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Tracking Costs of Alternatively Fueled Buses in Florida – Phase II

April 2013

Final Report



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Tracking Costs of Alternatively Fueled Buses in Florida – Phase II

FDOT BDK85 977-38

Prepared for:



Florida Department of Transportation

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Final Report

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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
ft³	cubic feet	0.028	cubic meters	m ³
yd³	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)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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Executive Summary

Transit agencies across Florida have been dealing with escalating fuel prices and changes in environmental regulations affecting the use of diesel engines and diesel fuel. In an effort to address rising fuel costs and environmental concerns, many agencies have introduced alternative fuel technologies to their traditional diesel-powered fleets, including biodiesel, compressed natural gas (CNG), hybrid-electric, battery-electric, hydrogen fuel cell, and other technologies. These advancements, however, have resulted in increased capital and operating costs for some fixed-route operators and created challenges for the widespread adoption of advanced transit technologies.

The Florida Department of Transportation (FDOT) is interested in collecting and evaluating up-to-date data on the performance of alternative fuel transit vehicles in Florida to assist the Department with evaluating benefits and costs of investment in advanced transit technologies. The Department has engaged the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) in the past to establish a reporting system for the collection of transit fleet performance and cost data, as detailed in the 2009 National Center for Transit Research (NCTR) project (FDOT BDK85 977-18). FDOT is interested in continuing regular data collection, monitoring, and evaluating field data on performance and operating costs of alternative fuel vehicles in Florida transit fleets.

CUTR contacted and approached all fixed-route transit agencies in the state with regular data requests. This was arranged through electronic and phone communication in coordination with the project manager. An attempt was made to collect data covering both fixed-route and demand response transit vehicles. Unfortunately, regardless of the continued efforts to maintain regular data reporting, the response rate to these data requests was less than ideal.

Despite difficulties with data collection, CUTR was able to obtain relevant operations and cost data for fixed-route buses from nine major transit agencies reporting during 2012, representing the majority of the fixed-route fleet in the state. The reporting, however, was not always regular, with only four agencies reporting their fleet data every quarter of 2012. The data sample was limited as to the number of paratransit vehicles covered and the information available. The above challenges limited the extent and reliability of the analysis that could be performed on this project.

The analysis of data for fixed-route buses revealed that the vast majority of transit buses in Florida are regular diesel buses (89% of the reported fleet) or gasoline vehicles (2% of the reported fleet), while only 9 percent are alternative fuel vehicles (mostly diesel hybrids). Over 76 percent of the diesel buses are 40-foot buses, with smaller 35-foot and 32-foot buses representing roughly 8 percent and 5 percent of the diesel fleet, respectively. Alternative fuel buses, on the other hand, are more likely to be of larger size than diesel buses. About 25 percent of the diesel hybrid buses are articulated buses, while only 1 percent of the diesel fleet is articulated. Forty-foot buses represent about 25 percent of the diesel hybrid fleet (compared to 76% for the diesel fleet).

The analysis of fixed-route data showed that alternative fuel buses have significantly higher acquisition costs and slightly better fuel mileage, compared to diesel buses. In addition, hybrid buses tend to have lower parts costs and maintenance costs per mile than comparable diesel buses. A 40-foot diesel hybrid bus has 21.2 percent better fuel economy (4.67 mpg for hybrid vs. 3.85 mpg for diesel), 63.3 percent lower parts cost per mile (\$0.123 per mile for hybrid vs. \$0.336 per mile for diesel), and 76.0 percent lower maintenance cost per mile (\$0.196 per mile for hybrid vs. \$0.815 per mile for diesel), compared to a traditional diesel bus of the same size. At the same time, a 40-foot diesel hybrid bus costs 71.1 percent more to acquire than the comparable diesel bus.

The aggregate comparison between traditional diesel buses and hybrid buses, regardless of vehicle size, shows that hybrid buses on average have 14.4 percent better fuel economy, 59.4 percent lower parts cost per mile, and a 61.3 percent lower maintenance cost per mile, compared to diesel buses. At the same time, hybrid buses on average cost 67.0 percent more than traditional diesel buses. The differential in performance can be attributed at least partially to the average age of the vehicles. An average hybrid bus in the current analysis is 2.3 years old, compared to 7.4 years for an average diesel bus.

Slightly different results were observed when weighted averages were used to calculate miles per gallon and cost per mile in order to account for potential differences in miles driven by different buses in the data sample. The analysis shows that when accounting for miles driven, hybrid buses of any size, in general, have comparable fuel mileage with diesel buses (4.49 mpg for diesel hybrid vs. 4.48 mpg for diesel). Hybrid buses also have 54.9 percent lower parts cost per mile, and 58.2 percent lower maintenance cost per mile compared to diesel buses.

These results, however, do not necessarily mean that the diesel hybrid power plant performs the same as or worse than a regular diesel. Instead, this may indicate that the dataset contains a relatively small number of earlier-generation hybrids with lower fuel efficiency that have logged a lot of miles. In addition, the data sample also includes a large number of older, high-mileage diesel buses that perform exceptionally well. These two factors combined may result in the reduced difference between the (weighted) average fuel efficiency of a typical hybrid bus and a typical diesel bus, when accounting for mileage driven.

Unlike fixed-route buses, the data for paratransit vehicles was limited, and no alternative fuel vehicles were reported in the demand response fleet. Forty percent of the paratransit fleet consists of diesel vehicles, 20 percent are gasoline-powered vehicles, and the power plant of the remaining 40 percent of the paratransit fleet is not known. The available data indicate that diesel paratransit vehicles perform better than gasoline vehicles in terms of both fuel economy and operating costs. The analysis shows that diesel-powered vehicles get 34.2 percent better fuel mileage (8.82 mpg for diesel vs. 6.57 mpg for gasoline) and 19.1 percent lower total cost per mile (\$0.369 per mile for diesel vs. \$0.456 per mile for gasoline), compared to gasoline-powered vehicles. Due to extremely small data sample, however, the extent of the analysis as well as the reliability of comparison between different paratransit vehicles is far from optimal.

Alternative fuel vehicles often require maintenance procedures that are not typical for the vehicles running on traditional fuels and may require certain modifications to transit agencies' maintenance facilities to address additional safety requirements.

The review of the literature indicated that the cost of modifying transit agencies' maintenance facilities to make them suitable for alternative fuel vehicles may run anywhere from \$50,000 to \$600,000 for a typical 150- to 200-bus garage. While being highly dependent on the type of alternative fuel and the current design of the facility, these modifications typically involve improvements in ventilation and the fire suppression system, as well as the installation of heat and smoke detectors, explosion-proof electrical wiring, and other improvements. In addition, the construction of a fueling facility for alternative fuel vehicles may cost transit agencies anywhere from \$200,000 to \$2.5 million, depending on the type of fuel and the scale of operation.

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 provide recommendations on the choice of a particular alternative fuel technology. Additionally, since the analysis was based on a relatively limited data sample, the results of the analysis should be treated with caution. As more field data are collected, the reliability of the analysis will improve.

To facilitate consistent and regular data collection, CUTR recommends implementing a Web-based reporting system that would allow agencies to input data electronically on a regular basis. It is also recommended that such data reporting should become a requirement for transit agencies under their grant agreements with FDOT.

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Chapter 1

Introduction

Background

Florida transit agencies have been dealing with volatile fuel prices and changes in regulations regarding diesel engines and fuel. In addition, there has been an increased emphasis on reducing the overall consumption of fossil fuels, as well as reducing carbon emissions by transit agencies. To address fuel price uncertainties and environmental concerns, many agencies have introduced alternative fuel vehicles into their fleets. This has occurred even as diesel technology has become “cleaner” with recent changes due to ultra-low sulfur fuel and enhanced emission control technologies. These advancements, however, have increased both capital and operating costs for some fixed-route operators and created challenges for the widespread adoption of advanced transit technologies.

One technology that is gaining popularity is the diesel hybrid-electric bus. Recent funding made available through the federal economic stimulus effort (American Recovery and Reinvestment Act of 2009; hereafter, ARRA) has aided the growth in the acquisition of these units. Some agencies in Florida have made applications and are receiving funding for these buses through the “Transit Investments for Greenhouse Gas and Energy Reduction” (TIGGER) Grant program, while others are using regular transit capital funds. The TIGGER Grants were created as part of the ARRA. Typically, FDOT funds 50 percent of the non-federal share of bus capital and stands to have substantial investment in this technology as acquisition costs for these buses average about \$150,000 more per unit.

FDOT is interested in collecting and maintaining up-to-date data on the performance and costs of alternative fuel vehicles as both the Department and local transit agencies continue to evaluate the benefits and costs of investment in the advanced transit technologies. FDOT has worked with CUTR in the past in attempts to quantify the potential cost differentials associated with various heavy-duty bus propulsion technologies. A 2009 National Center for Transit Research (NCTR) project (FDOT BDK85 977-18) provided for establishing a cost reporting system for the collection of fleet performance and cost data from Florida transit agencies. FDOT is interested in continuing this effort of collecting and reporting relevant performance and efficiency data on the operation of alternative fuel transit vehicles in Florida.

The Center for Urban Transportation Research, established in 1998, has become 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 collecting and reporting the data on the performance and costs of alternatively fueled public transit vehicles in the state, and to develop an alternative method of reporting Florida transit agency data in a consistent

manner in order to keep the Bus Fuels Fleet Evaluation Tool (BuFFeT) cost model current. The data, collected and reported, will enable policy makers to have actual field data to assist in future decision making on maintenance resources and future vehicle acquisitions.

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 assessment of alternative fuel transit fleet performance. It is understood that as more data are accumulated, the current assessment of alternative fuel transit vehicles' cost efficiency and performance may change. The current analysis is intended to provide decision support for policy makers regarding the costs involved in operating alternative fuel buses in the Florida transit fleet, rather than give definitive recommendations regarding the application of a particular alternative propulsion technology.

Additionally, one of the goals of the project is to provide assistance to the FDOT Office of Public Transportation in evaluating various local projects related to the performance of alternative fuel vehicles, as well as emission reduction and fuel efficiency strategies. This activity will be initiated by special requests from the project manager and will include coordination with appropriate FDOT district and transit agency personnel.

Chapter 2 Research Approach

During the course of the project, CUTR continued collecting data from the fixed-route transit service providers on the performance of alternative fuel vehicles in their fleet using the reporting tool established under the previous NCTR project (FDOT BDK85 977-18). The data collected from the transit agencies included agency name, unit number, length of the vehicle, power plant, fuel type, duty cycle, date placed in service, acquisition cost, warranty status, life-to-date mileage, life-to-date fuel usage, life-to-date parts costs, and life-to-date labor costs. Then the data collection tool was assembled in the form of a brief spreadsheet table to simplify the report to the extent possible, while not compromising the project objectives. In addition, to facilitate data collection, the agencies were offered an option to report their data in any format (other than the suggested reporting tool) that was more convenient to them.

CUTR sent data submission requests to all fixed-route transit agencies in Florida requesting their assistance in collecting the data. Agencies were requested to report on their entire fleet (both alternative and traditionally fueled), and they were asked to report on a quarterly basis. After the data collection mail-outs, CUTR also followed up with phone calls to the transit agencies to encourage their submissions. Regular reminders to submit operations and maintenance cost data for their fleets were sent to Florida transit agencies in coordination with the project manager. In addition, the principal investigator maintained regular contacts with the transit agencies, addressing their questions and concerns regarding the collection and submission of data.

Regardless of the tremendous efforts put in by CUTR researchers to collect the data, and the requests by the FDOT project manager to assist CUTR in this effort, the response to these data requests were less than ideal. During the calendar year of 2012, nine transit agencies provided relevant maintenance and cost data for their fleets, including Palm Tran (Palm Beach), StarMetro (Tallahassee), MDT (Miami), Broward County Transit (Broward County), Votran (Volusia County), Lee County Transit (Lee County), LYNX (Orlando), Pinellas Suncoast Transit Authority (Pinellas County), and Pasco County Public Transit (Pasco County). However, only four of those agencies reported their quarterly data consistently (i.e., every quarter) throughout the year. Nevertheless, having regular reporting by a few major 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.

The collected data was used to perform the analysis of the costs involved in operating alternative fuel vehicles in the Florida transit fleet. The results of this analysis were provided to the project manager in the form of quarterly summary reports that compared field performance and costs across different transit propulsion technologies.

These data have also been used to update the cost model used for the analysis. Keeping the model populated with the latest data is vital to enable accurate performance assessment of the various transit power plants, and is necessary for the model to be useful and valuable as

a decision support tool to the policy makers regarding the costs and benefits of investing in alternative propulsion transit vehicles in Florida.

In addition to fixed-route transit agencies, CUTR researchers also attempted to collect operating and cost data for the demand response vehicles operated in Florida. Data collection was performed using the same data reporting tool as for the fixed-route fleet. All fixed-route agencies running paratransit operations were requested to report their paratransit data separately from the fixed-route vehicles.

Unlike fixed-route, the data for paratransit vehicles was limited and not reported consistently. During 2012, CUTR was able to collect data for 95 demand response vehicles in the state. Of these vehicles, only 19 were reported consistently (every quarter), providing the complete cost and performance data that was requested. The data for the remaining 76 paratransit vehicles had serious gaps in it, which did not allow performing the same level of analysis as for the fixed-route fleet.

Since little reliable data could be collected on the costs and performance of the demand response vehicles in the state, the analysis of the paratransit fleet, presented in the current report, is limited and should be interpreted with caution.

Separate from the operating cost data collection and analysis, CUTR also provided assistance to the project manager in assessing specific efforts relating to alternative fuels, emissions reductions, and fuel efficiency strategies that stem from transit agencies' grant requests to FDOT.

Chapter 3

Cost Comparison Analysis

The Florida Department of Transportation has engaged CUTR to collect and report performance and cost data related to the operation and maintenance of Florida transit vehicles. During the course of the project, CUTR 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, the data collection was performed separately for fixed-route buses and paratransit buses. Consequently, the costs were also reported separately for these two types of transit service.

While CUTR was able to collect operating cost data for the majority of fixed-route buses in the state, the data for the paratransit fleet were limited. The analysis presented in the current report, therefore, focuses primarily on the fixed-route fleet. The analysis of paratransit fleet, on the other hand, should be interpreted with caution due to the limitations of the data on which it is based.

During 2012, some agencies reported their data consistently every quarter, while others reported only in certain quarters. For the purposes of the current analysis and in order to overcome the limitations of inconsistent reporting, the dataset covering all the vehicles reported in 2012 was assembled, regardless of whether the vehicles were consistently 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 fleet data was used for the purposes of performing annual analysis. The following agencies provided operation and maintenance cost data on their fleets for at least one quarter during 2012:

- Palm Tran (Palm Beach)
- StarMetro (Tallahassee)
- MDT (Miami)
- Votran (Volusia County)
- Lee County Transit (Lee County)
- LYNX (Orlando)
- Broward County Transit (Broward County)
- Pinellas Suncoast Transit Authority (Pinellas County)
- Pasco County Public Transit (Pasco County)

The data assembled from these transit agencies during 2012 covered 2,001 fixed-route vehicles (including 4 trolleys) and 95 paratransit vehicles. The summary statistics presented in this document were based on the cost data from these transit agencies that were reported sometime in 2012, although not necessarily consistently for each calendar quarter of the year.

Fixed-Route Buses

The summary of physical characteristics of the fixed-route transit fleet is presented in Table 3-1.

Table 3-1. Fixed-Route Fleet Summary

Power Plant	Length	Number of Buses
Diesel	Unknown	102
	25'	5
	29'	43
	30'	8
	32'	86
	35'	140
	40'	1,373
	45'	12
Diesel Hybrid	60' Articulated	18
	Unknown	12
	32'	1
	35'	35
	40'	45
	41'	13
Gasoline	42'	29
	60' Articulated	46
Gasoline Hybrid	Unknown	38
Trolley	Unknown	1
Total Fleet		2,011

Roughly 89.0 percent (1,787 buses) of the reported fixed-route fleet consists of the regular diesel buses, while about 9.0 percent (181 buses) are diesel hybrids. About 2.0 percent (39 buses) of the reported fleet runs on gasoline, including one gasoline hybrid vehicle. The comparison of diesel and diesel hybrid fleet by vehicle size is presented in Figure 3-1.

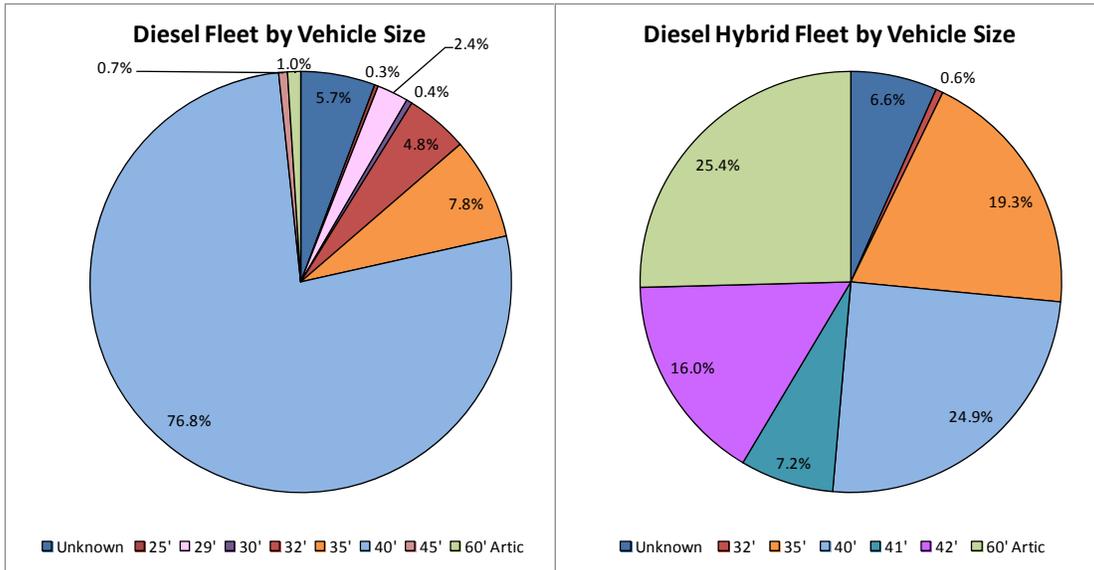


Figure 3-1. Diesel and Diesel Hybrid Fleet Composition by Vehicle Size

Over 76 percent of the diesel buses are 40-foot buses. Twenty-nine-foot, 32-foot, and 35-foot buses represent 2.4 percent, 4.8 percent, and 7.8 percent of the diesel fleet, respectively. Larger 60-foot articulated buses account for only 1.0 percent of the diesel fleet. The size of 102 diesel buses (5.7% of the diesel fleet) was not reported, hence the “unknown” category.

Unlike diesel buses, 60-foot articulated buses represent the largest share of the diesel hybrid vehicles. Sixty-foot articulated buses and 40-foot buses have essentially equal shares in the diesel hybrid fleet. They both represent about 25.0 percent of diesel hybrid vehicles (46 articulated buses and 45 40-foot buses). While 40-foot buses alone represent a quarter of all diesel hybrids, 40-foot, 41-foot, and 42-foot buses combined represent over 48 percent of all diesel hybrid vehicles. The size of the gasoline-powered fixed-route buses was not reported.

A detailed cost and performance comparison of transit buses is presented in Table 3-2. 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 2012 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	Maintenance Cost per Mile	Total Cost per Mile
Diesel	Unknown	102	8.5		4.72	\$0.426	\$0.15	\$0.642
	25'	5	10.4	\$135,794				
	29'	43	6.3	\$333,763	4.34	\$0.252	\$0.22	\$0.471
	30'	8	7.0	\$258,580				
	32'	86	5.4	\$308,252	3.98	\$0.496	\$1.440	\$1.937
	35'	140	4.7	\$330,054	4.05	\$0.240	\$0.210	\$0.450
	40'	1,373	7.8	\$357,494	3.85	\$0.336	\$0.815	\$1.102
	45'	12	6.3	\$564,014	3.26	\$0.345	\$1.413	\$1.759
	60' Artic	18	3.0	\$662,290	2.71	\$0.236	\$0.243	\$0.481
Diesel Hybrid	Unknown	12	2.3		4.90	\$0.067	\$0.042	\$0.221
	32'	1	3.0		5.47	\$2.050	\$4.340	\$6.390
	35'	35	2.3	\$565,937	4.33	\$0.153	\$0.112	\$0.265
	40'	45	2.9	\$611,703	4.67	\$0.123	\$0.196	\$0.332
	41'	13	2.4	\$577,220	4.18	\$0.091	\$1.016	\$1.107
	42'	29	1.2	\$632,513	4.37	\$0.113	\$0.297	\$0.411
	60' Artic	46	2.5	\$879,291	3.75	\$0.097	\$0.627	\$0.724
Gasoline	Unknown	38			16.95			\$0.204
Gasoline Hybrid	Unknown	1			3.77			\$0.880
Trolley	Unknown	4	11.3		5.45	\$0.245	\$0.147	\$0.393
Total Fleet:		2,011	6.9	\$364,234	4.16	\$0.323	\$0.736	\$1.002

The data for gasoline-powered vehicles, as well as trolleys, were reported inconsistently and often have gaps. Therefore, most of the analysis will focus on diesel and diesel hybrid buses, since the data for these types of vehicles is more complete and reliable.

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 mileage and lower parts costs and maintenance cost per mile, compared to diesel buses. For example, current data indicate that a 40-foot diesel hybrid bus has 21.2 percent better fuel mileage compared to a 40-foot diesel bus (4.67 mpg for diesel hybrid vs. 3.85 mpg for regular diesel). In addition, 40-foot diesel hybrid buses have 63.3 percent lower parts cost per mile (\$0.123/mile for diesel hybrid vs. \$0.336/mile for diesel), and 76.0 percent lower maintenance cost per mile (\$0.196/mile for diesel hybrid vs. \$0.815/mile for diesel), compared to diesel buses. At the same time, a 40-foot hybrid bus has a 71.1 percent higher acquisition cost than a comparable diesel bus. The comparison of performance and costs of a 40-foot diesel bus and a 40-foot diesel hybrid bus is graphically illustrated in Figure 3-2.

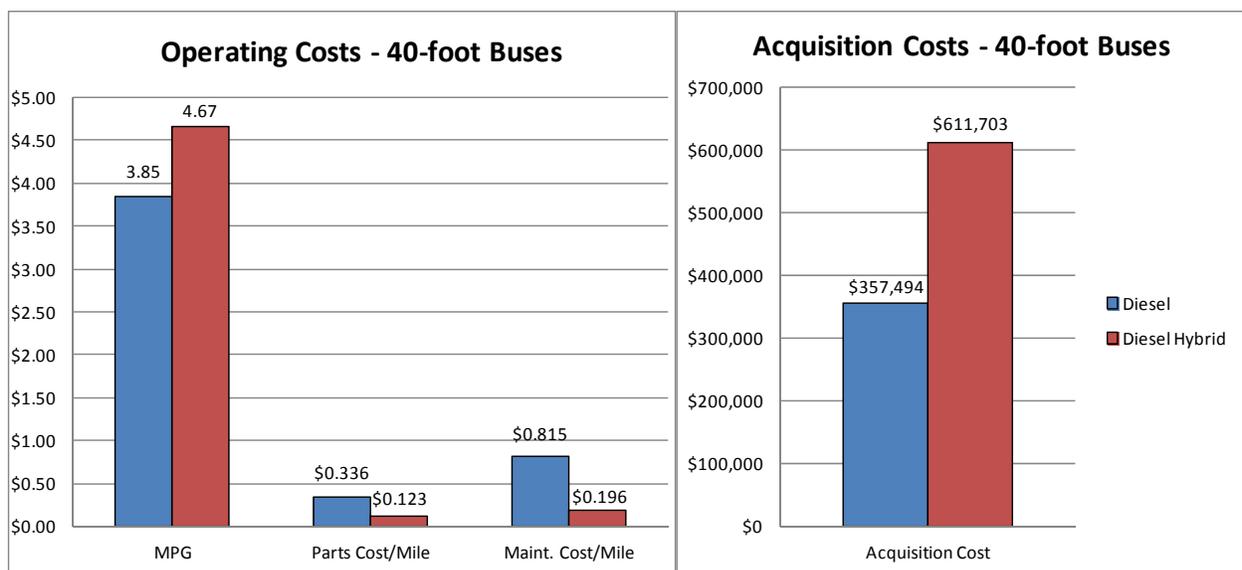


Figure 3-2. Comparison of Performance and Costs for 40-Foot Buses—Diesel vs. Hybrid

The difference in fuel mileage between diesel hybrid and diesel buses favors hybrid technology for larger articulated buses. A 60-foot articulated diesel hybrid bus has 38.5 percent better fuel mileage than a comparable diesel bus of the same size (3.75 mpg for hybrid vs. 2.71 mpg for diesel bus). However, the difference in parts costs per mile between diesel hybrid and regular diesel buses is less substantial for 60-foot buses than it is for 40-foot buses, while the difference in maintenance cost per mile is even reversed in favor of diesel. For example, 60-foot articulated hybrid buses have 58.9 percent lower parts cost per mile (compared to 63.3% for 40-foot buses) and 157.9 percent higher maintenance cost per mile (compared to 76.0% lower cost for 40-foot buses), compared to regular diesel buses.

The data indicate that the acquisition cost premium for these larger hybrid buses is 32.8 percent. A typical 60-foot diesel hybrid bus costs \$879,291 to purchase, compared to

\$662,290 for a 60-foot articulated diesel bus. The comparison between 60-foot diesel and 60-foot diesel hybrid buses is graphically demonstrated in Figure 3-3.

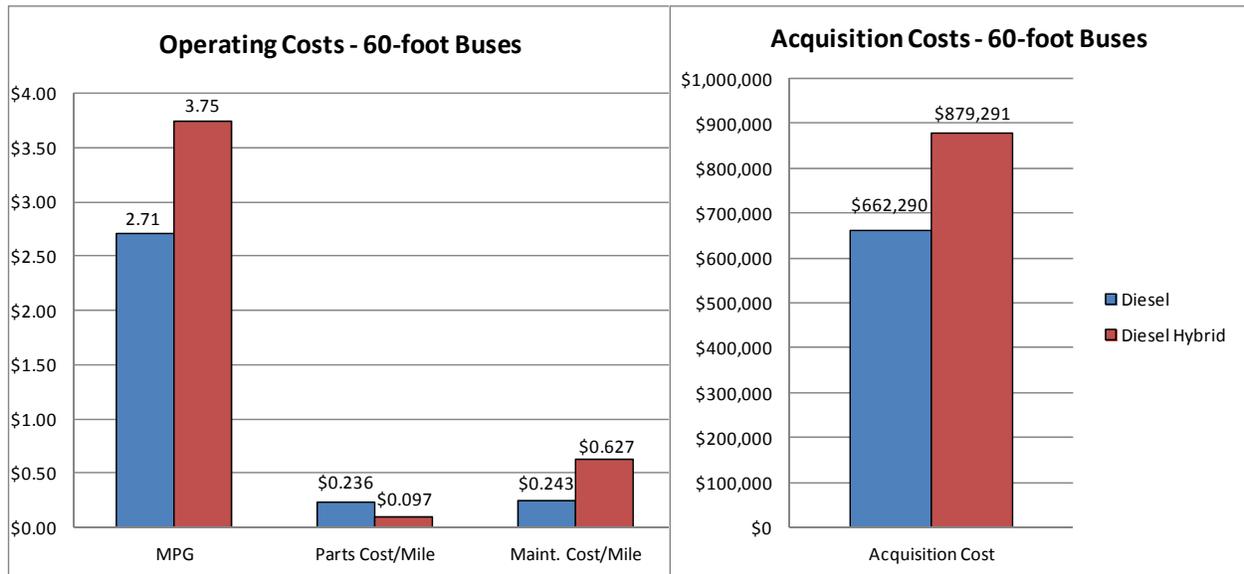


Figure 3-3. Comparison of Performance and Costs for 60-Foot Buses—Diesel vs. Hybrid

It has to be noted that in this data sample many articulated hybrid buses run Bus Rapid Transit (BRT) routes, while diesel buses are used on regular urban routes. The difference in duty cycles can be a significant factor in explaining the observed variations in fuel mileage and costs.

The difference in fuel mileage and parts/maintenance costs for hybrid buses can be attributed, at least partially, to the average age of the vehicles. In addition to being more efficient, hybrid buses are also newer buses with an average age of 2.3 years, as reported by the transit agencies. For comparison, the average age of diesel buses operated by the reporting Florida transit agencies is 7.4 years. Newer vehicles typically perform better and can cost less to operate than older vehicles.

The comparison of performance and maintenance costs between traditional diesel buses and diesel hybrid buses, at an aggregate level, is presented in Table 3-3. For proper comparison, reported vehicle acquisition costs have been adjusted to constant 2012 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	Maintenance Cost per Mile	Total Cost per Mile
Diesel	1,787	7.4	\$351,597	3.93	\$0.337	\$0.773	\$1.059
Diesel Hybrid	181	2.3	\$587,070	4.50	\$0.137	\$0.299	\$0.441
Gasoline	38			16.95			\$0.204
Gasoline Hybrid	1			3.77			\$0.880
Trolley	4	11.3		5.45	\$0.245	\$0.147	\$0.393
Total Fleet:	2,011	6.9	\$364,234	4.16	\$0.323	\$0.736	\$1.002

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

The data show that diesel hybrid buses (regardless of size) on average have 14.4 percent better fuel economy, 59.4 percent lower parts cost per mile, and 61.3 percent lower maintenance cost per mile compared to regular diesel buses. At the same time, diesel hybrid buses on average cost about 67.0 percent more to acquire than comparable diesel vehicles. The comparison between diesel and diesel hybrid buses of any size is demonstrated graphically in Figure 3-4.

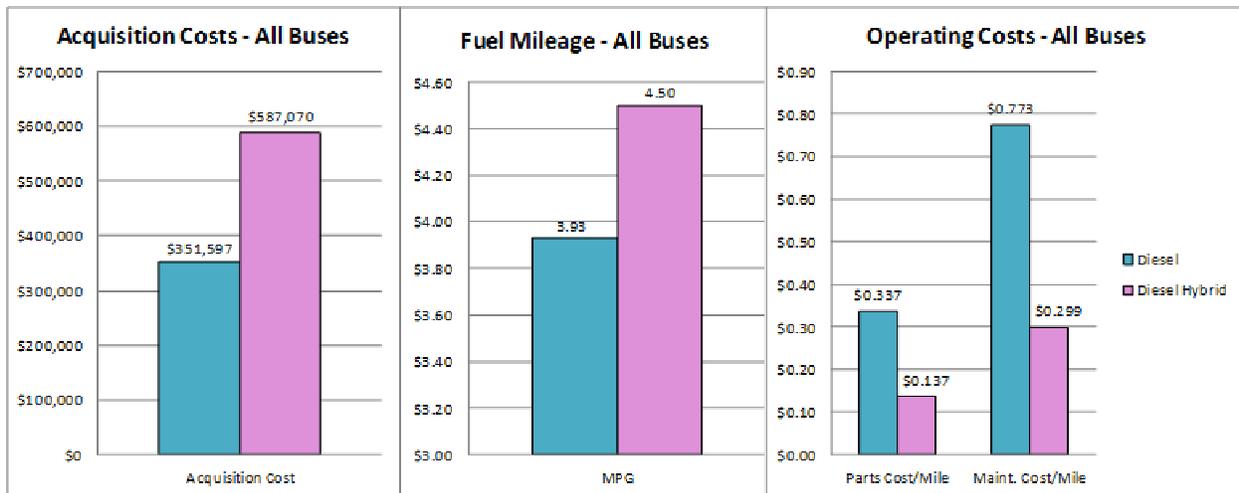


Figure 3-4. Comparison of Diesel vs. Diesel Hybrid—All Vehicle Sizes

These results, however, should be interpreted with caution since hybrid buses are much newer vehicles (with an average age of 2.3 years), and some of the cost differential could be attributed to that rather than the differences in performance of different power plants (diesel vs. hybrid). In addition, hybrid buses are often a preferred choice for BRT routes that are typically characterized by higher speeds and fewer stops. Therefore, some of the variation in performance between diesel hybrid buses and regular diesel buses can be attributed to the differences in the duty cycle rather than propulsion technology itself. Finally, the estimates for hybrid buses are based on a limited number of data points (only 181 vehicles out of 2,011 reported are diesel hybrid buses), limiting the robustness of the analysis. As more data are collected on the performance and maintenance costs of the alternative fuel transit vehicles, the reliability of the analysis will improve.

One potential flaw of the methodology used for the analysis could also include the use of 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 are significantly different. To account for the difference in mileage, the use of weighted averages for calculating MPG and costs per mile is warranted. Calculating weighted averages, rather than simple averages, will allow assigning higher weights to the calculated parameters that are 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 the 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)*	Maintenance Cost per Mile (Weighted)*	Total Cost per Mile (Weighted)*
Diesel	Unknown	102	4.43	\$0.262	\$0.081	\$0.664
	25'	5				
	29'	43	4.14	\$0.230	\$0.324	\$0.554
	30'	8				
	32'	86	3.91	\$0.480	\$1.456	\$1.937
	35'	140	4.05	\$0.212	\$0.238	\$0.449
	40'	1,373	4.52	\$0.274	\$0.744	\$0.854
	45'	12	3.28	\$0.335	\$1.393	\$1.728
	60' Artic	18	2.79	\$0.276	\$0.186	\$0.462
	Unknown	12	5.25	\$0.063	\$0.039	\$0.345
Diesel Hybrid	32'	1	5.47	\$2.045	\$4.343	\$6.388
	35'	35	4.79	\$0.121	\$0.077	\$0.198
	40'	45	4.48	\$0.139	\$0.180	\$0.323
	41'	13	4.24	\$0.092	\$1.001	\$1.092
	42'	29	4.37	\$0.103	\$0.415	\$0.518
	60' Artic	46	3.77	\$0.103	\$0.647	\$0.750
Gasoline	Unknown	38	15.66			\$0.225
Gasoline Hybrid	Unknown	1	3.77			\$0.884
Trolley	Unknown	4	5.50	\$0.215	\$0.132	\$0.347
Total Fleet:		2,011	4.49	\$0.271	\$0.721	\$0.847

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

The use of weighted averages significantly changes the results of the analysis, most notably for the 40-foot buses. The analysis reveals that, when accounting for the mileage driven, 40-foot hybrid buses have slightly (0.8%) *lower* fuel mileage than comparable diesel buses (4.48 mpg for diesel hybrid vs. 4.52 mpg for regular diesel). The weighted average analysis indicates that 40-foot hybrid buses do have lower costs per mile compared to diesel buses

of the same size (\$0.139 parts cost per mile for hybrid bus vs. \$0.274 parts cost per mile for diesel, and \$0.180 maintenance cost per mile for hybrid vs. \$0.744 maintenance cost per mile for diesel). However, the differential in cost efficiency between hybrid and diesel power plants is lower when miles driven are taken into account (i.e., when weighted averages are used). When weighted averages are used, 40-foot hybrid buses have 49.5 percent lower parts cost per mile than similar diesel buses (compared to 63.3 percent, when simple averages are used), and 75.8 percent lower maintenance cost per mile than diesel buses of the same size (compared to 76.0 percent when simple averages are used). The comparison between 40-foot diesel buses and diesel hybrid buses of the same size, using weighted averages to calculate fuel mileage and costs per mile, is demonstrated graphically in Figure 3-5.

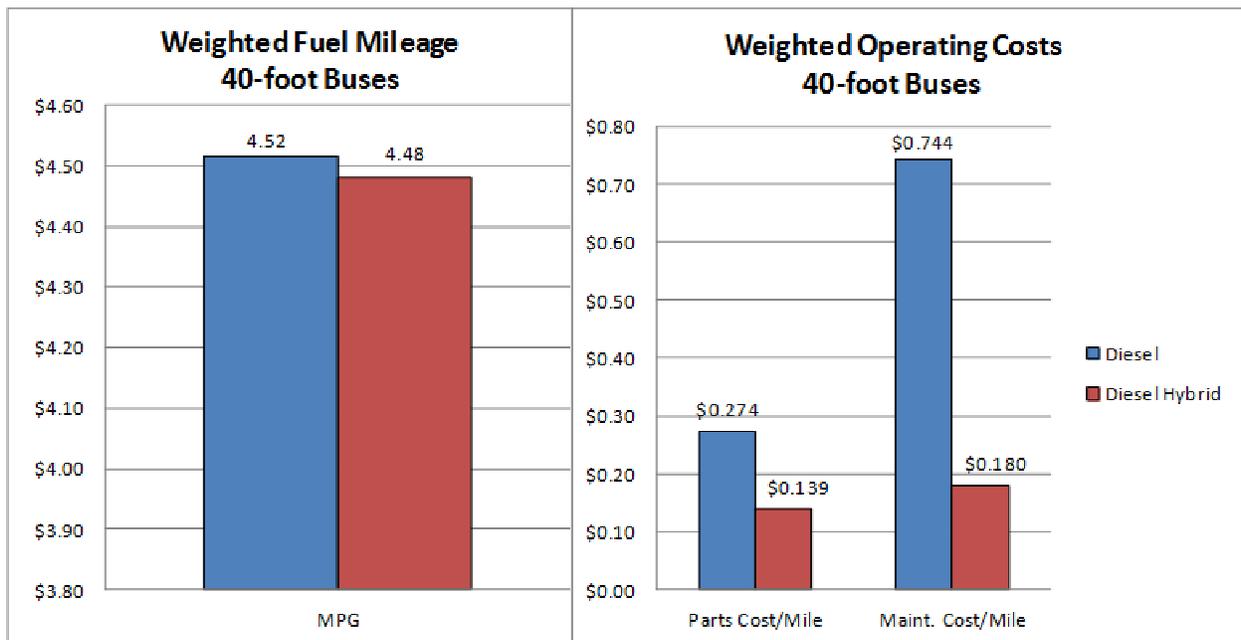


Figure 3-5. Weighted Cost and Performance Comparison for 40-Foot Buses—Diesel vs. Hybrid

The data indicate that hybrid buses of other sizes (other than 40-foot) perform better in comparison with diesel buses. For example, 35-foot diesel hybrid buses have 18.3 percent better fuel mileage, 43.0 percent lower parts cost per mile, and 67.6 percent lower maintenance cost per mile compared to diesel buses of the same size, accounting for mileage driven. However, since 40-foot buses are the most numerous buses in the reported data, the aggregate analysis provides similar results as the analysis of the 40-foot buses. Table 3-5 presents 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)*	Maintenance Cost per Mile (Weighted)*	Total Cost per Mile (Weighted)*
Diesel	1,787	4.48	\$0.277	\$0.744	\$0.867
Diesel Hybrid	181	4.49	\$0.125	\$0.311	\$0.440
Gasoline	38	15.66			\$0.225
Gasoline Hybrid	1	3.77			\$0.884
Trolley	4	5.50	\$0.215	\$0.132	\$0.347
Total Fleet:	2,011	4.49	\$0.271	\$0.721	\$0.847

*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, in general, have comparable fuel mileage with diesel buses (4.49 mpg for diesel hybrid vs. 4.48 mpg for diesel). Hybrid buses also have 54.9 percent lower parts cost per mile and 58.2 percent lower maintenance cost per mile compared to diesel buses. Aggregate comparison between diesel and diesel hybrid buses regardless of vehicle size, using weighted parameters, is demonstrated graphically in Figure 3-6.

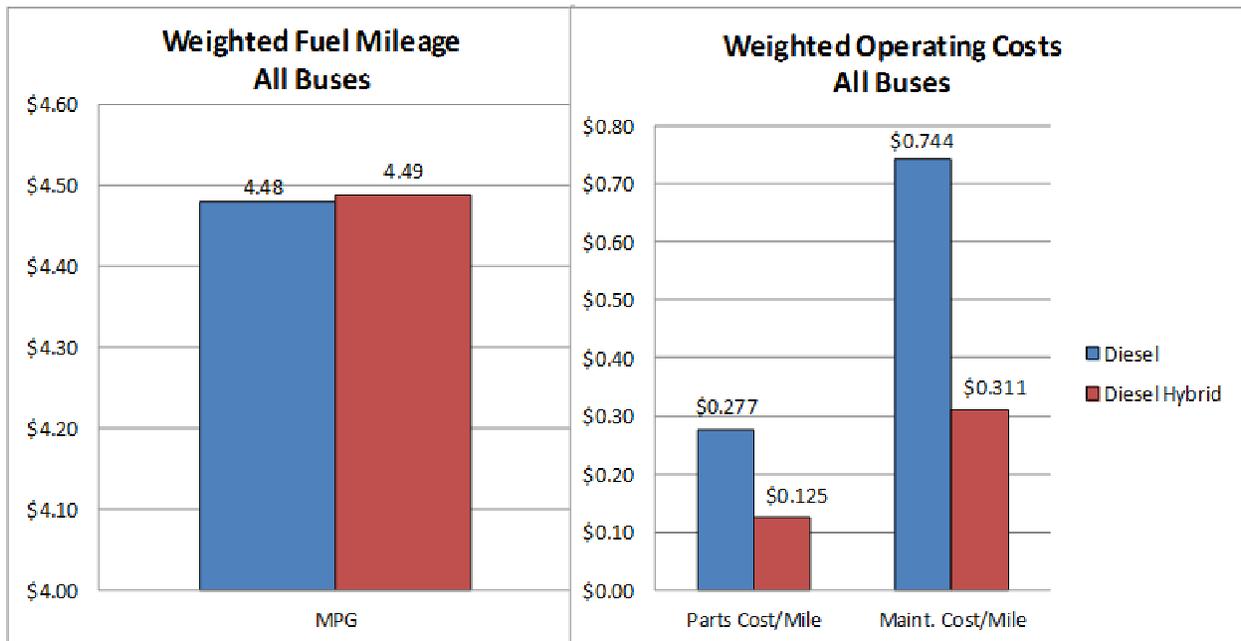


Figure 3-6. Weighted Comparison: Diesel vs. Diesel Hybrid—Buses of All Sizes

The observed results do not necessarily mean that a diesel hybrid power plant performs the same as or worse than a regular diesel. Instead, it may indicate that a relatively small number of hybrid buses in the dataset are earlier-generation hybrids 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. These two factors combined may result in a reduced difference between the (weighted) average fuel efficiency of a typical hybrid bus and a typical diesel bus, when accounting for mileage driven. As newer, more efficient hybrid buses are driven more miles and the number of later-generation hybrids in the dataset increases, the average fuel efficiency of the hybrid buses will improve.

Paratransit Buses

Table 3-6 presents aggregate comparison of the performance and costs of paratransit vehicles with different power plants. Vehicle acquisition costs have been adjusted to constant 2012 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	Maintenance Cost per Mile	Total Cost per Mile
Unknown	38	5.4		8.84	\$0.106	\$0.052	\$0.158
Diesel	38			8.82			\$0.369
Gasoline	19	2.6	\$80,346	6.57	\$0.186	\$0.264	\$0.456
Total Fleet:	95	4.5	\$80,346	8.38	\$0.130	\$0.118	\$0.302

There are no alternative fuel vehicles in the reported paratransit fleet. The data show that 40.0 percent of the demand response fleet consists of diesel vehicles, while 20.0 percent are gasoline-powered vehicles. In addition, the power plant of another 40.0 percent of the fleet is not known (i.e., was not reported).

The existing data indicate that diesel paratransit vehicles perform better than gasoline vehicles, both in terms of fuel mileage and total cost per mile. The analysis shows that diesel-powered vehicles get 34.2 percent better fuel mileage (8.82 mpg for diesel vs. 6.57 mpg for gasoline) and 19.1 percent lower total cost per mile (\$0.369 per mile for diesel vs. \$0.456 per mile for gasoline), compared to gasoline-powered vehicles. Using weighted average calculations to account for miles driven does not significantly impact the comparison between diesel and gasoline power plants of the demand response fleet. When accounting for miles driven, diesel-powered paratransit vehicles are still 33.5 percent more fuel-efficient (8.80 mpg for diesel vehicles vs. 6.59 mpg for gasoline) and have 16.9 percent better cost efficiency (\$0.370 total cost per mile for diesel vehicles vs. \$0.445 total cost per mile for gasoline).

The comparison of performance and costs between diesel and gasoline-powered paratransit vehicles is demonstrated graphically in Figure 3-7.

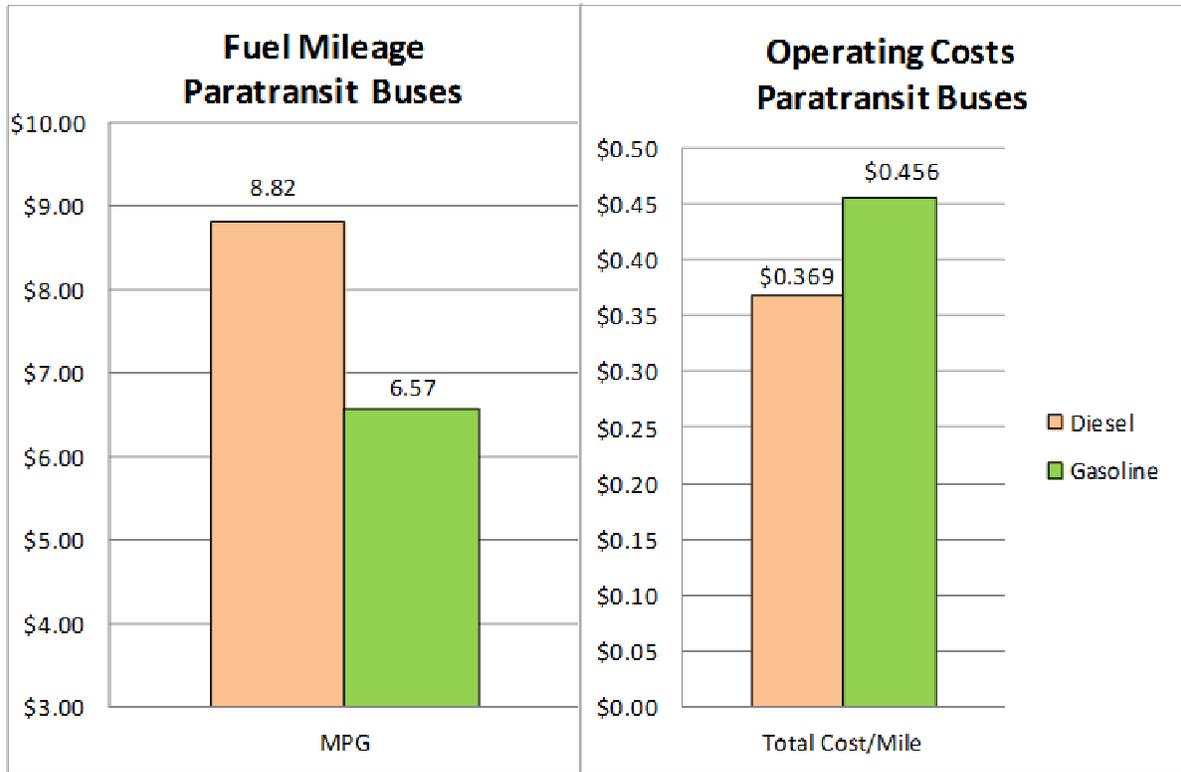


Figure 3-7. Comparison of Paratransit Vehicles—Diesel vs. Gasoline Power Plants

Table 3-7 presents a more detailed performance and cost comparison of the paratransit fleet by vehicle size (when available). 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 2012 dollars.

Table 3-7. Cost and Performance Comparison of Paratransit Fleet by Vehicle Size

Power Plant	Length	Number of Buses	Average Age (Years)	Average Acquisition Cost	Fuel Mileage (MPG)	Parts Cost per Mile	Maintenance Cost per Mile	Total Cost per Mile
Unknown	Unknown	31	5.5		8.81	\$0.101	\$0.053	\$0.154
	25'	7	4.6		9.00	\$0.126	\$0.048	\$0.175
Diesel	Unknown	38			8.82			\$0.369
Gasoline	Unknown	2			6.52			\$0.510
	25'	17	2.6	\$80,346	6.58	\$0.186	\$0.264	\$0.449
Total Fleet:		95	4.5	\$80,346	8.38	\$0.130	\$0.118	\$0.302

Due to the limited amount of data reported, as well as the large “unknown” category of vehicles’ power plant and size, little meaningful comparison could be performed for the

demand response vehicles. As more paratransit data become available, the level of detail of the analysis will improve.

Chapter 4

Maintenance Facility Modifications

Alternative fuel transit vehicles often require maintenance procedures that are not typical for vehicles running on traditional fuels. The introduction of alternative fuel vehicles to Florida transit fleets may require certain modifications to transit agencies' maintenance facilities in order to address additional safety requirements associated with alternative fuels. Whenever possible, transit agencies should try to modify the existing maintenance facility that could be shared with traditional-fueled vehicles, rather than build new facilities exclusively for maintaining alternative fuel vehicles. These modifications can vary significantly, from minor to extensive, depending on the type of fuel used and the specific circumstances of an individual agency.

In addition, many transit agencies typically have their own fueling facility on site. Building a dedicated fueling facility represents an additional capital cost to the transit agencies operating alternative fuel vehicles in their fleets.

The following section will discuss the common fleet maintenance requirements for different alternative fuels and will present rough cost estimates for modifying transit agencies' service and maintenance facilities. This effort is the continuation of similar research conducted under the previous NCTR project (FDOT BDK85 977-18). The estimates presented in the current section are mostly drawn from the previous NCTR research, with some recent updates where newer data were available.

Guidelines for Maintenance Facility Modifications¹

Vehicle maintenance facilities, regardless of fuel type used, are covered by a number of national and international codes. Here is the list of the existing codes that regulate maintenance facilities:

- International Code Council's International Fire Code (IFC 2012)
- International Mechanical Code (IMC 2012)
- International Building Code (IBC 2012)
- National Fire Protection Association's NFPA 30A (2012) Code for Motor Fuel Dispensing Facilities and Repair Garages
- NFPA 52 (2010) Vehicular Gaseous Fuel Systems Code
- NFPA 88A (2007) Standards for Parking Structures

¹ Douglas B. Horne, P.E., "Guideline for Determining the Modifications Required for Adding Compressed Natural Gas and Liquefied Natural Gas Vehicles to Existing Maintenance Facilities," Clean Vehicle Education Foundation (August 31, 2012).

Most of this section of the report dealing with facility modifications relating to CNG and LNG has been taken directly from this document.

These codes deal with traditional liquid fuels as well as provide guidance on handling alternative fuels. In addition to these codes, the local authorities can also impose additional requirements beyond the national codes. The existing codes were written as performance requirements, rather than design standards. Consequently, the actual standards for maintenance facilities servicing alternative fuel vehicles are often set by the local authority interpreting the codes. Such interpretations are not always consistent across local jurisdictions. Therefore, it is prudent for agencies to consult the local authority that has jurisdiction prior to final facility design and modifications.

This section discusses code requirements and standards for major maintenance facilities operating compressed natural gas (CNG) and liquefied natural gas (LNG) vehicles. It is important to note that the requirements are very different for major and minor repair facilities. In addition, the requirements for maintenance facilities handling CNG vehicles depend on whether odorized or non-odorized CNG is used.

There are seven main areas covered by the national codes for liquid and gaseous fuels that apply to CNG and LNG: general ventilation, ventilation of pits or basement, gas detection, heating equipment, electrical classification, vehicle preparation for entering repair garage, and decommissioning of fuel containers. Table 4-1 lists the main codes that apply to maintenance facilities, by category.

Table 4-1. National Codes for Maintenance Facilities

Category Covered by Code	Code Reference
General Ventilation	IMC (2012) Table 403.3; NFPA 88A (2007) 5.3.2; IFC (2009) 2211.7.1, 2211.1.1, 2211.7.1.2; NFPA 30A (2012) 7.5.1, 7.5.2, 7.5.3, 7.5.4, 7.4.7.2, 7.4.7.3
Ventilation in Pits	IFC (2009) 2211.3; NFPA 30A 7.4.5.4
Gas Detection	IFC (2009) 2211.7.2, 2211.7.2.1, 2211.7.2.2, 2211.7.2.3; NFPA 30A (2012) 7.4.7, 7.4.7.1, 7.4.7.2, 7.4.7.3, 7.4.7.4
Sources of Ignition	NFPA 30A (2012) 7.6.6
Electrical Classification	NFPA 30A (2012) 8.2.1
Preparation of Vehicles for Maintenance	IFC (2009) 2211.5
Maintenance and Decommissioning of Containers	NFPA 52 (2010) 6.13, 6.14

The above codes apply only to major repair facilities. Both national and international fire codes (NFPA 30A and IFC) exempt minor repair facilities from all of the code requirements specific to CNG and LNG. Agencies may be able to realize significant savings in the cost of maintenance facility modifications if the facility can be divided into separately designated areas for minor and major repairs. The codes provide some guidance for separating major and minor repair areas within a facility, including the following requirements:

- Interior walls separating major and minor repair areas should have a two-hour fire rating and be continuous from floor to ceiling.

-
- Major repair areas shall have at least one exterior wall, and primary access shall be from the outside through the exterior wall.
 - Interior access between major and minor repair areas shall be through self-closing fire doors with the appropriate rating for the location, as approved by the local authority.
 - Major and minor repair areas shall have separate ventilation systems.

If the major and minor repair areas cannot be separated, the entire maintenance facility should be modified to comply with the requirements established for major repairs of CNG and/or LNG vehicles.

IFC 2211.7 classifies repairs involving work on the vehicle fuel system, the use of open flames or welding as major repair activities, and requires appropriate modifications. All other repairs are considered minor and are exempt from the specific code requirements for CNG and LNG. NFPA 30A defines major repair activities as work involving engine overhauls, painting, body and fender work, and any repairs requiring draining vehicle fuel tanks. The maintenance work that can be done without any modification to the facilities includes lubrication, inspection, engine tune-ups, replacement of parts, fluid changes, brake system repairs, tire rotation, and other routine maintenance work as these activities are considered minor repair activities and are exempt from the specific code requirements for CNG and LNG.

Before considering modifications for CNG and LNG, it may be helpful to verify that the maintenance garage meets the existing code requirements for liquid fuels. NFPA 88A 5.3.2 requires a ventilation rate of one cubic foot per minute per square foot (cfm/ft²) of floor area for enclosed parking garages housing liquid and gaseous-fueled vehicles. Based on this requirement, the base rate of ventilation for all repair garages, both major and minor, should be at least one cfm/ft². Ventilation rates required for CNG or LNG maintenance facilities would simply increase this base rate. Additionally, while not required by the codes, consideration should be given to configuring exhaust ports of the ventilation system to the highest points of exterior walls or the roof.

Requirements for (Odorized) CNG

The code requirements address the hazards of CNG by setting performance criteria to reduce the presence of flammable mixture and/or eliminate potential source of ignition. The following requirements apply to maintenance facilities that handle vehicles with properly odorized CNG. The requirements for un-odorized CNG are equivalent to LNG vehicles/facilities and are discussed later.

Ventilation

NFPA 30A has no requirements for ventilation rates specifically for CNG garages. The same ventilation requirements that exist for liquid fuels also apply to CNG. The IFC has a specific requirement for continuous mechanical ventilation of CNG major repair facilities of five air exchanges per hour. When natural ventilation is used, an exception to this requirement may be granted by the local authority. Operation of the mechanical ventilation must be continuous, with possible exceptions when (1) the ventilation system is interlocked with and

controlled by a continuously operating natural gas detection system, or (2) the ventilation system is electrically interlocked with the lighting circuit for the garage.

Converting the base ventilation rate of one cfm/ft² of floor area, required for liquid fuel garages, to air exchanges per hour results in the expression: 60/room height in feet. Therefore, for a garage with a ceiling height of 12 feet, the base ventilation rate of one cfm/ft² equals five air exchanges per hour, as required for CNG facilities. For a ceiling height of 24 feet, the base ventilation rate would have to be increased to two cfm/ft² to maintain the required rate of five air exchanges per hour.

While NFPA 7.5.1–7.5.4 requires ventilation only for fuel dispensing areas within the maintenance facility, IFC 2211.7.1–2211.7.1.2 requires ventilation for all CNG repair facilities assuming that indoor fueling will always be part of a repair facility.

Ventilation in Pits

Ventilation of pits, below grade and subfloor work areas, is part of the basic requirements for regular liquid fuels. IFC requires the ventilation rate of 1.5 cfm/ft² while NFPA requires 1 cfm/ft² for these areas. The exact rate can be specified by the local authority (e.g., fire marshal). This requirement should already be met by an existing maintenance garage. There are no additional code requirements for adding CNG maintenance to major repair facilities.

Gas Detection

There are no requirements for a natural gas detection system for major maintenance garages that add CNG maintenance operations, as long as CNG is odorized. Although not required by code, some repair facilities may choose to install a gas detection system to enhance the efficiency of the ventilation system. If the garage decides to implement a natural gas detection system, the following guidelines are recommended:

- The gas detection system should be listed in accordance with UL 2075 or approved by the local authority (e.g., fire marshal).
- The system shall activate at 25 percent of the lower flammability limit.
- Upon activation, the natural gas detection system shall:
 - Activate the mechanical ventilation system
 - Deactivate tall heating systems located in the major repair facility
 - Initiate a distinct audible and visual alarm in the garage
- When the natural gas detection system fails, it shall:
 - Activate the mechanical ventilation system
 - Deactivate tall heating systems located in the major repair facility
 - Initiate a distinct audible and visual alarm in the garage

Sources of Ignition

IFC, IBC, IMC, and NFPA 70 all provide requirements for liquid fuels restricting potential ignition sources from the space within 18 inches from the floor. This requirement should already be met by the existing maintenance facility, regardless of the type of fuel. NFPA 30 has additional requirements for CNG vehicles major repair garages. The requirements include restricting open flame heaters and any heating equipment with exposed surfaces

with temperatures above 750 degrees Fahrenheit from any areas with a potential ignitable concentration of natural gas. The conservative approach would be to completely eliminate heating equipment of that type from any area of a major repair garage.

Electrical Classification

NFPA 30A requires that the space within 18 inches of the ceiling of a major CNG garage be classified as a Class 1, Division 2 location. As a result, all electrical equipment within that area must be suitable for that classification, as provided in NFPA 70, National Electrical Code. The code provides an exception from these requirements to facilities that have a ventilation rate of at least four air exchanges per hour. The design of the ceiling support structure should be considered when determining whether the proper ventilation rate could be achieved in the area directly below the ceiling. If the classified location cannot be easily eliminated by ventilation, the options may include either modifying electrical installations to meet Class 1, Division 2 requirements, or moving electrical equipment lower than 18 inches from the ceiling.

Preparation of CNG Vehicles for Maintenance

IFC is the only code that has requirements for preparing CNG vehicles for maintenance. When a CNG vehicle enters the repair garage, IFC requires it to valve off all its fuel storage cylinders in order to limit the amount of natural gas that could be accidentally released during maintenance procedures. Additionally, IFC requires that in the event of any suspected damage to the CNG fuel system, the entire system should be inspected and checked for leaks prior to bringing the vehicle in the repair garage.

Maintenance and Decommissioning of Fuel Containers

NFPA 52 requires that repair facilities have specific written procedures for inspection and decommissioning CNG cylinders. The code also requires that each repair garage install a proper defueling facility that complies with the requirements of the code and is approved by the local regulating authority. Consideration should also be given to adding a natural gas recovery system to reduce the amount of natural gas that is released into the atmosphere.

Requirements for LNG and Un-odorized CNG

Major repair garages that perform maintenance on vehicles using LNG or un-odorized CNG have additional requirements above those for odorized CNG. Proper ventilation of pits and a continuously operated gas detection system are required for these types of maintenance facilities. These and other requirements are discussed in more detail below.

Ventilation

NFPA 30A has no specific requirements for ventilation rates for LNG major repair garages, but does require that the natural gas detection system be interlocked with the ventilation system. The same ventilation requirements that exist for liquid fuels (ventilation rate of one cfm/ft²) also apply to LNG. The existing maintenance garage should already comply with this requirement.

The IFC has a specific requirement for continuous mechanical ventilation of LNG major repair facilities of five air exchanges per hour. When natural ventilation is used, an exception from this requirement may be granted by the local authority. Operation of the

mechanical ventilation must be continuous, except when (1) the ventilation system is interlocked with and controlled by a continuously operating natural gas detection system, or (2) the ventilation system is electrically interlocked with the lighting circuit for the garage. Agencies need to evaluate which ventilation option will be most suitable for their LNG maintenance facility based on the size and geometry of the garage.

Ventilation in Pits

Ventilation of pits, below grade and subfloor work areas, is part of the basic requirements for regular liquid fuels. IFC requires the ventilation rate of 1.5 cfm/ft² while NFPA requires 1 cfm/ft² for these areas. This requirement should already be met by an existing maintenance garage and should be maintained for LNG. There are no additional code requirements for major repair garages that add LNG maintenance. While LNG vapor is heavier than air at temperatures below -160 degrees Fahrenheit, once leaked it quickly warms up and dissipates similar to CNG.

Gas Detection

Major repair garages that add LNG or un-odorized CNG to their maintenance operations must install proper natural gas detection systems. When designing the natural gas detection system, the following requirements should be considered:

- The gas detection system should be listed in accordance with UL 2075 or approved by the local authority (e.g., fire marshal).
- The system shall activate at 25 percent of the lower flammability limit.
- Upon activation, the natural gas detection system shall:
 - Activate the mechanical ventilation system
 - Deactivate tall heating systems located in the major repair facility
 - Initiate a distinct audible and visual alarm in the garage
- When the natural gas detection system fails, it shall:
 - Activate the mechanical ventilation system
 - Deactivate tall heating systems located in the major repair facility
 - Initiate a distinct audible and visual alarm in the garage

Sources of Ignition

Both IFC and NFPA 30A provide a number of requirements addressing sources of ignition for liquid fuels. These requirements should already be met by the existing maintenance facility, regardless of the type of fuel. NFPA 30 has additional requirements for LNG vehicle major repair garages. The requirements include restricting open flame heaters and any heating equipment with exposed surfaces with temperatures above 750 degrees Fahrenheit from any areas with a potential ignitable concentration of natural gas (modeling natural gas release scenarios may be needed to identify those areas within a facility). The conservative approach would be to completely eliminate heating equipment of that type from any area of a major repair garage

Electrical Classification

NFPA 30A requires that the space within 18 inches of the ceiling of a major CNG garage be classified as a Class 1, Division 2 location. Technically, LNG is not included in this requirement, but it is expected that local authorities (e.g., fire marshal) will apply this

requirement to an LNG facility as well. As a result, all electrical equipment within 18 inches of the ceiling must be suitable for that classification, as provided in NFPA 70, National Electrical Code. The code provides an exception from these requirements to facilities that have a ventilation rate of at least four air exchanges per hour.

The design of the ceiling support structure should be considered when determining whether the proper ventilation rate could be achieved in the area directly below the ceiling. If the classified location cannot be easily eliminated by ventilation, the options may include either modifying electrical installations to meet Class 1, Division 2 requirements, or moving electrical equipment lower than 18 inches from the ceiling.

Preparation of LNG Vehicles for Maintenance

IFC is the only code that has requirements for preparing vehicles for maintenance. The maintenance preparation procedures for LNG vehicles include (1) operating the LNG vehicle to reduce the pressure in the on-board LNG tank to extend the time before the pressure relief valve would potentially need to open in the event of accidental release, and (2) limiting the quantity of natural gas that could be accidentally released by valving off all fuel storage tanks on the vehicle once it enters the repair garage. Additionally, IFC also requires that in the event of any suspected damage to the LNG fuel system, the entire system should be inspected and checked for leaks prior to the vehicle entering the repair garage.

Maintenance and Decommissioning of Fuel Containers

NFPA 52 requires that repair facilities have specific written records of inspection and maintenance of LNG tanks. The code also requires that each repair garage install a proper defueling facility that complies with the requirements of the code and is approved by the local regulating authority. Consideration should also be given to adding a natural gas recovery system to reduce the amount of natural gas that is released into the atmosphere.

Costs of Facility Modifications

The data on the additional capital cost required for upgrading maintenance facilities to accommodate alternative fuel transit vehicles are limited and often dated, but can still provide ballpark numbers for the expected costs of the facilities' conversion. Since the cost estimates provided in this section are generalized, and are typically based on historic costs encountered by other transit agencies, they should be treated accordingly and interpreted with caution.

Battery Electric Vehicles

The main considerations in alternative fuel vehicle maintenance, when compared to regular diesel buses, are related to handling batteries and high-voltage electrical cables in battery-electric and hybrid-electric buses. The regular fire protection construction standards for vehicle storage, motor fuel dispensing facilities, and repair garages (National Fire Protection Association codes: 88A, 30A) are applicable to the battery-electric and hybrid-electric bus

maintenance facilities. In addition, it is recommended that the garage conform to the requirements of NFPA 70 regarding the safe installation and handling of high-voltage electrical wiring and equipment.²

Battery storage and charging locations should be well ventilated to ensure that gasses emitting from the battery cells during charging are quickly evacuated from the building. Battery storage racks should be grounded to eliminate the possibility of a short in the circuit. It is also recommended to install smoke and heat detectors near the charging locations that would trigger an automatic shut-off of a charging unit if the temperature exceeds a maximum safe limit. The agencies performing maintenance on battery-electric and hybrid-electric transit vehicles would need to upgrade their facilities' fire detection and suppression systems to be compatible with electric fires. This is especially relevant for the systems installed near battery charging stations in the maintenance facility.³

Biodiesel

Since biodiesel is simply diesel fuel produced from biological sources (soybeans, vegetable oils, animal fats, etc.), no modifications to maintenance facilities are necessary to accommodate biodiesel-transit vehicles.

Compressed Natural Gas (CNG)

Transit agencies that operate CNG buses in their fleet typically need to modify their maintenance facility to include proper ventilation, gas leak detection, and fire suppression systems. Ventilation rates in the CNG maintenance facility should be high enough to disperse potential gas leaks, and should generally be at least equal to five air exchanges per hour. It is also recommended to design the system in such a way that the ventilation rate would increase upon detection of a leak.⁴ Since natural gas is lighter than air, it will tend to accumulate below the ceiling in case of a leak; therefore, roof ventilators are recommended.

Estimating the costs of modifying maintenance facilities is complicated since there are no generally accepted codes and building standards for CNG garages.⁵ The modifications may vary substantially depending on the size of the fleet, individual needs, and other characteristics of the agency. For example, SunLine Transit (Thousand Palms, CA) reported spending \$320,000 for modifying their facilities to accommodate CNG buses, while Los Angeles Metropolitan Transit Authority (Los Angeles, CA) spent about \$1 million for that purpose. According to the FTA, in 1998, the average cost to modify one diesel-fleet

² U.S. Department of Transportation, "Design Guidelines for Bus Transit Systems Using Electric and Hybrid Electric Propulsion as an Alternative Fuel" (FTA-MA-26-7071-03-1, March 2003).

³ Ibid.

⁴ Federal Transit Administration, "Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations" (TCRP Report 38, 1998).

⁵ Ibid.

maintenance garage for CNG buses was around \$600,000.⁶ The J.J. Taylor Distributing facility in Tampa, Florida, which recently converted their fleet to CNG, reported that the total cost to modify their maintenance facility was approximately \$60,000 (in 2012 dollars).⁷ The improvements included installing ceiling ventilation, installing a ventilation system in the service pits, positioning all electrical heating elements lower than 18 inches below the ceiling, and installing gas leak detectors that would turn off all heating elements and turn on the ventilation/air-conditioning once a leak is detected. J.J. Taylor's maintenance facility, however, consists of only two service bays. While this may be adequate for smaller fleets, larger agencies may expect higher costs to modify their maintenance facilities for CNG vehicles.

Agencies operating CNG buses generally prefer to invest in their own fueling stations, although the use of commercially available CNG facilities is also possible for smaller fleets. The costs to construct new CNG fast-fill fueling stations may vary from hundreds of thousands to millions of dollars, depending on the fueling capacity of the station. For example, Pierce Transit Authority (Lakewood, WA) spent about \$950,000 for constructing a CNG fueling facility, while New York City Transit (New York City, NY) reported an approximate cost of \$5 million (1998).⁸ FTA estimates that an average CNG fueling station for a typical 200-bus transit fleet will cost approximately \$1.7 million (1998).⁹ J.J. Taylor Distributing (Tampa, FL) reported spending about \$2.5 million (2012 dollars) to install a fast-fill fueling station, with enough capacity to support operation of a fleet of 50 tractor-trailers.¹⁰

Ethanol

Ethanol is more volatile than diesel fuel; thus the design of maintenance facilities should ensure the ventilation systems provide adequate airflow to disperse any potential gas leaks quickly and efficiently. Since ethanol vapor is heavier than air and tends to stay close to the ground, it is recommended to install classified (explosion-proof) electrical wiring at elevations lower than 18 inches above floor level in ethanol vehicle maintenance facilities.¹¹ In general, maintenance facilities' requirements for ethanol buses are similar to those of methanol vehicles.

It is estimated that modifying a typical maintenance facility for a 200-bus fleet, to address the specific requirements of ethanol vehicles, will cost on average \$300,000 (1998). In addition, modifying one fueling station to make it suitable for ethanol fueling can cost

⁶ General Accounting Office, "Use of Alternative Fuels in Transit Buses," Resources, Community, and Economic Development Division (GAO/RCED-00-18, December 1999).

⁷ J.J. Taylor Distributing, Facility Tour, Tampa, FL (February 26, 2013).

⁸ General Accounting Office, "Use of Alternative Fuels."

⁹ Ibid.

¹⁰ J.J. Taylor Distributing, Facility Tour.

¹¹ Federal Transit Administration, "Guidebook for Evaluating."

approximately \$400,000 (1998).¹² A later assessment, however, estimates a much lower cost. The National Renewable Energy Laboratory (NREL) surveyed the existing gas stations that implemented ethanol conversions and estimated an average cost for converting the tank to accommodate E-85 to be approximately \$21,000.¹³ As with other fuel types, costs may vary significantly depending on the desired capacity of the facility and the individual circumstances of transit agencies.

Hybrid-Electric Vehicles

Maintenance of hybrid-electric buses involves changing batteries approximately every three years. Transit agencies operating such vehicles may need to upgrade their maintenance facilities with lifts and cranes to handle the replacement of battery packs. In addition, the older lead acid batteries must be reconditioned every few months. For example, New York City Transit reported reconditioning the batteries of their hybrid buses every six months.¹⁴ The charging/conditioning equipment can cost up to \$50,000 to purchase.¹⁵ Reconditioning, however, is only required for lead acid batteries. The newer nickel metal hydride batteries do not require reconditioning.

Battery storage and charging stations for charging several batteries at a time should be ventilated and equipped with heat and smoke detectors to prevent overheating and the buildup of dangerous gasses emitting from the battery during charging.

The upgrades to the maintenance facilities may also include additional safety equipment required for high-voltage electrical systems. Since the electrical systems of regular diesel buses are low-voltage, a typical maintenance garage may not be equipped to perform maintenance on high-voltage vehicle systems native to hybrid buses. No reliable cost estimates for implementing these modifications to the bus maintenance facilities to accommodate hybrid electric buses could be found in the literature.

Hybrid buses use the same fueling infrastructure as regular diesel buses; thus no fueling facility modifications are needed.

Hydrogen Fuel Cell

While transit agencies often share existing diesel maintenance facilities with alternative fuel buses in their fleet, this setup may not be ideal for servicing hydrogen-powered buses. Many maintenance facility requirements for the hydrogen fleet will be similar to CNG buses. Upgrades to maintenance facilities will need to include gas leak sensors, explosion-proof

¹² General Accounting Office, "Use of Alternative Fuels."

¹³ National Renewable Energy Laboratory (NREL), "Cost of Adding E85 Fueling Capability to Existing Gasoline Stations: NREL Survey and Literature Search" (NREL/FS-540-42390, March 2008).

¹⁴ U.S. Department of Transportation, "Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells, Federal Transit Administration" (FTA-MA-26-7100-05-1, August 2005).

¹⁵ Ibid.

wiring, and improved ventilation of the maintenance areas. The agencies are advised to develop strategies to direct hydrogen away from potential ignition sources, eliminate the use of open flame equipment, and limit the use of hot element electrical heaters.¹⁶

Hydrogen is much lighter than air and tends to rise in the case of a leak and stay close to the ceiling. Ventilation strategies should take that property into account, providing for the fast evacuation of the gas below the ceiling. In general, an indoor maintenance facility used for servicing hydrogen-powered buses is recommended to have air ventilation rates in excess of six air changes per hour, higher than what would normally be required for a repair facility. Ideally, ventilation should be designed to direct any hydrogen leak to the outside of the building without being dispersed in the maintenance facility (e.g., use movable hoods at each bus bay during maintenance). It may also be prudent to design the facility in such a way that would allow electrical grounding of each hydrogen bus when it's parked for a long time.¹⁷

Since fuel-cell buses are still very rare, little field data are available on the costs of maintenance facilities' modifications.

Fueling facilities for fuel-cell buses will vary dramatically depending on whether hydrogen is stored on board the vehicle in a compressed state or generated by an on-board reformer from other fuels. The cost estimates for hydrogen fueling facilities vary dramatically and are usually based on a limited number of observations.

Liquefied Natural Gas (LNG)

LNG is produced by cooling natural gas to the point where it turns into a liquid state. LNG leaks are slightly different from CNG leaks. Since LNG vapor is initially colder and heavier than air, it tends to stay low (close to floor) in case of a leak, and rises only after it warms up to ambient temperature. It is recommended, therefore, to install only classified (explosion-proof) electrical wiring and equipment in all maintenance facility work areas at elevations less than 18 inches above the floor.¹⁸

Essentially the same safety requirements applicable to CNG fleets will be relevant to LNG maintenance facilities. Unlike CNG, however, there is limited data on modifying maintenance facilities to accommodate LNG buses. Therefore, the estimated costs for garage modification may not be accurate and reliable. The Transit Cooperative Research Program (TCRP) estimates that the median cost of modifying transit maintenance facilities to accommodate LNG fleets is approximately \$600,000 (1998) for a 150-200-bus garage.¹⁹

¹⁶ U.S. Department of Transportation, "Clean Air Program: Design Guidelines for Bus Transit Systems Using Hydrogen as an Alternative Fuel" (FTA-MA-26-7021-98-1, October 1998).

¹⁷ Ibid.

¹⁸ Federal Transit Administration, "Guidebook for Evaluating."

¹⁹ General Accounting Office, "Use of Alternative Fuels."

The cost of building an LNG fueling facility can vary depending on capacity desired and other circumstances. The average cost of designing and constructing an LNG fueling station is estimated to be approximately \$2.5 million, with an additional \$200,000 for the capability to fuel with both LNG and CNG (1998).²⁰

Liquefied Petroleum Gas (LPG)

The use of propane-transit vehicles requires certain modifications to existing maintenance and fueling facilities. There are specific LPG safety requirements that are not relevant to a traditional-fuel fleet. For example, propane storage and dispensing facilities must be located at a certain minimum safe distance from buildings, streets, underground tanks, etc. The upgrades to the maintenance facility should include explosion-proof wiring and electrical equipment in the areas where propane buses are maintained, flammable gas detectors to warn about dangerous concentrations of gasses (in case of a leak), a higher rate of ventilation compared to diesel garages, and other modifications. While these costs can vary substantially depending on the individual needs of the transit agency, it is estimated that the average cost of modifying a typical 200-bus maintenance facility to accommodate LPG buses is about \$300,000 (1998).²¹

While smaller transit agencies may be able to use commercially available LPG fueling stations, larger agencies typically prefer to have their own fueling facility for their fleet. An average construction cost for one propane fueling facility is approximately \$700,000 (1998).²²

Methanol

Operating methanol transit fleets may require additional capital investments in maintenance and fueling facilities. Since methanol is more volatile than diesel fuel, maintenance facilities for methanol buses should be designed to eliminate possible ignition source gases and ensure adequate ventilation of the main maintenance areas. In general, maintenance facility requirements for methanol buses are similar to those of ethanol vehicles.²³

It is estimated that modifying a typical maintenance facility for a 200-bus fleet, to address the requirements of the methanol vehicles, will cost an average of \$300,000 (1998). In addition, modifying one fueling station to make it suitable for fueling transit buses with methanol can cost approximately \$400,000 (1998).²⁴ As with other fuel types, costs may vary significantly depending on the desired capacity of the facility and the individual circumstances of transit agencies.

²⁰ Ibid.

²¹ Ibid.

²² Ibid.

²³ Federal Transit Administration, "Guidebook for Evaluating."

²⁴ General Accounting Office, "Use of Alternative Fuels."

Chapter 5 Technical Assistance to LAMTD

Task 5 of the project's scope of work states that CUTR will provide assistance to the project manager in assessing local efforts related to alternative fuels, emissions reductions, and fuel efficiency strategies that stem from transit agencies' grant requests to FDOT. During this project, CUTR evaluated the potential benefits of implementing a Computer Aided Dispatch and Automatic Vehicle Location (CAD/AVL) system at Lakeland Area Mass Transit District (LAMTD) to manage the operations of the agency's transit fleet.

The Office of Public Transportation and FDOT District One requested an assessment of a transit service development grant request made to FDOT by LAMTD to reassign funding from a previously submitted request for a "Fuel Master System–Brushless Generator" acquisition project to a new initiative to purchase and install a CAD/AVL system. The original grant award in 2008 was for \$253,750 (to be matched dollar for dollar by LAMTD, totaling \$507,500) for the brushless generator project, with an expected 5 percent fuel savings to the agency.

CUTR was asked to examine this proposed funding shift in context of the "energy economics" of LAMTD's request. The Department provided CUTR with historical information on the issue, and representatives of FDOT, LAMTD, and CUTR met in Lakeland on February 6, 2012, to discuss the project and this assessment. LAMTD provided data on the fleet, including vehicle age, mileage, and data of projected vehicle replacement.

After analyzing LAMTD's fleet and fuel use data, as well as reviewing the literature on successful CAD/AVL implementations, CUTR concluded that while it would be difficult to justify a \$500,000-dollar investment solely on the basis of a stated 5 percent reduction in fuel consumption, there were clear potential benefits to implementing the advanced bus management system. The main power of the proposed CAD/AVL implementation comes from the multitude of other potential operating efficiencies that may ultimately be realized if the system was fully exploited. The fleet reductions demonstrated in case studies throughout the country, combined with the high LAMTD bus spare ratio, indicated a potential for measurable efficiencies associated with the proposal.

While a reduction in fuel use is a likely outcome of exploiting all the features of a CAD/AVL system, a likely side benefit might be improved routing and scheduling. It has to be kept in mind, though, that the realization of fuel savings and the complementary emission reductions will be a function of how aggressively the technology is exploited to manage the system. The review of the proposal concludes that additional ability to more accurately manage the fleet, the routes, the operators, and the scheduling, enabled by implementing CAD/AVL system, could in fact result in fuel savings far exceeding the claim of 5 percent.

Finally, CUTR recommended that, if approved, the grant should include a requirement for monitoring and documenting reductions in fuel usage that resulted from implementing the system. Per request of the Department, CUTR assisted LAMTD and the FDOT district office in drafting a special consideration section of the joint participation agreement between the Department and LAMTD, developed project evaluation criteria, and suggested a monitoring

mechanism. These and other research efforts supported LAMTD's application for the Fuel Efficiency Retrofit and Systems Integration grant. LAMTD's grant application was ultimately approved by FDOT, providing more than \$500,000 to the agency to implement a CAD/AVL advanced bus management system.

Chapter 6 Challenges and Limitations

The greatest challenge in performing the analysis was related to the availability of data. Only nine of the Florida fixed-route transit agencies provided data on the performance and costs of their fleet. Consistency of reporting was also a problem. Of the nine reporting agencies, only four reported their data every quarter in 2012, with the remaining five agencies providing their data only in some quarters throughout the year.

The collected data revealed a limited number of alternative fuel vehicles in the Florida transit fleet. Of the 2011 fixed-route vehicles reported to CUTR in 2012, only 181 (or 9%) were alternative fuel vehicles. The low number of observations limits the reliability of the analysis, and should be interpreted with caution. In addition, the data also showed a lack of variety in the alternative propulsion technologies used by Florida transit agencies. The only alternative propulsion technology reported by the agencies (if at all) was diesel hybrid. Therefore, it was not possible to compare the performance between multiple alternative technologies on the market. The only comparison that could be made with the reported data was between diesel and diesel hybrid vehicles.

While the amount of data on the fixed-route fleet was more or less adequate, CUTR was unable to obtain a significant-size sample for demand-response vehicles. The data on the paratransit fleet, reported to CUTR, covered only 95 demand response vehicles. In addition, the majority of paratransit fleet data had significant gaps, which did not allow a meaningful analysis of costs. Complete and consistent data were available for only 19 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 on this project. The results of the analysis presented in this report should be treated with caution, recognizing that it is based on a limited amount of data. As more data on the performance and maintenance costs of alternative fuel vehicles, both fixed-route and demand-response, become readily available, the reliability and robustness of the analysis will improve.

Chapter 7

Conclusions and Suggestions

Despite the challenges with data availability and the low response rate from the transit agencies, CUTR was able to collect valid operating and maintenance cost data for the majority of the Florida fixed-route transit fleet. The analysis of data for fixed-route buses revealed that the vast majority of transit buses in Florida are regular diesel (89% of the reported fleet) or gasoline (2% of the reported fleet) buses, while only 9 percent are alternative fuel vehicles (mostly diesel hybrids). Over 76 percent of the diesel buses are 40-foot buses, with 35-foot and 32-foot buses representing 7.8 percent and 4.8 percent of the diesel fleet, respectively. Alternative fuel buses, on the other hand, are more likely to be larger in size than diesel buses. Articulated hybrid buses have the same share as the 40-foot hybrid buses, each representing about 25 percent of the hybrid bus fleet. Additionally, 40-foot, 41-foot, and 42-foot hybrid buses combined represent over 48 percent of all diesel hybrids.

The analysis of fixed-route data showed that alternative fuel buses have significantly higher acquisition costs and slightly better fuel mileage, compared to diesel buses. In addition, hybrid buses tend to have lower parts costs and maintenance costs per mile than comparable diesel buses. A 40-foot diesel hybrid bus has 21.1 percent better fuel economy (4.67 mpg for hybrid vs. 3.85 mpg for diesel), 63.3 percent lower parts cost per mile (\$0.123/mile for hybrid vs. \$0.336/mile for diesel), and 76.0 percent lower maintenance cost per mile (\$0.196/mile for hybrid vs. \$0.815 for diesel) compared to a regular diesel bus. At the same time, a 40-foot diesel hybrid bus costs 71.1 percent more to acquire than a comparable diesel bus.

The aggregate comparison of performance and maintenance costs of traditional diesel buses and hybrid buses, operated by Florida fixed-route agencies, revealed that hybrid buses (regardless of vehicle size) have 14.4 percent better fuel economy, a 59.4 percent lower parts cost per mile, and a 61.3 percent lower maintenance cost per mile, compared to diesel buses. However, hybrid buses on average cost 67.0 percent more than traditional diesel buses. The differential in performance can be attributed at least partially to the average age of the vehicles. An average hybrid bus in the current analysis is 2.3 years old, compared to 7.4 years for an average diesel bus. Newer buses typically perform better and cost less to operate and maintain. Additionally, unlike diesel buses, most of the hybrid buses were still under the original manufacturer's warranty, reducing possible repair costs to the agencies.

Surprising results were observed when weighted averages were used to calculate miles per gallon and cost per mile in order to account for potential differences in miles driven by different buses in the data sample. The analysis shows that when accounting for miles driven, hybrid buses of any size generally have comparable fuel mileage to diesel buses (4.49 mpg for diesel hybrid vs. 4.48 mpg for diesel). Hybrid buses also have 54.9 percent lower parts cost per mile and 58.2 percent lower maintenance cost per mile than diesel buses.

When accounting for the mileage driven, 40-foot hybrid buses show slightly lower (0.8%) fuel mileage than comparable diesel buses (4.48 mpg for diesel hybrid vs. 4.52 mpg for regular diesel). The weighted average analysis indicates that 40-foot hybrid buses do have lower costs per mile compared to diesel buses of the same size (\$0.139 parts cost per mile for hybrid bus vs. \$0.274 parts cost per mile for diesel, and \$0.180 maintenance cost per mile for hybrid vs. \$0.744 maintenance cost per mile for diesel). However, the differential in cost efficiency between hybrid and diesel power plants is lower when miles driven are taken into account (i.e., when weighted averages are used).

The observed results do not necessarily mean that a diesel hybrid power plant performs the same as or worse than regular diesel. Instead, these observations may indicate that the dataset contains a relatively small number of earlier-generation hybrids, with lower fuel efficiency, which have been in service for some time and have logged a lot of miles. In addition, the data sample also includes a large number of older, high-mileage diesel buses that perform exceptionally well.

Unlike fixed-route buses, the data for paratransit vehicles was limited, and no alternative fuel vehicles were reported in the demand response fleet. Forty percent of the demand response fleet consists of diesel vehicles, 20 percent are gasoline-powered vehicles, and the power plant of the remaining 40 percent of the paratransit fleet is not known (i.e., was not reported). The available data indicate that diesel paratransit vehicles perform better than gasoline vehicles in terms of both fuel economy and operating costs. The analysis shows that diesel-powered vehicles get 34.2 percent better fuel mileage (8.82 mpg for diesel vs. 6.57 mpg for gasoline) and 19.1 percent lower total cost per mile (\$0.369 per mile for diesel vs. \$0.456 per mile for gasoline), compared to gasoline-powered vehicles. Due to the extremely small data sample and significant gaps in the paratransit data, however, the extent of the analysis as well as the reliability of the comparison are far from optimal.

Alternative fuel vehicles often require maintenance procedures that are not typical for the vehicles running on traditional fuels and may require certain modifications to transit agencies' maintenance facilities to address additional safety requirements. These modifications typically involve improvements in their ventilation and fire suppression systems, as well as the installation of heat and smoke detectors, explosion-proof electrical wiring, and other improvements.

The review of the literature indicated that the cost of these modifications may run anywhere from \$50,000 to \$600,000 for a typical 150-200-bus garage, and is highly dependent on the type of alternative fuel and the current design of the facility. In addition, the construction of a fueling facility for alternative fuel vehicles may cost transit agencies anywhere from \$200,000 to \$2.5 million, depending on the type of fuel and the scale of operation.

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. Additionally, since the analysis

was based only on a relatively small data sample, the reliability may not be particularly high, and the results of the analysis should be treated with caution.

It is suggested to continue the efforts of collecting data from transit service providers on the performance and life cycle costs of alternative fuel vehicles. To encourage the agencies to regularly submit their data, it is recommended that such data reporting becomes a requirement under the transit agencies' grant or funding agreements with FDOT. As more field data are collected, the reliability of the analysis will improve.