gallon for gasoline, $0.12 per kilowatt-hour (kWh) for electricity, $2.09 per diesel gallon equivalent for CNG, and $2.42 per gallon of biodiesel (B-20). Figure 3-6 presents the comparison of operating costs per mile for 40-foot diesel and diesel hybrid buses, including maintenance and fuel costs and excluding operator expense.

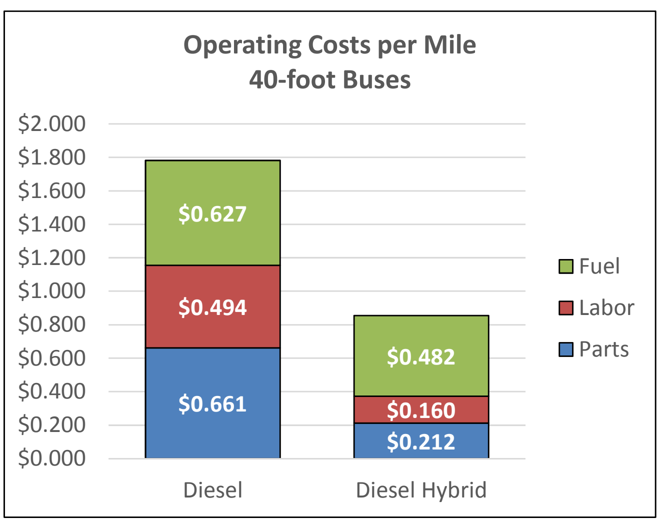


**Figure 3-6. Comparison of operating costs for different power plants – 40-foot buses.**

The graph demonstrates that diesel hybrids have significantly lower parts and labor costs per mile and slightly lower fuel cost compared to diesel vehicles of the same size.

The current sample contains data on four 35-foot battery electric buses running on batteries recharged from the electric grid. Energy consumption by these buses is reported in kilowatt-hours (kWh). For proper comparison of fuel economy, electricity consumed by these buses was converted into diesel gallon equivalents (DGE) using a conversion factor of 37.95 kWh = 1 DGE. Based on this conversion, battery electric buses demonstrate over 262.0 percent better fuel economy than comparable diesel buses. Battery electric buses also show 47.6 percent lower parts cost but significantly higher labor cost per mile (483.6 percent) than comparable diesel buses. Figure 3-7 presents the fuel economy comparison and Figure 3-8 demonstrates the comparison of parts and labor costs of 35-foot electric, diesel, and diesel hybrid buses.

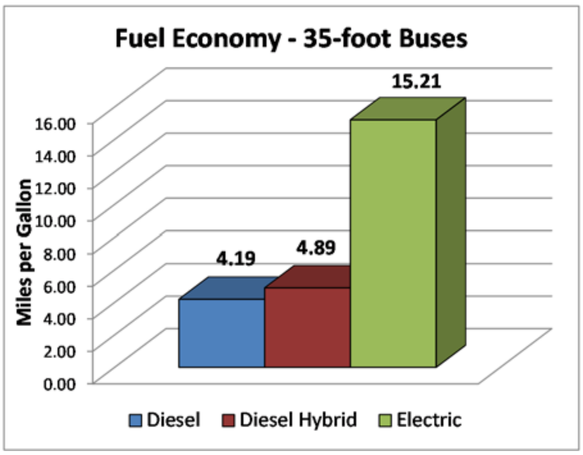


**Figure 3-7. Fuel economy comparison of different power plants – 35-foot buses.**

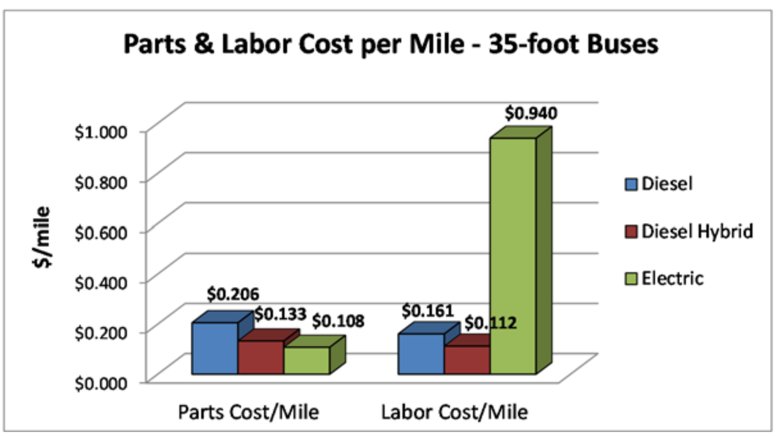


**Figure 3-8. Operating cost comparison of different power plants – 35-foot buses.**

With an acquisition cost of $1,220,914 per vehicle (in 2015 dollars), battery electric buses are significantly more expensive to purchase than both diesel and diesel hybrid buses (over three times more expensive than diesel and more than double the cost of diesel hybrids). The graph below combines all the operating costs, including fuel, to demonstrate the overall cost comparison associated with operating vehicles of different propulsion types. Figure 3-9 presents the comparison of operating costs, excluding bus operator, for 35-foot diesel, diesel hybrid, and electric buses.

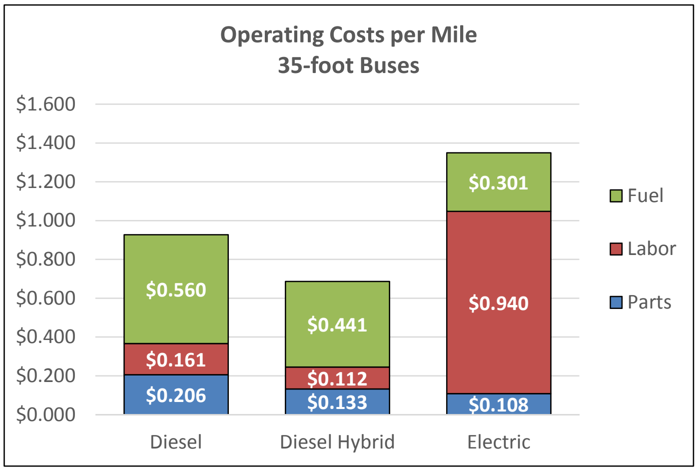


**Figure 3-9. Comparison of operating costs for different power plants – 35-foot buses.**

As illustrated in the figure above, 35-foot electric buses have lower fuel cost per mile, lower parts cost per mile, and significantly higher labor cost per mile than diesel or diesel hybrid buses of the same size. However, the lower fuel and parts costs do not compensate for increased labor cost, resulting in the overall higher operating cost for electric vehicles.

Average vehicle age contributes at least partially to the difference in fuel mileage and costs per mile for hybrid buses. In addition to being more efficient, hybrid buses are newer, with an average age of 3.0 years as reported by the transit agencies. For comparison, the average age of diesel buses operated by reporting agencies is 9.0 years. Newer vehicles typically perform better and cost less to operate than older vehicles.

Table 3-3 presents the comparison of performance and costs between buses with different power plants at an aggregate level. For proper comparison, reported vehicle acquisition costs have been adjusted to constant 2015 dollars using CPI.

**Table 3-3. Aggregate Comparison of Different Transit Vehicle Power Plants**

| Power Plant | Number of Buses | Average Age (Years) | Average Acquisition Cost | Fuel Mileage (MPG) | Parts Cost per Mile | Labor Cost per Mile | Fuel Cost per Mile | Total Operating Cost per Mile |
|---|---|---|---|---|---|---|---|---|
| **Biodiesel** | 119 | 8.1 | | | $0.252 | $0.331 | | |
| **CNG** | 3 | 0.5 | $413,998 | 4.01 | $0.079 | $0.289 | $0.515 | $0.883 |
| **Diesel** | 1,727 | 9.0 | $357,562 | 3.82 | $0.589 | $0.446 | $0.592 | $1.611 |
| **Diesel Hybrid** | 318 | 3.0 | $620,672 | 4.87 | $0.183 | $0.142 | $0.460 | $0.785 |
| **Electric** | 4 | 2.4 | $1,220,914 | 15.21 | $0.108 | $0.940 | $0.301 | $1.349 |
| **Gasoline** | 19 | 7.6 | $94,238 | 5.64 | $0.155 | $0.097 | $0.455 | $0.659 |
| ***Total Fleet*** | ***2,190*** | ***8.0*** | ***$393,097*** | ***3.99*** | ***$0.516*** | ***$0.402*** | ***$0.539*** | ***$1.443*** |

*Note: Articulated buses were excluded as outliers from the calculation of acquisition costs, fuel mileage, and costs per mile.*

The data show that diesel hybrid buses, regardless of size, on average have 27.5 percent better fuel economy, 69.0 percent lower parts cost per mile, and 68.1 percent lower labor cost per mile than regular diesel buses. At the same time, diesel hybrid buses on average cost about 73.6 percent more to acquire than comparable diesel vehicles.

Electric buses demonstrate an impressive 298.2 percent better fuel economy and 81.7 percent lower parts cost per mile, but 110.8 percent higher labor cost per mile, than comparable diesel buses. In addition, electric buses cost 241.5 percent more to acquire than comparable diesel vehicles. Figure 3-10 shows the comparison between buses of all sizes with different power plants.

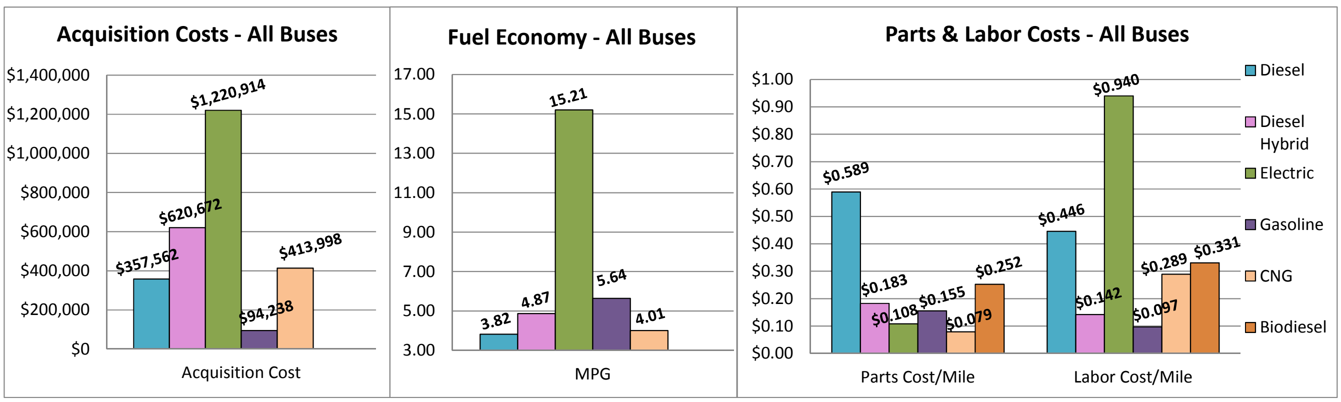


**Figure 3-10. Comparison of buses with different power plants – all vehicle sizes.**

Figure 3-11 summarizes total operating costs, including parts, labor, and fuel costs per mile, for different power plants. The fuel cost data for biodiesel buses is not available, making operating costs per mile for biodiesel vehicles incomplete and inaccurate.

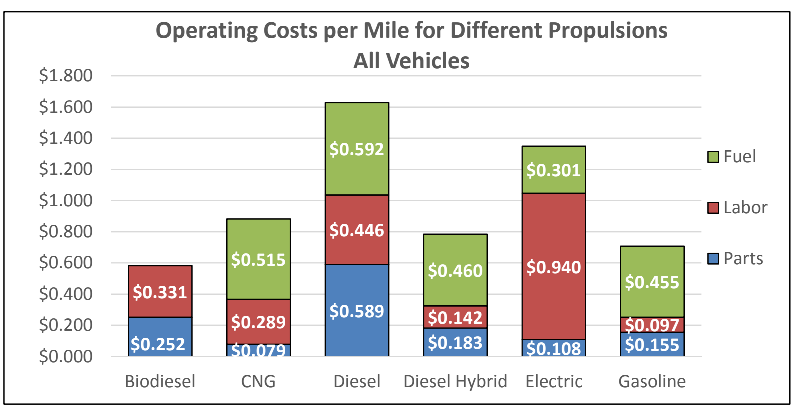


**Figure 3-11. Comparison of operating costs between different power plants.**

These results should be interpreted with caution since some cost differential may be attributed to hybrid buses being much newer vehicles (average age 3.0 years) than diesel buses, rather than the performance differences of hybrid versus diesel. In addition, agencies often prefer hybrid buses for bus rapid transit (BRT) routes that typically entail higher speeds and fewer stops. Therefore, duty cycle differences rather than propulsion technology account for some of the performance variation between diesel hybrid and regular diesel buses. Finally, the estimates for hybrid buses are based on a limited number of data points

(318 vehicles out of 2,190 reported), limiting the robustness of the analysis. As researchers collect more data on the performance and maintenance costs of alternative fuel transit vehicles, the reliability of the analysis will improve.

#### *Weighted Comparison*

One potential flaw of the methodology used for the analysis could include employing simple averages for calculating fuel mileage and costs per mile. This approach ignores the differences between miles driven by each bus and may result in incorrect calculations, especially when the miles driven by different types of buses vary significantly. Using weighted averages for calculating miles per gallon (MPG) and costs per mile accounts for the difference in mileage. Calculating weighted averages rather than simple averages assigns higher weights to the calculated parameters based on higher mileage, thus allowing them a higher influence on the final estimate. Table 3-4 presents a detailed performance and cost comparison of transit buses where the calculated parameters (MPG and costs per mile) are weighted by the mileage driven by each bus.

**Table 3-4. Fixed Route Cost and Performance Comparison – Weighted Parameters***

| Power Plant | Length | Number of Buses | MPG (Weighted) | Parts Cost per Mile (Weighted) | Labor Cost per Mile (Weighted) | Total Cost per Mile (Weighted) |
|---|---|---|---|---|---|---|
| **Biodiesel** | 35’ | 10 | | $0.104 | $0.100 | $0.204 |
| | 40’ | 109 | | $0.239 | $0.326 | $0.565 |
| **CNG** | 29’ | 3 | 4.06 | $0.081 | $0.268 | $0.350 |
| **Diesel** | Unknown | 29 | 5.60 | | | $0.470 |
| | 20’ | 1 | | | | |
| | 23’ | 1 | 7.23 | $0.209 | $0.297 | $0.506 |
| | 25’ | 3 | | $0.081 | $0.109 | $0.190 |
| | 27’ | 4 | | $0.080 | $0.051 | $0.131 |
| | 28’ | 4 | 10.30 | $0.114 | | $0.114 |
| | 29’ | 64 | 4.30 | $0.193 | $0.154 | $0.339 |
| | 30’ | 27 | 4.55 | $0.293 | $0.241 | $0.529 |
| | 31’ | 15 | 7.72 | $0.287 | $0.224 | $0.326 |
| | 32’ | 83 | 3.82 | $0.860 | $0.656 | $1.516 |
| | 35’ | 216 | 4.16 | $0.179 | $0.122 | $0.301 |
| | 40’ | 1,260 | 3.72 | $0.284 | $0.179 | $0.464 |
| | 45’ | 12 | 3.11 | $0.864 | $0.824 | $1.688 |
| | 60’ Artic | 8 | 2.86 | $0.221 | $0.241 | $0.462 |
| **Diesel Hybrid** | 29’ | 12 | 6.61 | $0.167 | $0.097 | $0.264 |
| | 31’ | 1 | 6.49 | $0.122 | $0.189 | $0.311 |
| | 35’ | 78 | 5.28 | $0.132 | $0.091 | $0.223 |
| | 40’ | 151 | 4.83 | $0.184 | $0.143 | $0.326 |
| | 60’ Artic | 76 | 3.64 | $0.264 | $0.259 | $0.522 |
| **Electric** | 35’ | 4 | 15.12 | $0.106 | $0.930 | $1.036 |
| **Gasoline** | 15’ | 1 | | | | |
| | 16’ | 9 | 4.99 | $0.206 | | $0.206 |
| | 23’ | 1 | | $0.093 | $0.090 | $0.183 |
| | 25’ | 8 | 5.87 | $0.062 | $0.097 | $0.158 |
| ***Total Fleet*** | | ***2,190*** | | | | |

**Miles driven by each bus are used as weights in calculating group averages.*

The use of weighted averages slightly changes the analysis results by decreasing the differential in fuel efficiency and costs per mile between diesel and diesel hybrid vehicles. These differences are most notable for 40-foot buses. Forty-foot hybrid buses demonstrate 30.0 percent better fuel mileage than comparable diesel buses when accounting for mileage driven (compared to 32.0 percent when miles driven are not considered). Additionally, when weighted averages are used, 40-foot hybrid buses have 35.4 percent lower parts cost per mile (compared to 67.9 percent when simple averages are used) and 20.6 percent lower labor costs per mile (compared to 67.6 percent when simple averages are used) than diesel buses of the same size. The data for 35-foot buses demonstrate a slightly different pattern: an increase in fuel mileage differential and a decrease in cost per mile differential when using weighted averages. Figure 3-12 shows the comparison between 40-foot diesel and hybrid buses, using weighted averages to calculate fuel mileage and costs per mile.

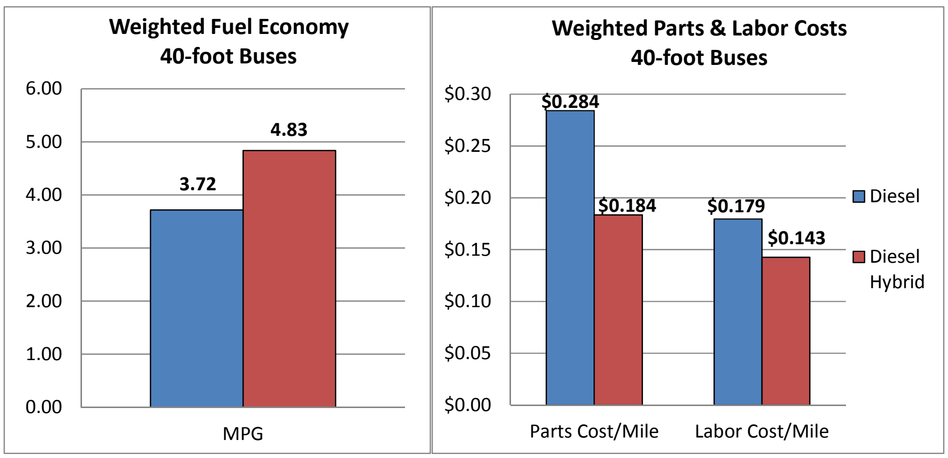


**Figure 3-12. Weighted cost and performance comparison for 40-foot buses.**

The data indicate that hybrid buses of all sizes perform better than diesel buses. However, the differential in fuel mileage and cost efficiency varies for different bus sizes. Table 3-5 presents an aggregate analysis of the entire fixed route fleet using weighted average calculations.

**Table 3-5. Fixed Route Aggregate Comparison – Weighted Parameters***

| Power Plant | Number of Buses | MPG (Weighted) | Parts Cost per Mile (Weighted) | Labor Cost per Mile (Weighted) | Total Cost per Mile (Weighted) |
|---|---|---|---|---|---|
| **Biodiesel** | 119 | | $0.222 | $0.297 | $0.520 |
| **CNG** | 3 | 4.06 | $0.081 | $0.268 | $0.350 |
| **Diesel** | 1,727 | 3.93 | $0.259 | $0.169 | $0.427 |
| **Diesel Hybrid** | 318 | 5.06 | $0.158 | $0.115 | $0.273 |
| **Electric** | 4 | 15.12 | $0.106 | $0.930 | $1.036 |
| **Gasoline** | 19 | 5.17 | $0.169 | $0.095 | $0.195 |
| ***Total Fleet*** | ***2,190*** | ***4.08*** | ***$0.243*** | ***$0.183*** | ***$0.423*** |

**Miles driven by each bus are used as weights in calculating group averages.*

The analysis shows that when accounting for miles driven, hybrid buses of any size generally have 28.7 percent better fuel economy than diesel buses (5.06 mpg for diesel hybrid vs. 3.93 mpg for diesel). Hybrid buses also have 39.0 percent lower parts cost per mile and 32.1 percent lower labor cost per mile than diesel buses. Battery electric buses demonstrate 284.4 percent better fuel economy and 59.2 percent lower parts cost per mile, but a 448.9 percent higher labor cost per mile, than diesel buses. CNG buses demonstrate 3.1 percent higher fuel economy, 68.6 percent lower parts cost per mile, and 58.3 percent higher labor cost per mile than diesel vehicles. Figure 3-13 presents an aggregate comparison between buses of different propulsion types, regardless of vehicle size, using weighted parameters.

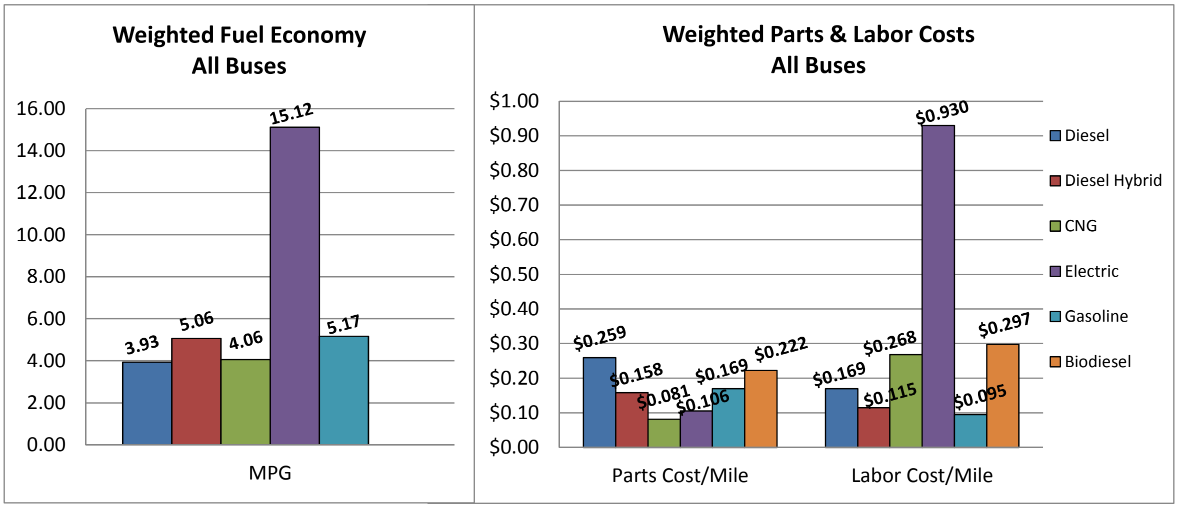


**Figure 3-13. Weighted comparison – all propulsion types and bus sizes.**

## Paratransit Fleet

The collected data sample for 2015 contains 218 paratransit vehicles. Of the reported paratransit fleet, 59.6 percent (130 vehicles) are gasoline, 38.5 percent (84 vehicles) are diesel, and 1.8 percent (4 vehicles) are CNG. No other power plants were reported for the paratransit fleet. Figure 3-14 shows the paratransit fleet composition by vehicle power plant.

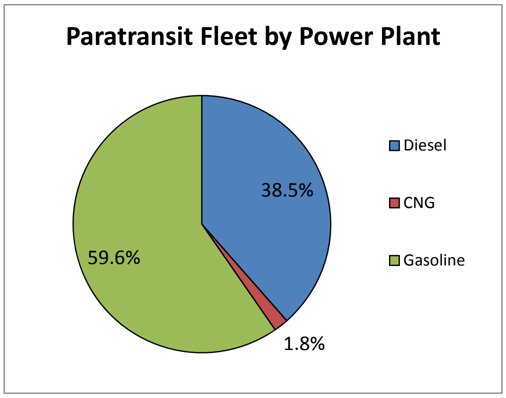


**Figure 3-14. Paratransit fleet by vehicle power plant.**

Table 3-6 presents a summary of the aggregate performance and costs of paratransit vehicles. Vehicle acquisition costs have been adjusted to constant 2015 dollars using CPI.

**Table 3-6. Comparison of Paratransit Vehicles of Different Power Plants**

| Power Plant | Number of Buses | Average Age (Years) | Average Acquisition Cost | Fuel Mileage (MPG) | Parts Cost per Mile | Labor Cost per Mile | Fuel Cost per Mile | Total Operating Cost per Mile |
|---|---|---|---|---|---|---|---|---|
| **Diesel** | 84 | 5.4 | $80,778 | 9.55 | $0.102 | $0.143 | $0.257 | $0.516 |
| **CNG** | 4 | 1.2 | $106,307 | 6.60 | $0.915 | $1.249 | $0.318 | $2.482 |
| **Gasoline** | 130 | 4.3 | $71,142 | 9.08 | $0.100 | $0.110 | $0.273 | $0.455 |
| ***Total Fleet*** | ***218*** | ***4.6*** | ***$75,939*** | ***9.22*** | ***$0.119*** | ***$0.154*** | ***$0.110*** | ***$0.364*** |

The analysis indicates that CNG paratransit vehicles demonstrate significantly higher costs per mile (792.3 percent higher parts cost and 771.5 percent higher labor cost per mile) than comparable diesel vehicles. CNG paratransit vehicles also cost 31.6 percent more to purchase than comparable diesel vehicles. Gasoline paratransit vehicles on the other hand demonstrate 2.2 percent lower parts cost per mile and 23.4 percent lower labor cost per mile. Gasoline vehicles also cost 11.9 percent less to purchase than diesel vehicles. Figure 3-15 graphically shows the comparison of performance and costs of demand response vehicles with different power plants.

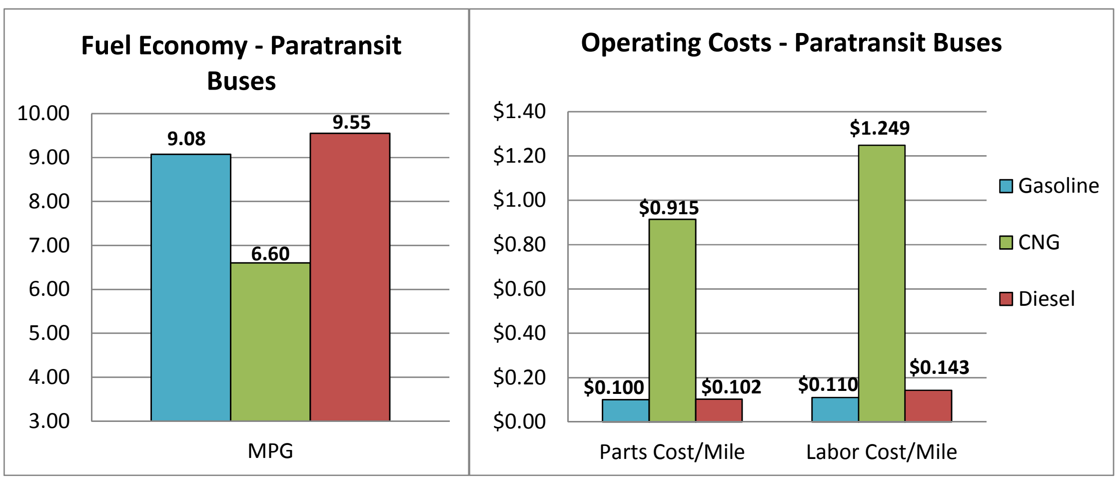


**Figure 3-15. Comparison of paratransit vehicles with different power plants.**

Fuel cost is a major expense for many agencies, sometimes accounting for up to half of all operating expenses, excluding vehicle operator. Adding fuel costs to the comparison provides a more complete picture of the expenses involved in operating vehicles with different propulsion. Figure 3-16 presents the comparison of operating costs, including parts, labor, and fuel, of paratransit vehicles with different power plants. Fuel costs were calculated using nationwide average fuel prices published by the U.S. Department of Energy.

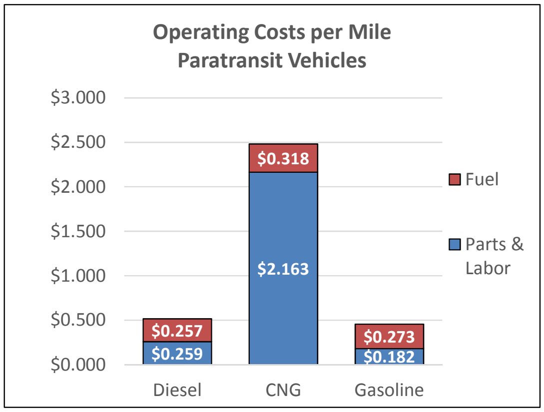


**Figure 3-16. Comparison of operating costs per mile – paratransit vehicles.**

CNG vehicles demonstrate the highest operating costs per mile of all propulsion types, mainly due to high parts and labor costs. In the current sample, gasoline vehicles show the highest share of fuel cost in overall operating costs (60.0 percent).

The most common vehicle sizes reported for the gasoline paratransit fleet are 23 feet (25.4 percent), 25 feet (23.1 percent), 26 feet (13.8 percent), and 16 feet (13.1 percent). No size was reported for 6.2 percent of gasoline vehicles. For the reported diesel paratransit vehicles, the most common size is 23 feet (57.1 percent) or 27 feet (16.7 percent). Additionally, no size was reported for 15.5 percent of diesel vehicles. All CNG paratransit vehicles in the sample are 25 feet in length. Table 3-7 presents a detailed cost and performance comparison of paratransit vehicles of different propulsion types and sizes.

**Table 3-7. Cost and Performance Comparison of Paratransit Vehicles**

| Power Plant | Length | Number of Buses | Average Age (Years) | Average Acquisition Cost | Fuel Mileage (MPG) | Parts Cost per Mile | Labor Cost per Mile | Fuel Cost per Mile* | Total Operating Cost per Mile |
|---|---|---|---|---|---|---|---|---|---|
| Diesel | Unknown | 13 | 6.5 | $74,907 | 11.35 | | | $0.216 | $0.542 |
| | 22’ | 4 | 6.5 | $82,930 | 9.49 | $0.096 | $0.160 | $0.238 | $0.494 |
| | 23’ | 48 | 4.8 | $82,362 | 8.89 | $0.097 | $0.149 | $0.273 | $0.519 |
| | 25’ | 4 | 6.4 | $78,040 | | $0.111 | $0.139 | | |
| | 26’ | 1 | 5.9 | $81,600 | | $0.155 | $0.125 | | |
| | 27’ | 14 | 5.6 | $80,434 | | $0.119 | $0.121 | | |
| CNG | 25’ | 4 | 1.2 | $106,307 | 6.60 | $0.915 | $1.249 | $0.318 | $2.482 |
| Gasoline | Unknown | 8 | 4.5 | $50,876 | 9.05 | $0.111 | | $0.242 | $0.353 |
| | 15’ | 5 | 0.8 | | 17.19 | $0.014 | | $0.142 | $0.156 |
| | 16’ | 17 | 7.2 | $72,407 | 11.39 | $0.190 | $0.044 | $0.200 | $0.393 |
| | 17’ | 2 | 2.5 | $48,265 | | $0.034 | $0.046 | | |
| | 18’ | 1 | | | | | | | |
| | 20’ | 5 | 0.0 | | 7.76 | | | $0.309 | $0.309 |
| | 21’ | 9 | 7.1 | $57,212 | | $0.066 | $0.111 | | |
| | 22’ | 2 | 2.2 | $40,476 | | $0.008 | $0.028 | | |
| | 23’ | 33 | 1.8 | $71,093 | 7.71 | $0.043 | $0.077 | $0.331 | $0.450 |
| | 25’ | 30 | 5.4 | $82,298 | 6.42 | $0.145 | $0.197 | $0.360 | $0.691 |
| | 26’ | 18 | 5.7 | $80,799 | | $0.117 | $0.106 | | |
| ***Total Fleet*** | | ***218*** | | | | | | | |

** Calculated based on nationwide average prices for fuel (reported by DOE).*

The comparison of 23-foot and 25-foot vehicles with different propulsion types shows that gasoline performs best for smaller vehicles, while diesel is more cost efficient than gasoline or CNG for larger vehicles. A 23-foot gasoline paratransit vehicle in the current sample has 13.3 percent lower fuel mileage, but provides 56.2 percent lower parts cost and 48.3 percent lower labor cost per mile than a comparable diesel vehicle. Additionally, a 23-foot gasoline vehicle costs 13.7 percent less to acquire than a diesel vehicle of the same size. Figure 3-17 shows the comparison of fuel economy and operating costs of 23-foot gasoline and diesel paratransit vehicles.

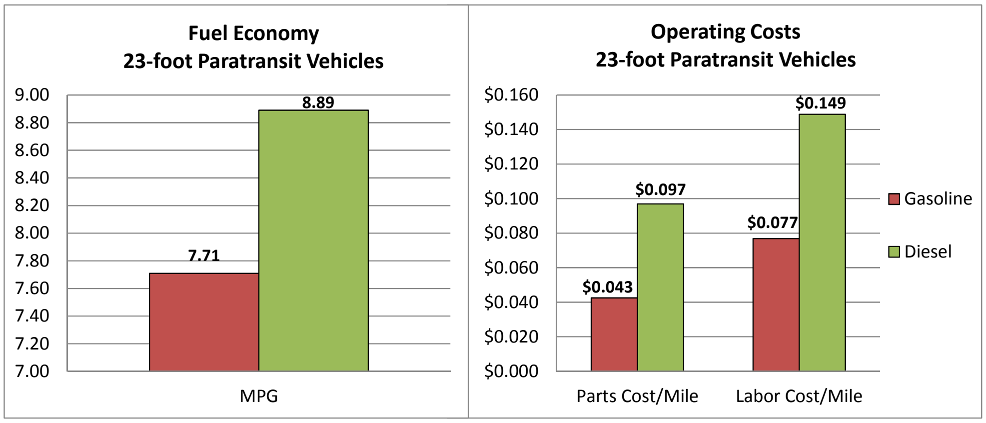


**Figure 3-17. Comparison of operating costs – 23-foot paratransit vehicles.**

In the current data sample, the only size reported for paratransit vehicles of all propulsion types is 25 feet. Figure 3-18 presents the comparison of performance and costs of 25-foot paratransit vehicles of different propulsion types.

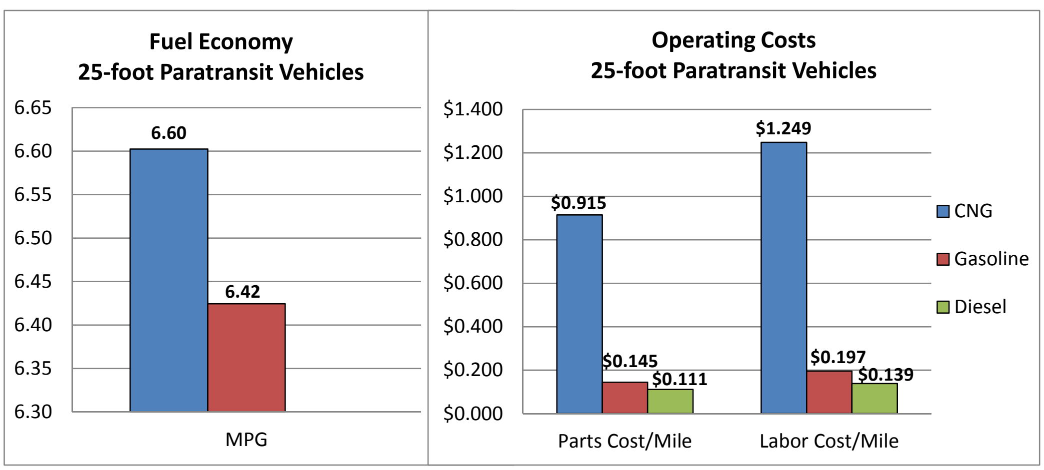


**Figure 3-18. Comparison of performance and costs – 25-foot paratransit vehicles.**

The data show that the diesel power plant provides the greatest cost advantage for 25-foot paratransit vehicles in the current sample, while the fuel mileage data for 25-foot diesel vehicles is missing. CNG vehicles provide the best fuel economy of all propulsion types in the sample, but also have the highest parts and labor costs per mile.

Due to the limited amount of data reported, little further analysis could be performed for demand response vehicles. As more paratransit data become available, the detail level of the analysis will improve.

# Chapter 4
# Facilitating Data Collection

## Site Visits

In order to facilitate regular data collection and encourage agency participation in the study, CUTR attempted to organize site visits to all 27 fixed route transit agencies in the state. The PI and Co-PI met with maintenance managers and senior staff of 25 fixed route transit agencies in order to discuss the current project, demonstrate the data collection tool, and connect with the staff responsible for data collection and submission. Despite repeated attempts, visits to two Florida transit agencies could not be arranged.

### *Fixed Route Agencies*

CUTR researchers visited and met with senior management of the following Florida fixed route agencies:

1. Bay County Transportation Planning Organization (Bay Town Trolley)
2. Broward County Transit (BCT)
3. Central Florida Regional Transportation Authority (LYNX)
4. City of Tallahassee Transit (StarMetro)
5. Collier Area Transit (CAT)
6. Council on Aging of St. Lucie County (CT)
7. Escambia County Area Transit (ECAT)
8. Gainesville Regional Transit System (RTS)
9. Hernando County Transit (The Bus)
10. Hillsborough Area Regional Transit Authority (HART)
11. Indian River Transit (GoLine)
12. Jacksonville Transportation Authority (JTA)
13. Lake County Connection (LCBOCC)
14. Lakeland Area Mass Transit District (LAMTD)
15. Lee County Transit (LeeTran)
16. Manatee County Area Transit (MCAT)
17. Miami Dade Transit (MDT)
18. Palm Beach Transit (PalmTran)
19. Pasco County Public Transportation (PCPT)
20. Pinellas Suncoast Transit Authority (PSTA)
21. Polk County Transit (WHAT)
22. Sarasota County Area Transit (SCAT)
23. Space Coast Area Transit (SCAT)
24. St. Johns County Transit Service (Sunshine Bus)
25. Volusia County Public Transit System (VOTRAN)

Visits to the following two fixed route agencies could not be arranged:

1. Ocala/Marion County Public Transit (SunTran)
2. Okaloosa County Transit (OCT)

***Rural Agencies***
In addition to the above fixed route agencies, researchers also visited three rural transit agencies to address FDOT's interest in expanding the data collection to rural communities served by transit. In order to provide diversity in the data sample, researchers selected rural agencies located in different parts of the state with different size fleets: one large, one medium-size, and one small agency. The rural agencies visited are listed below:

1. Good Wheels, Inc. (Large)
2. Citrus County Transit (Medium)
3. City of Key West (Small)

During the site visits, agencies were briefed for the first time about the goals of the current analysis and were asked to participate in the data collection. All the agencies expressed general willingness to provide their data for the analysis, but were also concerned about the resources needed to fulfill the task. None of the rural agencies reported using alternative fuels or had plans for acquiring alternative fuel vehicles in the near future. Further outreach and incentives may be needed to ensure participation of rural agencies in the study.

***Non-Florida Agencies***
In addition to Florida fixed route and rural agencies, researchers attempted to establish contacts and arrange site visits with a few key transit agencies outside of Florida to solicit their cooperation with the current data collection effort. The following agencies were contacted:

1. Los Angeles County Metropolitan Transportation Authority (LA Metro)
2. San Diego Metropolitan Transit System (San Diego MTS)
3. MTA New York City Transit (NYCT)
4. Metropolitan Atlanta Rapid Transit Authority (MARTA)
5. Washington Metropolitan Area Transit Authority (WMATA)

The agencies were chosen based on total fleet size and alternative fuel usage, particularly compressed natural gas (CNG). Of the five contacted non-Florida agencies, only two responded to the initial reaching-out.

In April 2016, CUTR researchers visited two non-Florida transit agencies: LA Metro and San Diego MTS, to discuss agencies' potential cooperation with data collection under this project. Both agencies expressed general interest and willingness to provide their data for CUTR analysis, but needed additional time to arrange data collection procedures on their end. CUTR will continue working with these agencies and other non-Florida transit agencies attempting to obtain a large sample of data covering the field performance of alternative fuel transit vehicles.

## Online Data Collection Tool
During the site visits, CUTR staff briefed the agencies about the goals of the alternative fuel vehicle evaluation study and demonstrated the online data reporting tool available for submitting data online. Since many of the visited agencies were not regularly submitting

data for the analysis, discussion of the project and its main goals was necessary to convey the importance of the assessment and its benefits to the entire transportation community.

Agencies that provided data in the past typically submitted data by e-mail to CUTR. However, CUTR recently developed and deployed a new reporting system that allows agencies to upload fleet performance and cost data online, using the data collection interface of the Advanced Transit Energy Portal (ATEP) website. ATEP was developed under a federal grant from the National Center for Transit Research (NCTR). Researchers envision that the website will be a single-point source of theoretical and practical knowledge about alternative fuel vehicles and advanced propulsion transit technologies. The main goals of ATEP are to facilitate information exchange and technology transfer, collect and share the latest developments in alternative fuel transit technologies (including advantages, limitations, and critical success factors), and assist government granting entities and transit agencies considering investment in alternative propulsion technologies.

Researchers suggested the new online data collection tool to the agencies as a convenient, optional alternative to standard data submission over e-mail. However, agencies were not required to use the new system. After seeing the demonstration, a few agencies took advantage of the system and submitted their fleet data online. It is expected that usage of the online data reporting system integrated with the ATEP website will increase over time.

# Chapter 5
# Recommendations

During the discussions researchers held with agency leadership and maintenance staff, agencies were able to voice concerns regarding the data collection process and recommend how to improve it. The most common concern expressed was a lack of resources to collect and report requested data on a regular basis. While larger agencies typically have management software and possibly an IT department to handle data collection, smaller agencies often struggle with data collection.

In some cases, smaller agencies do not have maintenance management software, have handwritten records, and lack sufficient staff to track vehicle mileage, fuel use, and costs. Gathering historic information about the fleet to report life-to-date figures requires tremendous effort for such agencies and is a main obstacle for participating in the data collection under this project. It was suggested that FDOT consider purchasing and providing management software to all the agencies, which would allow reporting data in a consistent format. It may also be helpful to create an inventory of all types of maintenance software used by state transit agencies to evaluate data availability and compatibility of reporting formats.

Transit agencies that are organized as part of a city or county government often have difficulty separating costs and fuel usage attributed to transit vehicles from the entire government fleet. In situations where maintenance records reflect data on an entire government fleet, it is challenging to report accurately transit fleet costs and fuel usage.

One suggestion repeated by several agencies was to standardize data reporting for different purposes, so the agency would not have to provide the same data multiple times. Agencies provide fleet reports to FDOT and FTA that often contain the same type of data requested for the purpose of this project. Short-staffed transit agencies find it challenging to provide multiple reports to different entities (or even the same entity) with essentially the same data but in different formats. Developing and employing a uniform format to report fleet data for multiple purposes and multiple recipients would be very helpful to agencies.

A few suggestions addressed improving the accuracy and value of the data analysis. These included comparing vehicles by emission year as well as by age, tracking whether a bus is equipped with electrified components such as an advanced thermal cooling system that might significantly increase fuel economy, and evaluating the costs for installing fueling infrastructure and retrofitting maintenance facilities to make them suitable for use by alternative fuel vehicles. Researchers have already implemented the most common suggestion, which was to provide quarterly reports to transit agencies submitting data so they could compare their fleet performance to a statewide average. All quarterly reports prepared for FDOT regarding alternative fuel fleet performance are posted on the ATEP website in public access. All transit agencies (whether or not submitting data) are encouraged to view these reports and use them for decisions regarding their fleets.

Another suggestion was to organize a daylong seminar to facilitate agency compliance with data collection requests and improve the quantity and quality of data collected. The event would allow all the agencies to share their experiences, successes, and challenges with data collection. The seminar would also focus on educating general managers of transit agencies and emphasizing the importance of data collection and reporting, and would include discussions with IT personnel involved in the actual data collection effort.

Finally, one agency suggested FDOT local districts should reconsider some of the rules regarding useful life of vehicles to allow for faster replacement of older vehicles that are costly to maintain. For example, FTA defines the life span of 25-foot vehicles as five years and/or 250,000 miles. However, the interpretation of the “and/or” requirement is left to the local districts. When an FDOT district interprets life span as “five years *and* 250,000 miles”, agencies often have to keep the vehicle for either longer than five years or longer than 250,000 miles, resulting in costly maintenance of a high-mileage vehicle. The interpretation of FTA’s vehicle life span rule as “a certain number of years *or* a certain number of miles” would provide opportunities for faster replacement of older vehicles with higher maintenance costs.

# Chapter 6
# Challenges and Limitations

The greatest challenge in performing the analysis was the availability of data. Only 13 of the Florida fixed-route transit agencies provided data on the performance and costs of their fleet during 2015. Consistency of reporting was also a problem. Of the 13 reporting agencies, only 4 reported data every quarter in 2015 and the remaining 9 provided data only in some quarters throughout the year.

The collected data revealed a limited number of alternative fuel vehicles in Florida's transit fleet. Of the 2,190 fixed route vehicles reported to CUTR in 2015, a total of 444 (or 20.3 percent) were alternative fuel vehicles, including 318 diesel hybrids, 119 biodiesel vehicles, 4 electric, and 3 CNG buses. The low number of observations, especially for electric and CNG buses, limits the reliability of the analysis, which should be interpreted with caution. Additionally, biodiesel data had gaps in it, which did not allow calculating fuel mileage. The only alternative propulsion technology consistently reported by the agencies and with enough fleet vehicles for reliable comparison was diesel hybrid. Therefore, it was not always possible to compare performance between multiple alternative technologies on the market. The only reliable comparison that could be performed using the reported data was between diesel and diesel hybrid vehicles.

While the amount of data on the fixed route fleet was mostly adequate, CUTR was unable to obtain a significant-size sample for demand response vehicles. The data on the paratransit fleet reported to CUTR in 2015 covered only 218 demand response vehicles. In addition, the majority of the paratransit fleet data had significant gaps, which did not allow a meaningful cost analysis. Complete and consistent data were available for only 44 paratransit vehicles. With such a small data sample, it was practically unfeasible to make any reliable estimates regarding the life cycle costs of operating alternative fuel paratransit vehicles in Florida.

The above challenges limited the amount and the reliability of the analysis that could be performed for this project. The results presented in this report should be treated with caution, recognizing that the analysis is based on a limited amount of data. As more data on the performance and maintenance costs of both fixed route and demand response alternative fuel vehicles becomes readily available, the reliability and robustness of the analysis will improve.

# Chapter 7
# Conclusions

While CUTR collected valid operating and maintenance cost data for the majority of Florida's fixed route transit fleet, no data was obtained from out-of-state transit agencies. All analysis presented in the current report is based on Florida transit fleets. The data analysis for fixed route buses revealed that the majority of transit buses in Florida are regular diesel buses (78.9 percent of the reported fleet), while 14.5 percent of the vehicles are diesel hybrids, 5.4 percent are biodiesel (B-20), 0.9 percent are gasoline, and very few vehicles are CNG or electric. About 73.0 percent of the diesel buses are 40-foot buses, with 35-foot and 32-foot buses representing 12.5 percent and 4.8 percent of the diesel fleet, respectively. Diesel hybrid buses, on the other hand, are more likely to be larger in size than diesel buses. Sixty-foot articulated buses represent 23.9 percent and 40-foot buses account for 47.5 percent of the diesel hybrid fleet.

The analysis of fixed route data showed that diesel hybrid buses have significantly higher acquisition costs but offer better fuel mileage than diesel buses. In addition, hybrid buses tend to have lower parts and maintenance costs per mile than comparable diesel buses. A 40-foot diesel hybrid bus has 32.0 percent better fuel economy, 67.9 percent lower parts cost per mile, and 67.6 percent lower maintenance cost per mile than a comparable diesel bus. At the same time, a 40-foot diesel hybrid bus costs 76.8 percent more to acquire than a diesel bus of the same size.

Electric buses in the sample demonstrate impressive fuel economy and lower parts cost per mile, but have significantly higher labor cost per mile than diesel buses. A 35-foot electric bus has 262.8 percent better fuel economy and 47.6 percent lower parts cost per mile, but 483.6 percent higher labor cost per mile and 254.1 percent higher acquisition cost than a 35-foot diesel bus. CNG buses in the sample demonstrate 13.8 percent lower fuel mileage, 51.0 percent lower parts cost per mile, 117.8 percent higher labor cost per mile, and 22.3 percent higher acquisition cost than diesel buses of the same size.

Average vehicle age contributes at least partially to the performance differential. The average age of a diesel hybrid bus in the current analysis is 3.0 years old and an average electric bus is 2.4 years old, compared to 9.0 years for an average diesel bus. Newer buses typically perform better and cost less to operate and maintain. In fact, comparing vehicles of the same age revealed that the performance and cost per mile differential between hybrid and diesel buses was the smallest for younger buses. The observation suggests that significant improvements in the efficiency of clean diesel technology have occurred in recent years.

Researchers observed surprising results when using weighted averages to calculate miles per gallon and cost per mile to account for potential differences in miles driven by different buses in the data sample. The use of weighted averages slightly changes the analysis results, most notably for 40-foot buses, reducing the differential in fuel and cost efficiency between diesel and diesel hybrid vehicles. When miles driven are considered, 40-foot hybrid buses demonstrate 30.0 percent better fuel economy (compared to 32.0 percent when miles driven are not considered), 35.4 percent lower parts cost (compared to 67.9 percent using simple averages), and 20.6 percent lower maintenance costs per mile (compared to 67.6 percent using simple averages) than diesel buses of the same size.

The observed results may indicate that a relatively large number of hybrid buses in the dataset are earlier-generation vehicles with lower fuel efficiency that have been in use for some time and have logged a lot of mileage. The dataset also contains a large number of older, high-mileage diesel buses that perform exceptionally well.

The analysis of paratransit data shows that almost 60 percent of the demand response fleet consists of gasoline-powered vehicles, 38.5 percent are diesel, and 1.8 percent (four vehicles) are CNG. The available data indicate that CNG paratransit vehicles have significantly higher parts and labor costs, while also having lower fuel efficiency, than both diesel and gasoline vehicles. CNG paratransit vehicles also have over 30.0 percent higher acquisition cost than comparable diesel or gasoline vehicles. Due to a small data sample and significant gaps in the paratransit data, the extent of the analysis and the reliability of the comparison are not optimal.

In order to facilitate the data collection effort, CUTR researchers visited 25 fixed route and 3 rural agencies in Florida, as well as 2 non-Florida fixed route agencies briefing senior maintenance staff on the goals of the current project and demonstrating a newly developed online data collection tool. The site visits improved agency participation and cooperation. A few of the transit agencies that had not previously participated in the analysis began cooperating with data collection requests after the outreach efforts by CUTR.

It is suggested that efforts continue in collecting more fleet data on the performance and costs of alternative fuel vehicles from transit service providers, both in Florida and outside of the state. Particular efforts should be directed at reaching large out-of-state transit agencies utilizing alternative fuel technologies, which are lacking in Florida. A significantly larger data sample for CNG and battery electric technologies may be needed to improve the reliability of the current analysis.

The intent of the current analysis was to contribute to the ongoing evaluation of the costs and benefits of investment in advanced transit technologies, rather than to provide recommendations on the choice of a particular alternative fuel technology. No attempt was made to provide a comprehensive comparative analysis of the existing advanced transit technologies, and the results should be treated accordingly.