2011

Houston METRO CNG Implementation Study

Matt Sandidge and John Overman

Texas Transportation Institute

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Key Findings

The following provides a summary of key findings from the study of the compressed natural gas (CNG)–fueled fleet at the Metropolitan Transit Authority of Harris County (METRO). Texas Transportation Institute (TTI) researchers conducted a literature and peer review to gain current information on the use of CNG in transit vehicles. In addition, TTI conducted a life-cycle cost analysis comparing CNG to other transit technologies. The following list provides the key findings from the report.

Transit Agency Objectives for Using CNG Vehicles

- Agencies began using CNG-fueled vehicles largely to reduce emissions. All peer agencies stated that emission reduction was the driving force behind switching to CNG.
- Agencies said a secondary objective was to benefit from a historically lower, more stable price for natural gas than diesel.
- Peer agencies did not choose CNG to lower operating costs.

Transit Agency CNG Implementation

- Peer agencies typically have a contract for fuel and are able to negotiate the CNG price based on purchase quantities.
- Peer agencies operating CNG-fueled fleets have at least one fueling station on-site. Of the seven agencies, five have at least two fueling stations or plans for two.
- Two agencies purchase liquefied natural gas (LNG) and convert it to CNG, while the remaining peer agencies purchase natural gas and compress it into CNG.
- The cost of maintenance-facility modifications to accommodate CNG vehicles is driven by the size and age of the facility.
- Agencies have multiple options in developing an arrangement for natural-gas supply and compression. These include "own and operate," "own and partially operate," "lease and operate," "lease and partially operate," and "turnkey." Three peer agencies use "own and operate," and four agencies use "own and partially operate."

Service Planning Considerations

- Modern CNG transit vehicles have a total operating range similar to that of diesel vehicles—between 350 and 450 miles between refueling.
- CNG vehicles are heavier due to the fuel tanks. In addition, CNG vehicles have reduced low-speed torque as compared to diesel vehicles. This makes CNG transit vehicles undesirable for regions with steep grades.
- When operating in freeway settings, representatives from RPTA and Foothill stated the CNG vehicles perform as well as diesel vehicles when merging onto freeways.
- CNG technology is compatible with METRO's short- and long-range plans.

Tax Credits and Incentives

- Multiple federal and state grants and credits exist for implementing a CNG bus operation.

- The most significant incentive for operating CNG transit vehicles is the $0.54 per diesel gallon equivalent (DGE) federal tax credit. This credit expires December 31, 2011; however, U.S. Congress H.R. 1380 proposes to extend this credit.

Emissions Considerations

- The 2010 emission standards on heavy-duty diesel engines make the emissions advantages of operating CNG less significant.
- The 2010 CNG engine reportedly has a 17 percent reduction in greenhouse gas (GHG) tailpipe emissions compared to the cleanest diesel engines (Science Applications International Corporation 2011).

Maintenance Considerations

- The 2010 diesel engines have higher maintenance costs than previous diesel models. This, in combination with new CNG engine technology and reduced maintenance cost, makes the maintenance costs of diesel and CNG engines comparable.

Life-Cycle Cost (LCC) Comparison

- The CNG scenarios have a lower LCC than the diesel and hybrid scenarios. The following list provides the total cost for each LCC scenario:
  - CNG 40 foot bus—$105,354,275
  - CNG 45 foot bus—$97,691,239
  - Diesel 40 foot bus—$128,440,600
  - Diesel 45 foot bus—$112,496,129
  - Hybrid 40 foot bus—$144,064,254
  - Hybrid 45 foot bus—$132,386,944
- Without the tax credit the Total LCC for the CNG scenarios would be:
    - CNG 40ft – $113,321,488 (as compared to $105,354,275)
    - CNG 45ft - $103,291,239 (as compared to $97,691,239)
- Fuel economy and the price of fuel have major impacts on the output of the LCCM. Minor adjustments made to these variables lead to significant changes in the output.
- The cost of building, maintaining, and operating a CNG fueling facility is significant; however, the price advantage of natural gas outweighs the infrastructure costs.
- Fleet size matters—infrastructure cost per vehicle is reduced for each additional vehicle.

CNG Financial Risk Assessment

- The price of CNG per DGE would need to average $2.99 for the LCCs of 40-foot CNG and diesel to break even. This would represent an increase of about 53 percent in the cost of CNG per DGE.
- The price of diesel would need to drop to $2.53 for the LCCs of 40-foot CNG and diesel break even. This represents a decrease of 31 percent in the price of diesel.
- Maintenance costs for 40-foot CNG would need to increase 58 percent to $0.76 per mile for the CNG scenario to have the same LCC as the diesel scenario. Maintenance

costs for 45-foot CNG would need to increase 74 percent to $0.75 per mile for the CNG scenario to have the same LCC as the diesel scenario.

- To implement a CNG fueling operation, the agency needs at least 10 CNG vehicles to break even with the cost of operating diesel vehicles over a 12-year vehicle life.
- When using the METRO bus purchase scenarios in the LCC, the purchase of CNG vehicles instead of diesel vehicles leads to about $92 million in savings over cumulative service lives of the vehicles (12 years for each vehicle).

1. Introduction

Purpose of the Study

The purpose of the study was to provide case study research and technical assistance to the Metropolitan Transit Authority of Harris County (METRO) in evaluating and implementing a compressed natural gas (CNG)–fueled bus fleet. The Texas Transportation Institute (TTI) completed the study in conjunction with a similar project sponsored by the Capital Metropolitan Transit Authority (Capital Metro) in Austin, Texas. This study involved three primary tasks:

- Task 1—Conduct state-of-the-practice scan, review, and peer research. The purpose of this task was to conduct a state-of-the-practice review of CNG bus-fleet and service practices using online published resources and personal contacts. The desktop scan and review identified CNG-fleet implementation experiences at transit agencies and documented the industry status of CNG use in bus fleets.
- Task 2—Estimate life-cycle cost (LCC) of a CNG fleet. The purpose of this task was to conduct an LCC analysis for a CNG bus fleet. The LCC analysis uses the spreadsheet model for estimating life-cycle costs for both hybrid and CNG buses as recommended in *Transit Cooperative Research Program (TCRP) Report 132: Assessment of Hybrid Bus Technology* (2009).
- Task 3—Assess financial planning considerations for CNG implementation. The purpose of this task was to assess strategic procurement, facility, and CNG market considerations in fuel selection.

The project was initiated with a kick-off meeting on June 14, 2011. During the kick-off meeting, METRO staff and TTI researchers confirmed the work tasks and approaches presented in the scope of services. METRO staff and TTI researchers also confirmed work task priorities and established information and data-sharing requirements. These data were the basis for conducting the LCC analysis.

Organization of Report

The report is organized into three chapters. The chapters are as follows:

- Chapter 2, "CNG State of the Practice," provides information resulting from gathering data from current and relevant literature regarding CNG transit-vehicle operation and implementation. In addition, the chapter provides the experience of seven peer agencies currently operating sizable CNG transit fleets.
- Chapter 3, "METRO Life-Cycle Cost Comparison," provides a cost comparison of the 12-year life cycle of five fleet purchase scenarios. The scenarios include CNG, diesel, and hybrid purchase scenarios.
- Chapter 4, "Financial Risks Associated with Implementing CNG," offers information on financial risks associated with implementing and operating a CNG vehicle fleet.

At the end of each chapter is a list of key findings from the research. The key findings serve as a summary of each chapter and offer guidance for the METRO staff.

2. CNG State of the Practice

This section provides a review of the CNG bus fleet state of the practice and peer research. TTI researchers conducted a literature review, and interviewed and collected data from eight transit agencies operating CNG buses. The purpose of this task was to examine current literature on CNG use and implementation in transit fleets. Additionally, this task provided information on peer transit agencies that have implemented CNG-fueled fleets, and examined the key planning factors that affect CNG implementation decisions.

The section is divided into the following subsections:

- **Methodology for Literature Review and Peer Study—**provides the TTI methodology for the literature review and peer selection, and basic details on each of the peer agencies.
- **Purpose of Using CNG—**provides an overview of the reasons agencies consider using CNG as a fuel for transit vehicles. The subsection provides reasons identified within the literature and also feedback from the peer transit agencies.
- **CNG Implementation—**provides a discussion of the different ways an agency may implement a CNG fueling operation. The subsection provides information on contracting out the CNG fueling station and on fuel purchasing.
- **CNG Service Planning—**provides the historical consideration of using transit vehicles powered by CNG. The subsection also provides information on the latest technology for CNG bus operation.
- **METRO Service Planning—** provides information on METRO current and long range transit plans. The subsection provides information on how CNG ties into METRO service plans.
- **CNG Incentives and Tax Credits—** provides information on the current state and federal incentives and tax credits available to transit agencies operating CNG vehicles.
- **Emissions Considerations—**provides a discussion of the historical emissions benefits and information on new technology and emissions standards.
- **Bus Fleet Maintenance, Safety, and Training—** provides information on the maintenance consideration related to CNG vehicles. The subsection also provides information on safety and training for a CNG fueling and bus maintenance operation.
- **Key Findings—**provides a summary of the state of the practice research conducted by TTI.

Methodology for Literature Review and Peer Study

TTI sought current resources to use in the state-of-the-practice review. TTI used a combination of available literature and information gathered from transit agencies operating CNG transit vehicles. This section provides the methodology that TTI researchers used to gather the available literature and collect information from peer transit agencies.

Literature Review

As outlined in the scope of work, TTI conducted a review of online literature. TTI used databases available from the Texas A&M University library as a means to collect the most recent studies conducted on the use of CNG in current transit operations. TTI researchers also used the Transportation Research Board's (TRB's) Transport Research International Documentation database to locate relevant literature. A main source of data originated from TRB's TCRP. The TCRP reports used for the review include *Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations* and the update to that report, *Report 146: Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements* (Science Applications International Corporation 2011). TRB developed these reports to guide transit agencies in fuel choice for fleets.

Peer Agency Selection and Data Collection

TTI researchers used a peer-selection methodology tool to identify peers for comparison. In addition, both Capital Metro and METRO identified agencies that they wanted to learn about. The peer selection tool was created by *TCRP Report 141: A Methodology for Performance Measurement and Peer Comparison in the Public Transportation Industry*. The tool compares a number of characteristics to get a likeness score to a particular agency. The method is an objective way to select peer agencies. The characteristics used for comparison include the following:

- Rail (yes or no).
- Rail only (yes or no).
- Heavy rail (yes or no).
- Urban area population.
- Total vehicle miles operated.
- Total operating budget.
- Population density.
- State capital (yes or no).
- Percentage of college students.
- Population growth rate.
- Percentage of low-income population.
- Annual delay (hours) per traveler.
- Freeway lane miles per capita.
- Percentage of service demand response.
- Percentage of service purchased.
- Distances from peer city.
- Service area type—Agencies are assigned one of eight service types, depending on the characteristics of their service (e.g., entire urban area, central city only, or commuter service into a central city).

The top 25 agencies with the highest likeness scores were then further analyzed to determine the vehicle mix. TTI researchers identified peers agencies having a minimum of 50 CNG-fueled vehicles.

TTI researchers contacted maintenance directors from each of the agencies, provided a questionnaire to each director, and talked through each question. In addition, a TTI researcher conducted a site visit with the Regional Public Transit Authority in Phoenix, Arizona, and Sun Metro in El Paso, Texas, and spent several hours discussing the CNG fueling program with agency representatives. Table 2-1 provides the agencies participating in the peer review.

Table 2-1 Peer Transit Agencies

Transit Agency	Service Area Size	Service Area Population	Fleet Size[1]	CNG Fleet	% CNG
Sun Tran	230	0.5 million	240	88	37
Omnitrans	456	1.4 million	169	166	98
Sun Metro	205	0.6 million	163	150	92
Foothill Transit	327	1.5 million	303	270	89
North County Transit District	403	0.85 million	120	90	75
Regional Public Transit Authority	732	2.5 million	172	135	78
Washington Metropolitan Area Transit Authority	692	3.3 million	1,492	461	31
Sacramento Regional Transit District	277	1.1 million	212	212	100

Source: National Transit Database 2009
1. Peer agency interview

The following subsections introduce each of the transit agencies used in the peer analysis.

City of Tucson Department of Transportation (Sun Tran). Sun Tran is the transit agency for Tucson, Arizona, and is a function of the City of Tucson. The agency provides public transportation service to an area of 230 square miles and includes a population of 544,000. Sun Tran provides local fixed-route and demand-response paratransit and park-and-ride service for the area. Sun Tran operates a fleet of 240 fixed-route transit vehicles that include 151 biodiesel, 88 CNG, and 1 hybrid diesel vehicles. Sun Tran began operating CNG transit vehicles in 1991. Sun Tran owns and operates the CNG fueling program. The City of Tucson shares the CNG fueling station with other functions of the City of Tucson. Sun Tran has not purchased new CNG vehicles since 2000; however, with the recent fluctuations in the price of diesel, the agency is considering purchasing new CNG vehicles.

Omnitrans. Omnitrans is located in San Bernardino, California, and provides bus transit service for the San Bernardino Valley in southern California. The agency provides public transportation service to an area of 456 square miles and includes a population of 1.4 million residents. Omnitrans provides local fixed-route and demand-response paratransit for the service area. Omnitrans has 169 fixed-route transit vehicles, consisting of 166 CNG and 3 hybrid-diesel vehicles. Omnitrans began operating CNG vehicles in 1997 and operates two liquid compressed natural gas (LCNG) fueling stations (it purchases LNG and converts it to CNG). Omnitrans' most recent CNG procurement included 27 2009 New Flyer 40-foot vehicles, with options for up to 90 vehicles.

City of El Paso's Mass Transit Department (Sun Metro). Sun Metro is a department of the City of El Paso and provides public transportation to the El Paso city limits. Sun Metro provides local fixed-route and demand-response paratransit for its service area. The Sun Metro service area is 205 square miles and includes a population of about 600,000. Sun Metro operates 150 fixed-route CNG vehicles and 13 LNG vehicles. Sun Metro began operating CNG vehicles in 1993. The agency began fueling using a slow-fill CNG operation. The agency now uses the LCNG method by converting LNG to CNG. Sun Metro has two fueling stations for the vehicle fleet and 78,000 gallons of LNG storage, which is replenished each day. The agency's most recent CNG vehicle procurement included a mix of 103 35-foot and 40-foot North American Bus Industries transit vehicles.

Foothill Transit. Foothill Transit is a joint-powers authority of 22 member cities in the San Gabriel and Pomona Valleys in southern California. The Foothill Transit service area encompasses 327 square miles and a population of 1.5 million. Foothill Transit operates local fixed-route bus service, bus rapid transit, and demand-response paratransit for its service area. Foothill Transit operates 277 CNG, 23 diesel, and 3 electric transit vehicles. The agency began operating CNG vehicles in 2002, and since then all procurements have been for CNG vehicles. The most recent procurement included 14 North American Bus Industries 42-foot transit vehicles.

North County Transit District (NCTD). NCTD is located in San Diego, California, and has a service area of 403 square miles. The service area includes a population of 850,000. NCTD provides local fixed-route bus service, demand-response paratransit, commuter rail, and light-rail transit service. The agency operates a mix of bus transit vehicles. The fleet mix includes 30 diesel vehicles and 90 CNG vehicles. The agency began operating 6 CNG vehicles in 1991, and in 2000, the agency began procuring only CNG vehicles. The most recent procurement included 13 New Flyer 40-foot transit vehicles.

Regional Public Transit Authority (RPTA). RPTA is located in Phoenix, Arizona, has a service area of 732 square miles, and includes a population of 2.5 million. RPTA operates local fixed-route bus service, park-and-ride commuter service, bus rapid transit, and demand-response paratransit. The agency operates a fleet of 172 fixed-route transit vehicles, consisting of 37 diesel and 135 CNG vehicles. RPTA began operating CNG in 2002. The agency has been replacing diesel vehicles with CNG vehicles. RPTA most recently purchased 37 40-foot New Flyer CNG transit vehicles.

Washington Metropolitan Area Transit Authority (WMATA). WMATA is located in Washington, D.C., has a service area of 692 square miles, and includes a population of 3.3 million. WMATA operates local fixed-route, park-and-ride, bus-rapid-transit, and demand-response paratransit bus service. In addition to bus transit, WMATA operates five heavy-rail lines within the service area. WMATA has a fixed-route bus fleet of 1,492 vehicles. The fleet consists of 602 diesel, 461 CNG, and 429 hybrid diesel vehicles. WMATA began operating CNG vehicles 2001, beginning with a fleet of 64 CNG vehicles.

Sacramento Regional Transit District (SACRT). SACRT is located in Sacramento, California, has a service area of 277 square miles, and includes a population of 1.1 million. SACRT operates local fixed-route, park-and-ride, and demand-response paratransit bus service. In addition, SACRT operates two light-rail transit (LRT) lines throughout the service area. The agency has a fixed-route fleet of 212 CNG vehicles. SACRT began operating CNG vehicles in 1993 and began replacing all existing diesel vehicles with CNG vehicles. The most recent vehicle procurement consisted of 91 40-foot Orion transit vehicles.

Purpose of Using CNG

Historical Context

Transit agencies began using CNG in the 1990s in response to the political rhetoric warning about U.S. dependence on foreign oil and to improve air quality. At the federal level, three laws encouraged these goals:

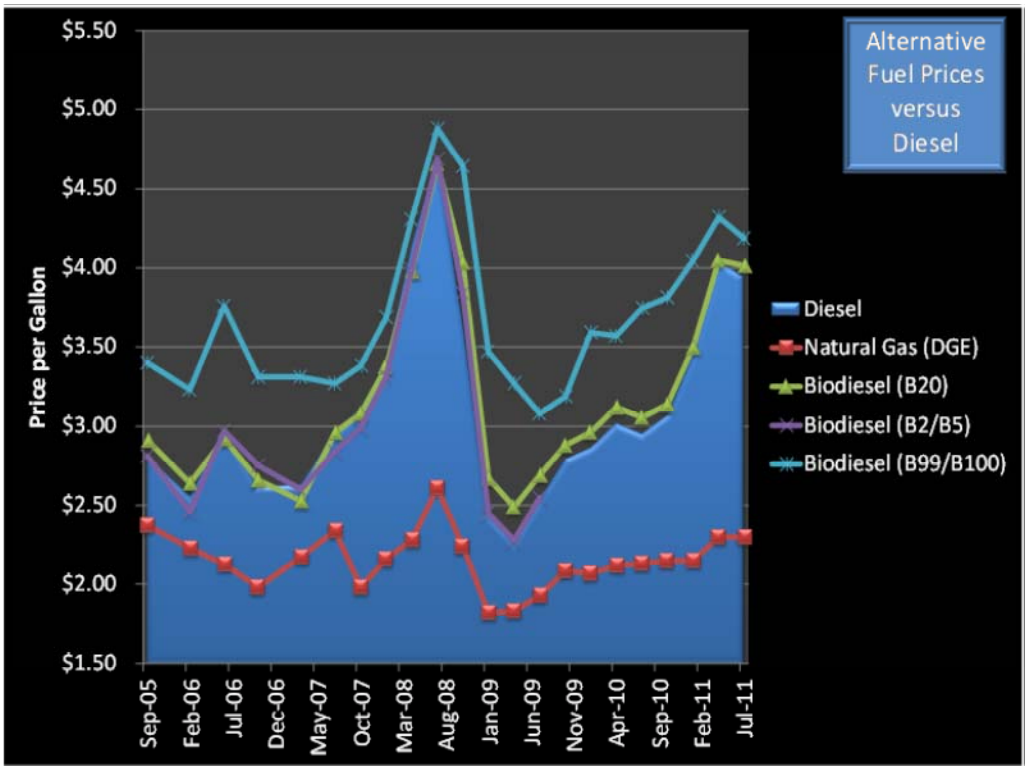
- The Clean Air Act Amendments of 1990 required cities with significant air-quality issues to use vehicles that met a specific emissions standard starting with model year 1994 buses.
- The Energy Policy Act of 1992 promoted the use of alternative-fueled vehicles to reduce the dependence on foreign oil.
- The Alternative Motor Fuels Act of 1998 encouraged the development, testing, and demonstration of alternative-fueled vehicles and included a provision for the Department of Energy to assist government agencies in testing alternative-fuel buses in urban settings (Eudy 2002).

In the 1990s, many states implemented more stringent requirements for transit agencies. In 1991, the Texas Legislature passed legislation that required 30 percent of transit-agency vehicles to be powered with cleaner technology by September 1991 (Eudy 2002). In California, the California Air Resources Board (1998) required 1996 model year or newer buses to reduce nitrogen oxide (NOx), making the emission standard for transit buses more stringent than the Environmental Protection Agency (EPA) standard (Arcadis Gerahty and Miller, Inc. 1998). By switching to using CNG-powered transit vehicles, agencies reduced NOx emissions. TTI researchers provide details on current emissions and environmental considerations more in depth in the Emissions Consideration section of this chapter.

Fuel Cost

Natural-gas retail sales are often in units of therms, where one therm is equal to 100,000 British thermal units (a traditional unit of energy). In order to compare natural-gas use to diesel use, TTI researchers refer to natural-gas volume in terms of diesel gallon equivalent (DGE).

Historically, the cost of CNG per DGE is less than diesel and is a reason many agencies have chosen to implement CNG bus fleets over diesel-fueled fleets. Clean Cities, part of the U.S. Department of Energy, produces a quarterly price report called the *Clean Cities Alternative Fuel Price Report* (U.S. Department of Energy 2011b). This report provides prices for the regional and nationwide fuel price averages for gasoline, diesel, CNG, ethanol (E85), propane, biodiesel (B20), and biodiesel (B99-B100). The latest report released was for the quarter ending in July 2011. Figure 2-1 provides the historic prices of both CNG and diesel per DGE.



Source: *Clean Cities Alternative Fuel Price Report,* July 2011

Figure 2-1 Fuel Price: Diesel versus CNG, September 2000 to July 2011

The figure displays that the price of CNG has trended lower than diesel for the past 11 years. The figure also shows that spikes in fuel prices that have occurred over the last decade are typically lower in magnitude for CNG than diesel. Since 2009, the price of CNG has been relatively stable, while diesel has trended upward.

Table 2-2 provides a summary of the price peer transit agencies are currently paying for CNG in terms of DGE. The purchase price of CNG reported by the peer agencies often includes additional fees because of various terms and conditions in the purchase contract. For example, these fees may include price adjustments to cover the maintenance and electricity costs associated with CNG delivery and fueling facilities. Additionally, not all agencies were able to provide the cost of CNG in terms of DGE. In these instances, researchers converted the reported price to DGE.

Table 2-2 Peer Agency CNG Prices

Agency	Price per DGE	Comments
Foothill Transit	$0.69 Arcadia/ $0.84 Pomona	Maintenance costs were removed
NCTD	$0.58	Commodity only
Omnitrans	Not available	Contract for fuel is hedged; could not disclose
RPTA	$1.17	Includes maintenance and electricity
SACRT	$0.80	The price includes a fee to DGS (about 0.0065%) and 0.0513 per therm to PG&E for delivery
Sun Metro	$1.83	Purchased as LNG and converted to CNG

The price per DGE has some variation between the agencies. This is a result of fuel contracts and the arrangements in which fuel is purchased. Sun Metro reported the highest fuel price, and Omnitrans reported the second highest fuel price. Both of these agencies actually purchase LNG and convert it to CNG. Therefore, the purchase price per DGE is typically dependent on the fuel source supplier and the arrangement the agency has with the supplier to purchase fuel. Fuel-purchasing arrangements are discussed in more depth in a later section of this report.

Peer Agency Objectives

The peer study identified reasons the agencies use CNG as a transit fuel. Table 2-3 provides a summary of these reasons.

Table 2-3 Peer Agency Implementation Objectives

Agency	Emission Reduction	Lower Fuel Price	Stability of Fuel Price	Lower Operating Costs	Domestic Fuel Source	Comments
Foothill Transit	X	X	X	X	X	Emissions requirement
NCTD	X					Emissions requirement
Omnitrans	X					Emissions requirement
RPTA	X	X	X	X	X	
SACRT	X	X				Emissions requirement
Sun Metro	X	X	X		X	
Sun Tran	X					

All transit agencies listed emissions reduction as a reason for implementing a CNG fueling operation. The second most reported reason is the price advantage of natural gas over diesel. Fuel price stability and the advantages of using a domestic fuel source are the third most stated reason for using CNG. The least important reason reported by transit agencies was lower operating costs. Agencies discussed that historically the maintenance costs of CNG vehicles have been higher than those on diesel vehicles, thus making operating savings on fuel negligible. A discussion of the cost of maintaining CNG vehicles versus diesel vehicles is provided the safety and maintenance considerations section of this chapter.

CNG Implementation

This section of the literature and peer review provides details on CNG implementation. Transit agencies have the option to contract out the CNG fueling operation to a third-party provider. These contract arrangements allow for flexibility in the operations and financial structure of vehicle fueling. Additionally, when implementing CNG, transit agencies usually need to make modifications to their bus maintenance facilities. This section provides:

- Discussion of the facility improvements and modifications necessary for CNG implementation.
- Information on the common contract arrangements associated with a CNG fueling operation.
- Implementation strategies and experience of peer transit agencies.

CNG Fueling Station

Transit agencies operating CNG transit vehicles must have a CNG fueling station on-site designed to accommodate the capacity of the fleet. Fueling stations have four main components:

- Gas dryer to remove moisture in the natural gas (see Figure 2-2).
- Compressors to compress the gas to a pressure of 3600-4500 pounds per square inch (psi) (see Figure 2-3).
- Buffer storage to allow compressors to remain running during the agency's fueling window (this reduces stress on compressors from constant turning off and on) (see Figure 2-4).
- Fuel dispensers to provide fuel to vehicles.

Figure 2-2 Gas Dryer at RPTA in Phoenix, Arizona

Figure 2-3 Compressing Stations

Figure 2-4 CNG Buffer Storage

Agencies have the ability to customize fueling stations to meet their fueling needs. The needs are dependent on the number of CNG vehicles to refuel, the fueling window available, and the staff available to refuel the vehicles. The fueling needs of the agency determine the number and type of compressors the agency must have. The total flow in standard cubic feet per minute (SCFM) from the compressors determines the number of buses and how quickly they are fueled. Agencies can determine the number of compressors and size of compressors required by taking the fuel load per bus, multiplied by the number of buses fueled per night, divided by the productive time during a fueling shift each night. Agencies must also provide redundant compressors. Redundancy provides backup compression so that if one compressor fails, the redundant compressor can make up for the loss. This is also beneficial when compressors are undergoing routine maintenance (Adams and Home 2010). Depending on the fleet replacement or expansion plans, the station should have room for additional dispensers and additional compressors (Adams and Home 2010).

A report sponsored by the National Renewable Energy Laboratory (NREL) and conducted by R. Adams and D.B. Horne, titled *CNG Transit Bus Experience Survey,* provided the survey results of 10 transit agencies operating CNG transit fleets. The study revealed preferences of types of compressors used—gas or electric drive. The report states, "Seven of the 10 respondents either currently or previously owned CNG stations with natural gas-engine-driven compressors. Two of these agencies have already converted to electric-drive compressors, and two more indicated that they would go electric if they could do it over." The report states that electric-driven compressors typically have lower energy costs, are quieter, and require no special environmental permit. The report also states that the industry is shifting toward electric compressors.

TTI researchers asked peer agencies several questions about CNG fueling stations. Table 2-4 provides information on each of the peers' fueling stations and compressors.

The table shows many of the agencies have multiple CNG fueling stations. The table also shows that the number of compressors at each station varies from two to six. Each of the peer agencies has a fast-fill operation, with the majority of the agencies able to fill each vehicle in under 10 minutes. Sun Metro's and Omnitrans' fill times are 15 and 8 minutes, respectively. These agencies convert LNG to CNG, and therefore the fueling process is different than the other agencies'. Sun Metro and Omnitrans do not use compressors in the fueling process; therefore, not all agencies have information on compressors.

Of the peer agencies, only Foothill Transit operates a station using a gas-driven compressor. All other stations contain electric-drive compressors. The electrical expenses for each of the fueling stations vary. RPTA pays $0.06 per therm of natural gas used. In fiscal year 2011, SACRT had an electricity expense of $311,211 for its one station operating five compressors. In fiscal year 2011, NCTD had an electricity expense of $271,133 for its two stations with four compressors in total.

The agencies reviewed currently have few fueling capacity issues. However, Sun Metro and Sun Tran noted that cold weather affects the speed and completeness of refueling. SACRT noted that the size of tanks on some vehicles limited the mileage range; these vehicles had to come in for midday refueling. Adjustments in onboard tank capacity and improvements to the fueling station, enabling a more complete fill, curtailed the fueling-capacity issue. NCTD stated that fuel capacity could be an issue if additional vehicles are added to the Escondido facility.

Gas Detection

Natural gas (CH_4) is ignitable at concentrations in air between 5 and 15 percent. Agencies must meet local and national fire safety codes such as those required by the National Fire Protection Association Code 52 when implementing a CNG fueling operation. Agencies must have discussions with the fire marshal to ensure the facilities are up to local fire code. To detect and prevent concentrations of CNG, maintenance facilities must be equipped with methane detection sensors above all service bays to detect leaks. These sensors are connected to a master control panel. Two types of detection systems are typically used—catalytic bead and infrared. A catalytic bead detection system has a platinum coil embedded in a catalyst. When gases reach the coil, a reaction occurs, causing the element to heat up and trigger the sensor. Infrared methane detection uses infrared radiation to determine gas levels in the air (General Monitors n.d.). Infrared detection is the most commonly installed today (Richardson and McAllister 2009).

Table 2-4 Peer-Agency Fueling Station

Agency	CNG Fueling Capacity										Compressor Details				
	Fueling Stations	Natural Gas Inlet Pressure	CNG Storage	Compressors at Each Station	Fuel Dispenser s	Fuel Time	Vehicles Fueled per Night	Midday refuel	Capacity Limitations	Capacity Limitation Solutions	Electric or Gas	Total SCFM	Discharge Pressure	Gas Expenses	Annual Electricity Expenses
Foothill Transit	2	Unknown	Buffer only	8 (electric) and 6 (gas)	P = 6 A = 4	10 minutes or less	P = 150 A = 129	0	None	None	Both	P = 5,648 A = 3,650	4,500 psi	Not separately metered	Unknown
NCTD	2	O = 256 psi E = 140 psi	Buffer only	2	2 at each	O = 6 minutes E = 8 minutes	O = 40 E = 30	No	Charges for electricity; fill time could be an issue if the fleet is increased at Escondido	Enough labor at Oceanside to fill and clean vehicles fast enough	Electric	O = 1,200 E = 500	3,600 psi	Not separately metered	$271,133
Omnitrans	2	N/A	60,000 and 20,000 LNG	N/A	2 at each station	8 minutes	140-150	No	None	Maintain excess capacity for LNG	N/A	N/A	N/A	N/A	N/A
RPTA	1	100 psi	Buffer only	3	4	4 minutes	135	No	None	Enough tank storage on vehicles to reach 480 miles	Electric	1,500	3,600 psi	Not separately metered	0.06 per therm
SACRT	1 (#2 is being con-structed)	400 psi	Buffer only	5 and 3	4 and 4	6-7 minutes	135	No	Initially yes	The tank size on vehicles was increased, and improvements in 2002 to station allowed for all buses to be fueled in the evening. Initially would swap out the bus midday.	Electric	Unknown	3,600 psi	Not separately metered	$311,211
Sun Metro	2	N/A	60,000 and 18,000 LNG	N/A	4 and 1	15 minutes or less; worst case 30 minutes	150	Yes but not needed	The cold weather impacts how quickly the bus can be fueled	None	N/A	N/A	N/A	N/A	N/A
Sun Tran	1	Unknown	Buffer only	4	2 fast fill and 1 slow fill	5-7 minutes; slow fill is 20-30 minutes	88	No	Temperature impacts more complete fill	Made 3600 psi intake to get more complete fill; improved this about 4 years ago	Electric	Unknown	3,600 psi	Not separately metered	No

The Central Arkansas Transit Authority (CATA) had a study completed on implementing a CNG fueling operation in 2009. The study stated that the main shop would need 24 methane sensors (12 bays with two sensors per bay). The sensors are positioned directly over the actual repair bays. The paint booth and body shop also require sensors. Each fueling lane and wash bay require two sensors each, equaling an additional six sensors. Since the fueling and wash building is separate from the main facility, the building requires a zone control panel that links to the master panel in the main facility. Each compressor skid requires a methane sensor with a control panel linked to the master control panel. If the compressor skid is an open-air canopy, no methane detection is necessary (Richardson and McAllister 2009).

Electrical System Improvements

Agencies must have electrical system improvements within the maintenance facility when CNG is implemented to meet National Fire Protection Association codes. These codes require electrical connections and devices found within 18 inches of the lowest portion of the ceiling to be classified as explosion proof (Class 1, Division II). To meet this requirement, certain electrical connections are upgraded or the light fixtures lowered. The electrical system must be connected to the methane detection system. If the detection system detects a gas leak, the system shuts down electrical supply (Richardson and McAllister 2009).

Heating Ventilation and Air Conditioning Improvements

Agencies operating CNG transit vehicles must have mechanical ventilation systems. These ventilation systems are responsible for venting the room at six room air exchanges per hour. If a gas leak is detected, the ventilation rate increases to 12 air exchanges per hour, and all doors automatically open (Arcadis Gerahty and Miller, Inc. 1998).

Facility Upgrade Costs

The cost of modifying the maintenance facilities for CNG operation varies widely depending on the size and age of the facility. The CATA CNG study estimates the cost of retrofitting its facilities to be CNG compliant would be roughly $150,000. CATA operates a fleet of about 50 fixed-route buses, which would indicate the size of the maintenance facility is substantially smaller than other large agencies (300+ vehicles). The CATA estimate is lower than would be the case at larger transit agencies. Leslie Eudy, in the report *Natural Gas in Transit Fleets: A Review of Transit Experience*, states that the costs of modifying a maintenance facility to make it compliant with CNG could range from $100,000 to $10 million. Eudy explains the most important variables are the size and age of the facility (Eudy 2002).

TTI researchers asked peer transit agencies about the modifications required during CNG implementation and the costs associated with those modifications. Many of the agencies implemented CNG in the early 1990s and could no longer supply a record of the facility modification costs. In the early 2000s, NCTD retrofitted a portion of an existing facility to accommodate the use of CNG. The NCTD retrofit cost the agency about $75,000. Table 2-5 provides the responses to facility modifications discussions.

Table 2-5 Peer Agency Facility Modifications

Transit Agency	Year of Implementation	Facility Modifications
Foothill Transit	2002	Facility was built with CNG fueling ability
NCTD	2001	10 bays with methane detection, two automatic roll-up doors, exhaust fans, and fire-proof door to separate from the other part of the facility
Omnitrans	1997	Methane detection, fall protection, LNG storage, pumps, vaporizer, and CNG buffer storage
RPTA	1998	Facility was built with CNG fueling ability
SACRT	1993	Emergency shutdown if methane detected, exhaust fans, and explosion-proof fixtures
Sun Metro	1993	Explosion-proof fixtures, methane detectors, air exchangers, fire extinguishers, and exhaust hose to vent gas; lights were lowered
Sun Tran	1991	Methane detection and defueling station

Contract versus Own and Operate

Transit agencies have the option to own and operate the CNG fueling station or contract it out to a third-party provider. A CNG fueling station requires expertise and institutional knowledge for maintaining and troubleshooting problems in natural-gas compression. The requirements of a CNG fueling operations are sometimes better suited to a company that specializes in operating and maintaining CNG fueling stations. This section describes the arrangements available to transit agencies and provides information on each of the peer transit agencies' CNG fueling operations.

The CNG fueling arrangement types include the following: own and operate, own and partially operate, lease and operate, lease and partially operate, and turnkey. Table 2-6 provides the arrangements available to transit agencies when implementing an on-site CNG fueling operation.

Table 2-6 Contract versus Own and Operate Options

Type of Arrangement	Fueling Station	Maintenance of Fueling Station	Maintenance of Vehicles	Fueling of Vehicles	Fuel Supply
Own and operate	In-house	In-house	In-house	In-house	Contracted
Own and partially operate	In-house	Contracted	In-house	In-house	Contracted
Lease and operate	Contracted	Contracted	In-house	In-house	Contracted
Lease and partially operate	Contracted	Contracted	In-house	In-house	Contracted
Turnkey	Contracted	Contracted	In-house	In-house	Contracted

A third party provides fuel supply in each scenario arrangement. The fuel supplier can be the local gas company, the local municipality, or the third party used for natural-gas compressor maintenance. As Table 2-6 indicates, transit agency staff or contract staff (e.g., First Transit, Veolia, etc.) conduct the maintenance and fueling of CNG vehicles in-house in each arrangement. A common arrangement found in the peer research is own and partially operate. In this arrangement, the transit agency contracts for compressor maintenance and monitoring. When an agency leases the compressors from a third party, the third party maintains the compressors. The third-party company can also upgrade or add additional compressors if the transit agency's demand surpasses the fueling station's capacity.

The report *Natural Gas in Transit Fleets: A Review of the Transit Experience* provides information on the benefits and downside to owning or contracting out the CNG fueling station operations (Eudy 2002).

For own and operate, the advantages and disadvantages are as follows:

- Advantages:
  - Ownership of the station provides the agency control of the fueling operation.
  - The total cost to the agency is lower if the station is efficiently managed.
- Disadvantages:
  - Up-front capital costs are high for the agency.
  - The agency is responsible for maintenance and operation.

For contracting to a third part, the advantages and disadvantages are as follows:

- Advantages:
  - Up-front capital costs are low or nonexistent.
  - Station maintenance is conducted by the contractor.
  - A long-term contract can provide a stable fuel price.
  - The contractor has experience.
  - Continuing upgrades to the facility can be performed.
- Disadvantages:
  - The agency may have possible issues with proprietary technology.
  - The agency takes a risk on the performance of the contractor.
  - Contracting can be potentially more expensive overall than ownership.

Peer Transit Agency Experience

Table 2-7 displays the arrangements in which each of the peer agencies operate and maintain CNG fueling operations.

Table 2-7 Peer Agency Contract versus Own and Operate

Transit Agencies	Fueling Station	Maintenance of Fueling Station	Maintenance of Vehicles	Fueling of Vehicles	Fuel Supply
Foothill Transit	In-house	Contracted	In-house	In-house	Contracted
NCTD	In-house	Contracted	In-house	In-house	Contracted
Omnitrans	In-house	Contracted	In-house	In-house	Contracted
RPTA	In-house	Contracted	In-house	In-house	Contracted
SACRT	In-house	In-house	In-house	In-house	Contracted
Sun Metro	In-house	In-house	In-house	In-house	Contracted
Sun Tran	In-house	In-house	In-house	In-house	Contracted

Each peer transit agency maintains and fuels vehicles in-house. Additionally, each agency owns the CNG fueling station(s). Contractors specializing in CNG fueling operations allow for stability in fueling within a transit agency. The function most commonly contracted out is maintenance of the fueling station. Fuel-station compressors require ongoing maintenance that may be more appropriate for a contractor to complete. RPTA, Omnitrans, Foothill Transit, and NCTD contract out fuel-station maintenance. These agencies contract for maintenance on a per-therm basis. Maintenance contracts negotiated between the entities involve multiple variables to reach a cost per therm for maintenance. The cost of maintenance per therm is determined by the total number of CNG therms the agency uses as well as the number, age, condition, and type (gas or electric drive) of compressors housed at the fueling station. Table 2-8 provides the amount each agency pays for station maintenance.

Table 2-8 Maintenance Cost of Fuel Station

Agency	Cost of Fuel Station Maintenance per DGE
NCTD	$0.30
Foothill Transit	$0.39 Arcadia and $0.84 Pomona
RPTA	$0.20
Omnitrans*	$270,000 per year

*Omnitrans uses an LCNG operation that does not use compressors, so it has a different type of maintenance contract.

In some instances, the contractor providing maintenance to the fueling station is also the fuel supplier. NCTD and Omnitrans use the same contractor for both fuel supply and station maintenance. However, Omnitrans has the same contractor for each function because the original contractor for the fuel supply was bought out after Omnitrans had already entered into a contract with them; therefore, Omnitrans has two separate contracts for the fuel supply and station maintenance. Table 2-9 lists the contractors for the fuel supply and station maintenance for the peer agencies.

Table 2-9 Contractors for Fuel Supply and Station Maintenance

Agency	Fuel Supplier	Station Maintenance
Foothill Transit	Southern California Gas	Clean Energy
NCTD	Trillium	Trillium
Omnitrans*	Clean Energy and Applied LNG Technology	Clean Energy
RPTA	City of Mesa	Clean Energy

CNG Service Planning

This section discusses the service planning implications for CNG vehicles. The section provides a brief history of CNG-vehicle service planning and provides information on some of the considerations with today's available technology.

During the late 1980s and early 1990s, many transit agencies in the United States began operating CNG transit vehicles. Many of these vehicles had an operating range of 150 to 200 miles. When the bus route required more miles, these buses had to refuel at midday to complete the day's service. Another service-planning concern involved the road grade on which the CNG vehicles operated. When CNG vehicles operated on hills, the vehicles sometimes struggled to make it up the hill. The weight of the CNG fuel tank—about

3,000 lb—contributed to this problem and affected the performance of the vehicle. In addition, CNG engines operated at higher temperatures, and operating on hot days led to the risk of overheating (Eudy 2002). Agencies considered these items when developing service plans.

Today, transit properties operating both CNG and diesel vehicles typically mix the two bus types on the routes provided. The Regional Public Transit Authority in Phoenix, Arizona, has a fleet of 135 CNG vehicles and 37 biodiesel vehicles. The buses are intermixed and expected to operate on each of the fixed routes. The exceptions to this are the buses used for bus-rapid-transit service. These vehicles have a specific design and operate only on the bus-rapid-transit routes. The RPTA expects the CNG and diesel vehicles to have a range of more than 400 miles and sufficient horsepower to traverse all routes (Hyinke 2011). The National Renewable Energy Laboratory evaluated WMATA in 2006. WMATA had 232 buses operating out of the Bladensburg depot, of which 164 were CNG powered. The diesel and CNG vehicles were interchangeable on all routes that used 40-foot buses (Chandler et al. 2006). Of the eight transit agencies used in the peer analysis, three of the agencies do not operate diesel vehicles at all. Therefore, all vehicles must be able to complete all routes.

CNG performs at a slightly lower level than diesel in acceleration and hill climbing. CNG engines have peak power ratings similar to comparable diesel engines; however, they have reduced low-speed torque due to the lower volumetric efficiency of CNG engines. The low-speed torque combined with the increased weight of the CNG fuel tanks leads to acceleration reductions. In 2006, the City of San Francisco purchased hybrid electric rather than CNG due to the hilly operating conditions within San Francisco (Science Applications International Corporation 2011). According to *TCRP Report 146: Guidebook for Evaluating Fuel Choices for Post-2010*, the newest Cummins Westport engine claims to have a 30 percent increase in low-speed torque for its stoichiometric, cooled exhaust-gas-recirculation engine compared to its previous engine (Science Applications International Corporation 2011). TTI researcher spoke with representatives from RPTA and Foothill Transit about CNG vehicle performance on freeway on-ramps with a full load of passengers. The representatives stated the vehicles performed as well as their diesel vehicles when merging onto freeways.

Modern CNG transit-vehicle technology allows for greater range due to fueling and fuel-storage technology. The increased range is attributable to getting a more complete CNG fill and increased fuel capacity. SACRT struggled with the range of CNG vehicles through the 1990s. In 2002, the new CNG buses received by the agency had increased tank capacity. In addition, SACRT made modifications to the fueling station to increase the completeness of the CNG fill on buses (Barnhart 2011).

TCRP Report 146 documents the fuel efficiency of CNG vehicles as being about 2.7 miles per gallon (mpg). The fuel efficiency of a vehicle is dependent on the operating characteristics of the bus route. *TCRP Report 146* provides the miles per gallon of diesel as being about 3.2. Of the eight peer agencies reviewed, the average miles per gallon reported for the CNG fleet is 3.42. The low value is 2.7 mpg, and the high value is 3.98 mpg.

CNG vehicles require CNG fueling stations for fuel. Transit agencies with multiple garages may only have one CNG fueling station. This means that all CNG buses must be housed out of the same garage and cannot be interchanged with buses at other garages. Of the eight peer transit agencies, three have two fueling stations, and SACRT is in the process of constructing an additional facility.

METRO Service Planning

The purpose of this section is to document METRO's short- and long-range service plans, and examine the impacts of CNG implementation on existing and future bus-service planning. Additionally, this section provides information on fleet mix and an overview of the METRO maintenance facilities.

Short-Range Service Planning

METRO has a detailed short-range service plan. Most of the focus of METRO's service plan is on becoming more cost efficient and effective. The service plan ties into the overall agency strategy to improve service system-wide and add additional service based on the adopted service standards. The short-range plan prioritizes new services and sets implementation time frames. The purpose of the plan is to enhance service efficiency by reducing and/or eliminating trips that are poor performers. Additionally, proposed service changes seek to address major customer-service requests and complaints.

The service changes occurring in 2011 will reallocate resources saved in the previous year, improve specific services, and simplify the overall transportation network. In addition, proposed service changes place emphasis on potential market opportunities, especially areas where residential and commercial growth is occurring. A number of low-ridership trips were targeted by METRO staff in 2010 and selected for elimination in 2011. Proposed service will be added to routes experiencing overcrowding or on-time performance issues, or to alleviate the future retirement of articulated buses.

Service changes can be summarized by grouping them into the three service-change periods for METRO: January, June, and August.

In January, METRO staff worked to reallocate resources saved in the August 2010 service change. Service changes were made to accommodate the growth of the Washington Avenue entertainment district and residential development on Reed Road. Service was also designed to address early work start times in the Texas Medical Center, expand services offered by Neighborhood Centers, Inc., improve weekend headways on the 137 Northshore Route, and improve service on Gessner, Kempwood, and Hammerly. Lastly, two unproductive routes were removed from service.

For the June service change, METRO focused additional service improvements on market opportunities, such as improved access to retail and commercial services on Highway 6, and growing the 32 Renwick route by adding Saturday service. A third bus route was discontinued due to low productivity, and staff implemented a taxi-cab voucher pilot program as a replacement for the discontinued service.

The August service change emphasized continued improvements for cost efficiencies. The 352 Swingle Shuttle was replaced with an extension of Route 52, and staff made additional improvements to improve on-time performance of several routes.

Long-Range Service Planning

In 2004, METRO commissioned a study that looked at plans for nine major corridors in the METRO area. The study emphasized the importance of a long-range transit plan, and METRO used the findings from the nine corridor studies to develop a system-wide 2025 plan. The 2025 plan, known as METRO Solutions, identifies transit improvements and includes the following elements:

- Bus-fleet replacement.
- Service improvements.
- New, relocated, and expanded transit-passenger facilities.
- High-occupancy-vehicle extensions and improvements.
- General mobility improvements.
- METRORail from Downtown to Reliant Park.
- Advanced high-capacity transit in candidate corridors.

In summary, the plan calls for 72 additional miles of rail service, 50 percent more bus service, implementation of Signature Express bus service, 250 miles of bi-directional, all-day park-and-ride service, 9 new park-and-ride lots, and 9 new transit centers (H-GAC 2010).

METRO is currently beginning the process to update the long-range plan for the agency. The new plan, METROVision, is slated to look at potential service through the year 2035.

Fleet Mix

METRO has approximately 1,200 buses across several different facilities. METRO has 801 40-foot buses, 383 45-foot suburban buses, 32 60-foot articulated-style vehicles, and 25 29-foot buses. These buses are further broken down into additional categories, depicted in Figure 2-5. For additional information on the METRO fleet, refer to the Appendix A.

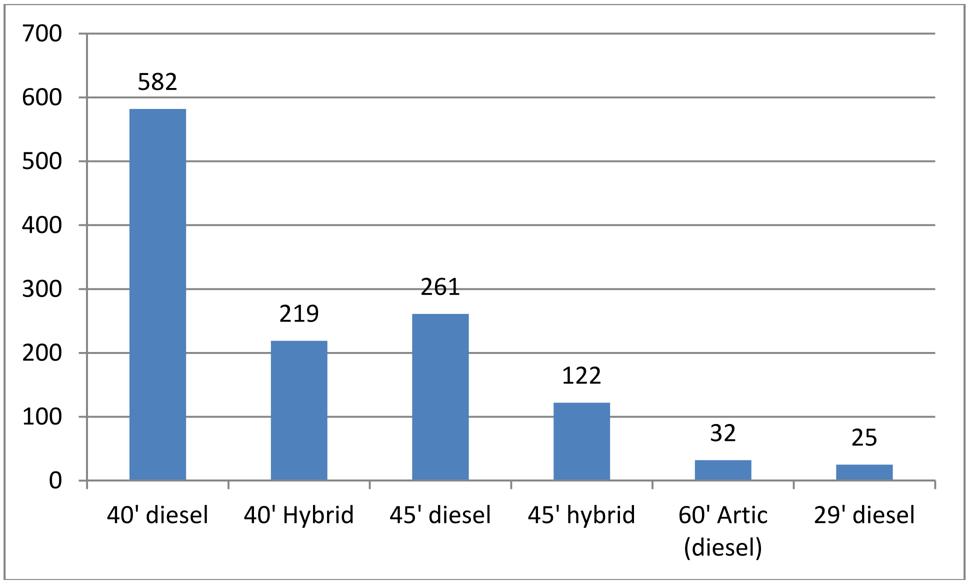


Figure 2-5 Fleet Mix

According to METRO's Bus Fleet Replacement Plan, the agency plans on retaining roughly the same number of vehicles through the year 2021. The fleet will average about 1,200 vehicles, and METRO will plan to retire approximately 85 vehicles annually and purchase 85 new vehicles annually. This consistent fleet replacement plan will aid in the planning and purchase of new CNG vehicles.

METRO Facility Planning

METRO currently has six bus-maintenance facilities. This section provides a brief overview of the maintenance and operating capacity at each facility, and describes the implications for operating CNG vehicles out of particular facilities.

Table 2-10 describes the current bus facilities, and Figure 2-6 provides a map of the facility locations.

Table 2-10 METRO Maintenance Facilities

Facility	Address	Parking Spaces	Fueling Lanes	Fueling Pumps	Diesel Storage (Gallons)	Service Bays
Fallbrook BOF	111 Fallbrook Drive, Houston, TX 77038	250	4	4	125,800	24
Hiram Clarke BOF	4175 Uptown Drive, Houston, TX 77045	250	3	3	142,200	21
Kashmere BOF	5700 Eastex Freeway, Houston, TX 77026	250	2	4	147,000	19
Polk BOF	5700 Polk Street, Houston, TX 77023	260	2	4	145,500	23
West BOF	11555 Westpark, Houston, TX 77082	250	3	3	100,000	26
Northwest BOF (Contract Facility)	5555 Deauville Plaza Drive, Houston, TX 77023	300	4	3	144,000	23

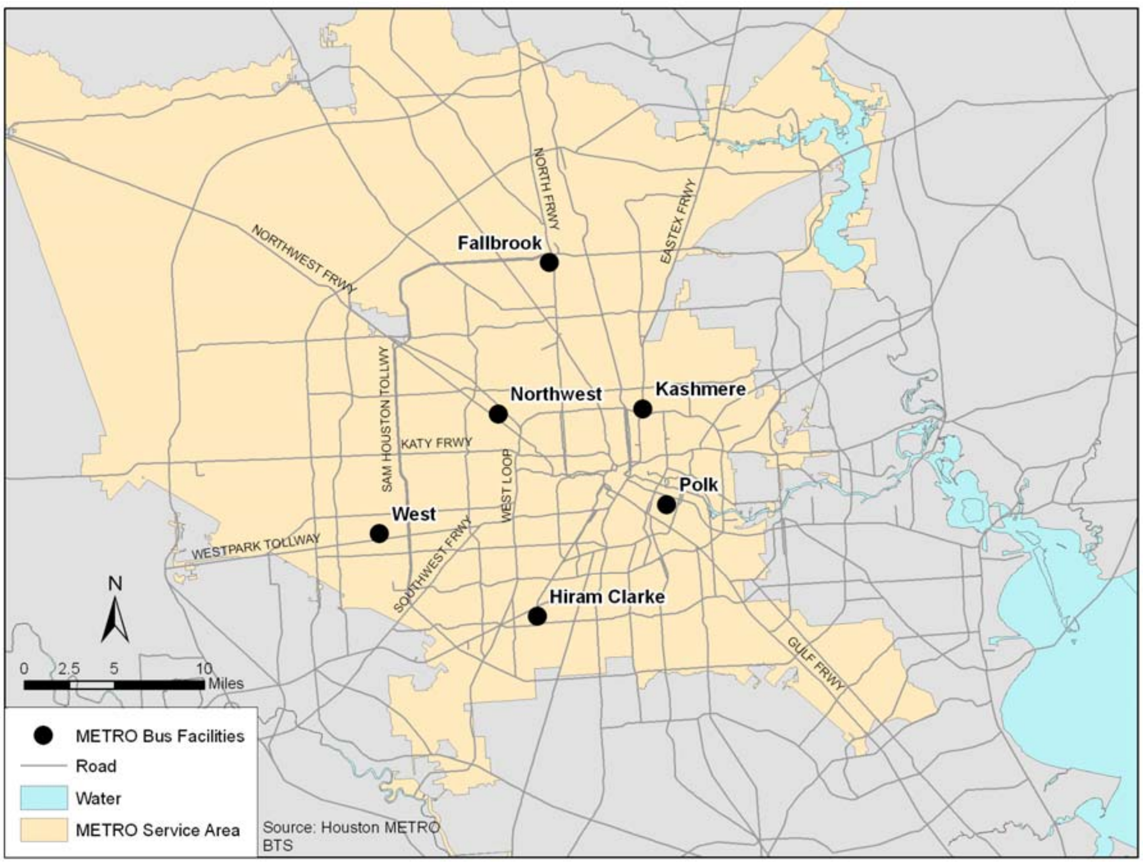


Figure 2-6 Map of METRO Facility Locations

As seen in the table, METRO has several facilities to house its 1200+ vehicle fleet. The majority of the service facilities have 20+ service bays. As discussed in the "CNG Implementation" section, each service bay requires at least two methane sensors. The size and age of the facility have the largest impacts on the cost of retrofitting a facility for accommodating CNG vehicles. Therefore, facilities with more service bays will cost more to retrofit. If METRO plans to operate a mix of vehicles including CNG at a particular facility, the agency may choose to retrofit only the portion of the facility in which the CNG vehicles are maintained.

CNG Incentives and Tax Credits

Transit agencies using alternative fuels such as CNG have the opportunity to receive federal and state incentives and tax credits. This section provides the most current information on the availability of those credits.

Federal Incentives and Tax Credits

At the federal level, the most significant incentive for the users of CNG includes the Alternative Fuel Excise Tax Credit. This credit is effective through December 31, 2011, and provides $0.54 per DGE of CNG used. State and local governments that dispense CNG from an on-site fueling station for use in vehicles qualify for the incentive. The agency must first use the tax credit against any tax liability the agency has. Agencies may claim the excess over the fuel-tax liability as a direct payment from the Internal Revenue Service. Public transit agencies are not liable for the federal fuel excise tax; therefore, agencies operating CNG claim the entire Alternative Fuel Excise Tax Credit (U.S. Department of Energy 2011a).

An additional tax credit available at the federal level is the Alternative Fuel Infrastructure Tax Credit. This is a tax credit available for the cost of alternative fueling equipment placed into service after December 31, 2005. Alternative fuels include natural gas, liquefied petroleum gas, hydrogen, electricity, E85, or diesel fuel blends containing a minimum of 20 percent biodiesel. The tax credit provides up to 30 percent of the cost, not to exceed $30,000, for equipment placed into service in 2011. Equipment placed into service in 2009 and 2010 may receive a credit for 50 percent of eligible costs, not to exceed $50,000. Agencies that install multiple fueling stations at separate locations can receive the credit for each location. This credit also expires December 31, 2011 (U.S. Department of Energy 2011a).

Agencies operating alternatively fueled vehicles are eligible for Improved Energy Technology Loans. The U.S. Department of Energy provides these loans through the Loan Guarantee Program. Eligible projects include those that reduce air pollution and greenhouse gases, and support early commercial use of advanced technologies (U.S. Department of Energy 2011a).

The federal tax credits expire December 31, 2011. There is proposed legislation that aims to extend the tax credits—H.R. 1380: New Alternative Transportation to Give Americans Solutions Act of 2011. The bill was introduced to the House of Representatives on April 6, 2011. The bill includes extensions of existing tax credits and expanded tax credits. The bill calls for the following incentives for natural gas operations (Kalet 2011):

- Extension of the excise tax credit ($0.54 DGE).
- Increase of the Alternative Fuel Infrastructure Tax Credit (from 30 percent, up to $30,000, to 50 percent, up to $100,000).
- Vehicle purchases:
  - For light-duty vehicles, 80 percent of the cost differential, up to $7,500.
  - For heavy-duty vehicles, 80 percent of the cost differential, up to $65,000.
  - Additional tax incentives for natural-gas-vehicle original equipment manufacturers (OEMs).

Several House committees are currently reviewing the bill.

State Incentives and Tax Credits

The Texas Commission for Environmental Quality has multiple incentives for agencies looking to implement CNG. The following list details the available state-level incentives (U.S. Department of Energy 2011):

- Alternative Fueling Infrastructure Grants effective September 1, 2011, provide 50 percent of the eligible costs, up to $500,000, to construct, reconstruct, or acquire a facility to store, compress, or dispense alternative fuels in Texas air-quality nonattainment areas.
- Natural Gas Vehicle and Fueling Infrastructure Grants effective September 1, 2011, provide the incremental costs of purchasing CNG-fueled vehicles. The grant also provides funding for fuel-station development. The infrastructure grant amounts may not exceed $100,000 for a CNG fueling station, $250,000 for an LNG station, or $400,000 for a station providing both forms of natural gas. Stipulations tied to the grant funds include the requirement of the funded fueling station to be open to the public and within 3 miles of an interstate highway. The grant program ends August 31, 2017.
- Emissions Reduction Incentive Grants provide funds for clean-air projects to improve air quality in the state's nonattainment areas. Eligible projects include those that involve heavy-duty vehicle replacement, retrofit, or repower; alternative-fuel dispensing infrastructure; idle reduction and electrification infrastructure; and alternative-fuel use.
- New Technology Research and Development Grants provide funds for alternative-fuel and advanced-technology demonstration and infrastructure projects to encourage and support research, development, and commercialization of technologies that reduce pollution.
- The Texas Clean Fleet Program encourages owners of fleets to remove diesel vehicles from the road and replace them with alternatively fueled vehicles. The program provides grant funds to cover the incremental costs of replacing diesel vehicles with alternatively fueled vehicles. The new vehicles must reduce emissions of nitrogen oxides or other pollutants by at least 25 percent.
- The Natural Gas Vehicle (NGV) Initiative Grant Program encourages public-sector fleets in certain counties to increase the use of heavy-duty NGVs. The grants aim to cover the incremental cost of replacing diesel vehicles with NGVs.

- The Natural Gas Program provided by the Texas General Land Office offers competitive prices on natural gas to school districts and other state and local public entities for use in NGVs.

Emissions Considerations

Many agencies that began using CNG in the 1990s and early 2000s did so for the environmental benefits CNG transit vehicles offered. This section provides information on the historic and current implications of the air-quality impacts of CNG transit vehicles.

Historical Implications of Using CNG in Transit Fleets

Traditionally CNG transit vehicles have cleaner-burning engines producing fewer emissions than diesel vehicles. The early CNG transit vehicles were capable of having extremely low particulate-matter rates. CNG vehicles also had the potential to achieve NOx rates about 50 percent lower than the diesel baseline when properly calibrated. The lower emissions rates are a result of CNG engines having a more complete burn of light hydrocarbons (Science Applications International Corporation 2011). However, the NOx rate was sensitive to the air/fuel ratio. The NOx rates of natural-gas engines could easily exceed the diesel baseline in the event the fuel system was miscalibrated or given inadequate maintenance (Arcadis Gerahty and Miller, Inc. 1998). Because of the possible significant air-quality benefits CNG transit vehicles offered, many transit agencies implemented CNG fleets.

Modern-Day Implications of Using CNG in Transit Fleets

EPA has put more stringent emissions regulations on diesel engines; therefore, the gap between CNG and diesel engines is closing. The air pollutants that fall under the Clean Air Act include hydrocarbons, NOx, particulate matter, non-methane hydrocarbons, and carbon monoxide (CO) (Science Applications International Corporation 2011). New emissions standards became effective in 2004, 2007, and 2010—each time becoming more stringent. The changes that came in 2007 and 2010 required significant changes for CNG buses. These changes included some modifications to CNG engines and exhaust treatment systems (Science Applications International Corporation 2011).

The 2010 emission standards have created differences in the emissions of CNG and diesel vehicles. *TCRP Report 146* says that a typical 2006 CNG bus emits less CO and NOx than a 2006 diesel bus, but the 2010 diesel bus may have lower CO emissions than natural-gas buses. To achieve the 2010 emission standards, diesel transit vehicles need a diesel particulate filter and a selective catalyst reduction. CNG vehicles must use stoichiometric cooled-exhaust-gas recirculation with a three-way catalyst (Science Applications International Corporation 2011).

The 2010 emissions technology is relatively new, and the number of emissions tests available is limited. However, *TCRP Report 146* provides EPA certification data available on 2010 CNG vehicles. Table 2-11 provides the EPA certification test results for the 2010 CNG engine.

Table 2-11 2010 CNG Engine EPA Certification Test

Pollutant	Grams/Mile
Carbon monoxide	21.91
Nitrogen oxides	0.22
Particulate matter	0.00
Non-methane hydrocarbons	0.02

Source: (Science Applications International Corporation 2011)

Transit agencies must also consider greenhouse gases (GHGs). GHGs consist of carbon dioxide (CO_2), CH_4, and nitrous oxide (N_2O). The GHG of most concern is CO_2. There are two sources of GHGs from vehicle operations:

- Well-to-tank emissions are released during fuel exploration, development, production, refining, delivery to refueling sites, and the refueling process.
- Tank-to-wheel emissions occur during operation of the vehicle and primarily escape from the tailpipe.

Well-to-tank GHG emissions range between 20 to 30 percent of the total life cycle of GHG emissions. Well-to-tank emissions are estimated to be 12 percent higher for CNG than for diesel (Science Applications International Corporation 2011).

TCRP Report 146 provides CO_2 comparisons for 2006 diesel and CNG transit vehicles. Table 2-12 provides information on GHG emissions from 2006 transit vehicles.

Table 2-12 GHG Emission from 2006 CNG and Diesel Buses

		CO_2 Equivalent Grams/Mile*		
		Diesel	**CNG**	**Change with CNG**
Well to tank				
	Total	**636**	**711**	**12% increase**
Tank to wheels				
	CO_2	2,258	1,872	17% reduction
	CH_4	3	230	76-fold increase
	N_2O	46	14	69% reduction
	Total	**2,306**	**2,117**	**8% reduction**
Total well to wheels				
	Total (net)	**2,942**	**2,828**	**4% reduction**

Source: (Science Applications International Corporation 2011)
*Assumes 1 g CH_4 = 23 g CO_2; 1 g N_2O = 296 g CO_2

When comparing 2006 diesel and CNG vehicles, CNG has a slight edge overall. Cummins Westport produces the only CNG engine currently available for transit vehicles. The 2010 CNG engine reportedly has a 17 percent reduction in GHG tailpipe emissions compared to the cleanest comparable diesel engines (Science Applications International Corporation 2011).

Bus Fleet Maintenance, Safety, and Training

Transit agencies that implement a CNG operation provide a certain level of training to mechanics. In addition, some states require a different level of certification for mechanics to work on CNG. This section provides information on CNG maintenance training and safety.

CNG Safety Considerations

Natural gas is ignitable at concentrations in air between 5 and 15 percent. Odorant added to natural gas makes it detectable at concentrations below 5 percent. CNG leaks are characterized as slow or fast leaks. Slow leaks result from a small gap such as a loose fuel-line fitting. Fast leaks can occur from a rupture in a high-pressure line in the refueling system. Each type of leak poses a fire hazard risk (Science Applications International Corporation 2011). The high pressure of CNG poses a potential risk to mechanics while working on the vehicle. Gas released from pressure or thermal-relief devices, or an improper or damaged fitting or high-pressure line, can cause injury. An improperly fitted or damaged refueling hose can disconnected and whip individuals standing near.

Maintenance Considerations

CNG transit vehicles require a few special maintenance considerations. *TCRP Report 146* provides a list of the maintenance needs that are relevant for CNG buses (Science Applications International Corporation 2011):

- Periodic spark-plug replacements for spark-ignited engines (in contrast to typically lower-maintenance compression ignition diesel engines).
- Possible greater frequency of brake and suspension component replacement as a result of the heavier weight of CNG buses compared to diesel buses.
- Annual visual inspection of onboard CNG fuel tanks (per American National Standard for Natural Gas Vehicle Containers).
- Recommended emptying of onboard CNG tanks before working on the fuel system.
- Periodic maintenance of refueling equipment (gas dryer, compressor, etc.).

Maintenance Training Considerations

Mechanics require some additional training when working on CNG transit vehicles, and in Texas mechanics must have certification through the Railroad Commission of Texas. The Texas Statutes Natural Resource Code 116 provides additional information regarding the licensing and certification of CNG use in Texas (Texas Constitution and Statutes 2011).

In the peer study, TTI researchers asked agencies about required training for CNG vehicles. Table 2-13 provides the peer responses about maintenance-training requirements.

Table 2-13 Peer Training Experience

Transit Agency	Training Required	Cross-trained for Multiple Technologies
Foothill Transit	Contractor responsibility	Yes
NCTD	4 hours (not CNG specific)	Yes
Omnitrans	20 hours (not CNG specific)	Yes
RPTA	40 hours (not CNG specific)	Yes
SACRT	Safety briefings, no CNG requirement	Yes
Sun Metro	Training on each new bus order (not CNG specific); CNG certification	Yes
Sun Tran	8-16 hours on CNG specific; CNG certification	Yes

As seen in the peer research, there is typically no requirement by the agency to have additional CNG training. Sun Tran and Sun Metro have additional certification requirements. All peer agencies have mechanics trained to work on each type of vehicle the agency operates.

Key Findings

Objectives for Using CNG

- Agencies began using CNG-fueled vehicles largely to reduce emissions. Secondary purposes include the fact that historically natural gas has had a lower, more stable price than diesel. All peer agencies stated that emission reduction was the driving force behind switching to CNG.
- Peer agencies did not choose CNG to lower operating costs.

CNG Implementation

- Peer agencies typically have a contract for fuel and are able to negotiate CNG fuel price based on usage.
- Peer agencies operating CNG-fueled fleets have at least one fueling station on-site. Of the seven agencies, five have at least two fueling stations or plans for two.
- Omnitrans and Sun Metro purchase LNG and convert it to CNG, while the remaining peer agencies purchase natural gas and compress it into CNG.
- The cost of maintenance-facility modifications to accommodate CNG vehicles is driven by the size and age of the facility.
- Agencies have multiple options in developing an arrangement for natural-gas supply and compression. These include "own and operate," "own and partially operate," "lease and operate," "lease and partially operate," and "turnkey." Three peer agencies use "own and operate," and four agencies use "own and partially operate."

Service Planning

- Modern CNG transit vehicles have a total operating range similar to that of diesel vehicle—between 350 and 450 miles between refueling.
- CNG vehicles are heavier due to the fuel tanks. In addition, CNG vehicles have reduced low-speed torque as compared to diesel vehicles. This makes CNG transit vehicles undesirable for regions with steep grades.

- When operating in freeway settings, representatives from RPTA and Foothill stated the CNG vehicles perform as well as diesel vehicles when merging onto freeways.
- CNG technology is compatible with METRO's short- and long-range plans.

Tax Credits

- Multiple federal and state grants and credits exist for implementing a CNG bus operation.
- The most significant incentive for operating CNG transit vehicles is the $0.54-per-DGE tax credit. This credit expires December 31, 2011; however, H.R. 1380 proposes to extend this credit.

Emissions

- The 2010 emission standards on heavy-duty diesel engines make the emissions benefits of operating CNG less dramatic.
- The 2010 CNG engine reportedly has a 17 percent reduction in GHG tailpipe emissions compared to the cleanest diesel engines.

Maintenance

- The 2010 diesel engines have higher maintenance costs than previous diesel models. This, in combination with new CNG engine technology and reduced maintenance cost, makes the maintenance costs of diesel and CNG engines comparable.

3. METRO Life-Cycle Cost Comparison

TTI researchers used the LCC model developed by *TCRP Report 132* to determine the capital, variable, and total life-cycle cost of different vehicle purchase scenarios. TTI researchers used data available from METRO and nationally established assumptions as inputs for the model. This section of the report outlines the methodology, inputs, assumptions, and results of the LCC model for METRO.

About the LCC Model

The Life-Cycle Cost Model (LCCM) was developed as part of *TCRP Report 132: Assessment of Hybrid-Electric Transit Bus Technology*, published in 2009. The LCCM was developed using a variety of inputs, including literature reviews, surveys, and detailed data gathering from government agencies, the fuel industry, and transit agencies. The LCCM is being used here to compare the various upfront and recurring (life-cycle) costs of owning and operating diesel, hybrid, and CNG buses, in various configurations. The model allows inputs based on an agency's actual operational experience, but also has default data inputs that were obtained from operating experience at several transit agencies.

The input factors that have the greatest effect on LCC include fuel pricing, average speed, vehicle mileage, fleet size, and facility costs. Unpredictable future fuel pricing is the greatest challenge of reliable LCC prediction and has the most profound effect on LCC outputs. Input factors that have minor impact include tax and purchase incentives and air conditioning and heating use.

LCC Methodology

Scenarios

TTI researchers worked with METRO representatives to gather data and develop assumptions for the LCCM. Researchers collected data on six scenarios of bus purchases:

- CNG 40-foot buses.
- CNG 45-foot buses.
- Diesel 40-foot buses.
- Diesel 45-foot buses.
- Hybrid 40-foot buses.
- Hybrid 45-foot buses.

These six scenarios represent the planned procurements of METRO.

Model Inputs

The LCCM allows users to select either default values or input actual fleet agency data for the input variables. TTI researchers sought to gather the most current data available from actual METRO fleet data, literature sources, or mutually agreed-upon default variable inputs and assumptions. When available, TTI used actual fleet data provided by METRO. For default assumptions, TTI reviewed the various model inputs with METRO staff to ensure the model was representative of the METRO fleet. This section describes the model inputs and highlights the input variables with the greatest impact on LCC. This section also details the assumptions made by TTI within each of the model's sections. Table 3-1 provides the inputs used for each model variable.

Table 3-1 LCCM Scenarios and Inputs

#	Variable Inputs	CNG 40 Foot	CNG 45 Foot	Diesel 40 Foot	Diesel 45 Foot	Hybrid 40 Foot	Hybrid 45 Foot
1	Technology (type of bus)	CNG	CNG	Diesel	Diesel	Hybrid	Hybrid
2	Number of vehicles in purchase	100	100	100	100	100	100
3	Purchase year	2011	2011	2011	2011	2011	2011
4	Annual mileage per vehicle	45,000	35,000	45,000	35,000	45,000	35,000
5	Fuel economy						
5A	Average speed	13	18.5	13	18.5	13	18.5
5B	Air-conditioning load	9	9	9	9	9	9
5C	Heater load	6	6	6	6	6	6
5D	Fuel economies	3.66	4.05	4.00	4.43	3.86	4.94
6	Purchase cost (in 1000 dollars)	450.33	530.33	438.71	515	602.5	745
7	Extended powertrain warranty costs	0	0	0	0	0	0
8	Engine rebuild/replacement costs for bus lifetime (6,4 and 7,5 schedule)	33.7	33.7	33.7	33.7	28.7	28.7
9	Transmission rebuild/replacement costs for bus lifetime	22.25	22.25	22.25	22.25	90	90
10	Training costs	44.18	44.18	0	0	23.32	23.32
11	Unscheduled maintenance costs	0.3	0.25	0.35	0.3	0.14	0.12
12	Scheduled maintenance costs	0.18	0.18	0.15	0.15	0.19	0.19
13	Infrastructure-specific costs						
13A	New or additional infrastructure costs	2,500	2,500	0	0	0	0
13B	Operating and maintenance (O&M) costs for facilities	442.62	311.11	0	0	0	0
14	Hybrid-specific costs						
14A	Diagnostic equipment	0	0	0	0	117.42	117.42
14B	Energy-storage replacement	0	0	0	0	Figured into engine rebuild costs	
14C	Spare energy-storage packs	0	0	0	0	123.41	123.41
15	Projected average fuel costs	1.96	1.96	3.65	3.65	3.65	3.65
16	Incentives, credits, and taxes						
16A	Fuel taxes	0	0	0.20	.20	0.20	0.20
16B	Fuel credits	0.54	0.54	0	0	0	0
16C	Purchase credits	0	0	0	0	0	0
16D	Miscellaneous credits and grants	0	0	0	0	0	0
16E	Miscellaneous future-year one-time costs	0	0	0	0	0	0

The following is an explanation of each variable input:

1. Technology (type of bus)—The LCCM makes required calculations for each type of bus selected in each column. The buses chosen for the LCCM are the buses in METRO's vehicle replacement plan for the next 10 years. These include CNG 40-foot, CNG 45-foot, diesel 40-foot, diesel 45-foot, hybrid-diesel 40-foot, and hybrid-diesel 45-foot vehicles.
2. Number of vehicles in purchase—To compare the life-cycle costs of vehicle purchases, TTI researchers used 100 buses for each scenario.
3. Purchase year—The LCCM makes the necessary inflation calculations and other (technology-based) calculations based on specific purchase years. The base year 2011 is used for the LCCM
4. Annual mileage per vehicle—TTI researchers used the bus roster data supplied by METRO to determine diesel and hybrid average annual mileage for each type of vehicle.

5A. Average speed—TTI researchers used the actual route statistics provided by METRO to determine average speeds for each type of vehicle.

5B. Air-conditioning load—The LCCM allows the user to consider the effect air conditioning has on fuel economy by selecting a numeric value from 0 to 10. METRO provided an air-conditioning load of 9 out of 10. METRO operates the bus air conditioners the majority of the year and thought it was necessary to use a load of 9 within the model.

5C. Heater load— The model allows for the accommodation of heater loads on fuel efficiency. The default value is 5, which indicates the bus is not equipped with an auxiliary heater (or it is not used); 10 indicates that the auxiliary heater is always used (i.e., frigid climate). Since METRO operates the air conditioner the majority of the year and operates the heater only a couple months of the year, the heater load is 6.

5D. Fuel economies—TTI researchers worked with METRO to determine the fuel economy of each scenario. The hybrid-diesel scenario is based on actual METRO fuel economy experience. METRO used WMATA CNG fuel economy experience as the basis for determining the 40-foot CNG fuel economy for the LCC model. Table 3-2 shows the calculation used to determine CNG 40-foot fuel economy. As shown, the percent difference between a WMATA subfleet and a METRO subfleet was applied to actual WMATA CNG experience to arrive at the 40-foot CNG figure for the METRO LCC scenario. Actual METRO 40-foot diesel bus experience compared to 45-foot diesel bus experience was used to determine the 45-foot CNG fuel economy. METRO's current experience with post-2010 diesel fuel economy is similar to that of METRO's 2001 model diesel vehicles, therefore a comparable fuel economy was used.

Table 3-2 Calculations Used for CNG Fuel Economy Assumption

40-foot Bus MPG Calculation						
WMATA Vehicles			METRO Vehicles			
Year	Vehicle	MPG	Year	Vehicle	MPG	% Difference
2000	Orion Diesel	3.419	2000	New Flyer Diesel	3.526	3.13%
2005	Orion CNG	3.546	2011	METRO CNG	3.657	3.13%
45-foot Bus MPG Calculation						
METRO 40-foot Buses			**METRO 45-foot Buses**			
Year	**Vehicle**	**MPG**	**Year**	**Vehicle**	**MPG**	**% Difference**
2001	NF Diesel	3.946	2001	MCI Diesel	4.373	10.82%
2011	METRO CNG	3.657	2011	METRO CNG	4.052	10.82%

6. Purchase cost—METRO provided the average purchase price of the vehicles for each scenario. The purchase price of the vehicles is expressed in 1,000 dollars per bus. Additionally, annual fuel tax was added to the cost of CNG vehicles. This is $444 per year. Over a 12-year life, this equals approximately $5,328.
7. Extended powertrain warranty costs—The model allows for a one-time cost per bus for extended warranties. Researchers assumed there were no extended warranties added to the purchases.
8. Engine rebuild/replacement costs for bus lifetime—For all bus types, these costs apply to rebuilding the internal combustion engine, and are based on replacing the original engine with a rebuilt unit obtained from an OEM-authorized rebuilding facility. TTI researchers gathered data on each engine scenario from METRO. Researchers and METRO assumed CNG and diesel engine rebuilds are similar in costs. Researchers received the total cost of rebuilding the engine, propulsion, and associated parts for two different types of hybrid vehicles over a 12-year period. These two totals were averaged. The costs of replacing the hybrid propulsion system are in the transmission-rebuilding portion of the model.
9. Transmission rebuild/replacement for bus lifetime—For diesel and CNG buses, these costs are based on replacing the original automatic transmission with a rebuilt unit obtained from an OEM-authorized rebuilding facility. For hybrid buses, costs are based on removing the original hybrid drive system and replacing it with a factory-remanufactured unit. Researchers received data from METRO that the average transmission rebuild for CNG and diesel is roughly $22,250. Researchers received the total cost of rebuilding the engine, propulsion system, and associated parts for two different types of hybrid vehicles over a 12-year period. These two totals were averaged. The costs of replacing the hybrid propulsion system are used in the transmission-rebuilding portion of the model.
10. Training costs—The costs of training operators and mechanics on new hybrid and CNG diesel buses are incremental to (above and beyond) training costs associated with diesel buses. TTI researchers used the default medium training costs available in the model based on the number of METRO operators and mechanics available per 100 buses. This is about 315 operators (at $15 per hour) and 31.5 mechanics (at $20 per hour) per 100 vehicles. The medium default value for a 100-vehicle purchase for CNG or hybrid-diesel is $44,180 and $23,320, respectively.

11. Unscheduled maintenance costs—TTI researchers consulted with METRO on the maintenance costs of vehicles. The agreed-upon assumption for unscheduled maintenance is the low estimate available within the LCCM for each vehicle type.
12. Scheduled maintenance costs—TTI researchers consulted with METRO on the maintenance costs of vehicles. The agreed-upon assumption for scheduled maintenance for diesel and hybrid-diesel vehicles is the low estimate available within the LCCM for each vehicle type. Alternatively, TTI used the estimate provided in *TCRP Report 146* (METRO felt the estimates within the model were low as compared to actual experience) for CNG scheduled maintenance.
13. New or additional infrastructure costs—This section of the LCCM accounts for the costs associated with constructing a fueling facility and modifying other bus facilities, along with costs associated with operating and maintaining the fueling facility. TTI used the rule of thumb provided by *TCRP Report 146* for CNG infrastructure. This is $1 million plus $15,000 for every CNG vehicle.

13B. O&M costs for facilities—This section represents costs needed to maintain the CNG fueling infrastructure on an annual basis and includes costs associated with powering the CNG fueling compressors, rebuilding them, and maintaining the overall CNG infrastructure. The National Renewable Energy Laboratory conducted a survey in 2009 and 2010 that included a median value for maintaining a CNG fueling station ($0.18 per DGE) and also powering a CNG fueling station ($0.18 per DGE). This value was applied to the number of gallons the fleet would use over a year, based on the listed miles per gallon and number of annual miles.

14A. Diagnostic equipment—The LCCM accounts for hybrid diagnostic equipment costs incremental to (above and beyond) diesel and CNG buses. TTI received information on equipment and software necessary for maintaining a hybrid fleet.

14B. Energy-storage replacement—This section is only applicable to hybrid vehicles. METRO said that energy-storage replacement is on a 12-year schedule. TTI documented this expense within the engine rebuild.

14C. Spare energy-storage packs—This section accounts for the costs of keeping spare energy-storage packs in inventory (as opposed to keeping a bus down until a replacement pack is ordered and arrives). TTI used the low default for this input.

15. Projected average fuel costs—This section estimates the cost of fuel for the 12 years of the vehicle's life. Fuel-cost calculations in this section do *not* include taxes. TTI used the latest price provided by the *Clean Cities Alternative Fuel Price Report* to estimate the price of fuel.

16A. Fuel taxes—This section accounts for the price of taxes on fuel. No federal tax was added. TTI used only state tax for diesel.

16B. Fuel credits—CNG receives approximately $0.54 per DGE through December 31, 2011. There is a possible extension HR 1380.

16C, 16D, and 16E were left blank for the model.

Model Outputs

The LCCM projects the 12-year total cost of each purchase scenario. Table 3-3 provides the results of the model. The columns in the output table reflect the five purchase scenarios. The rows of the table provide each of the expenses associated with the purchase scenarios.

The last three rows of the table provide the capital, variable, and total LCC. The two scenarios with the lowest life-cycle costs are the CNG 40-foot and CNG 45-foot. The diesel scenarios have a lower total life cycle cost as compared to the two hybrid scenarios. The LCCM includes the tax credit currently available to transit agencies operating CNG. Without the tax credit the Total LCC for the CNG scenarios would be:

- CNG 40ft – $113,321,488 (as compared to $105,354,275)
- CNG 45ft - $103,291,239 (as compared to $97,691,239)

As stated previously, certain variables have a greater effect on LCC. For this LCCM scenario, the variables with the greatest impact on the LCC were:

- Annual mileage per vehicle.
- Fuel economy.
- Price per DGE.

Ultimately, the amount of fuel an agency uses and the price of fuel have the greatest impact on the LCC. The "fuel costs" row provides the amount of fuel used in each purchase scenario. This category shows the wide variation in fuel cost based on the type of vehicle used. The two CNG scenarios have significantly lower fuel cost as compared to the other three scenarios using diesel fuel.

The fuel price for CNG used in this model scenario is $1 more per DGE compared to what many peer agencies currently pay for CNG fuel. Other fuel-pricing scenarios observed in the literature have used a range of fuel pricing with high, medium, and low values. The decision to use a relatively high CNG fuel price value represents a maximum anticipated CNG fuel cost.

Table 3-3 LCCM Outputs

Scenario Comparisons: Tabulated Results (All Medium Values)						
Purchase Scenario Number	**CNG 40-foot**	**CNG 45-foot**	**Diesel 40-foot**	**Diesel 45-foot**	**Hybrid 40-foot**	**Hybrid 45-foot**
Technology	CNG	CNG	Diesel	Diesel	Hybrid-Diesel	Hybrid-Diesel
Number of Units	100	100	100	100	100	100
Purchase Year	2011	2011	2011	2011	2011	2011
Mileage per Year	45,000	35,000	45,000	35,000	45,000	35,000
Cost Inputs						
Purchase Scenario Number	**1**	**2**	**3**	**4**	**5**	**6**
One-Time Costs						
Training [1000 dollars]	44.18	44.18	0.00	0.00	23.32	23.32
Hybrids - Diagnostics [1000 dollars]	0.00	0.00	0.00	0.00	117.42	117.42
Fueling Infrastructure [1000 dollars]	2500.00	2500.00	0.00	0.00	0.00	0.00
One-Time Grants [1000 dollars]	0.00	0.00	0.00	0.00	0.00	0.00
One-Time Costs per Bus						
Purchase [1000 dollars]	450.33	530.33	438.71	515.00	602.50	745.00
Purchase after Discount [1000 dollars]	450.33	530.33	438.71	515.00	602.50	745.00
Warranty [1000 dollars]	0.00	0.00	0.00	0.00	0.00	0.00
IC Engine Replacement [1000 dollars]	33.70	33.70	33.70	33.70	28.70	28.70
Transmission [1000 dollars]	22.25	22.25	22.25	22.25	90.00	90.00
Hybrids - Energy Storage Replacement [1000 dollars]	0.00	0.00	0.00	0.00	0.00	0.00
Hybrids - Spare Energy Storage [1000 dollars]	0.00	0.00	0.00	0.00	123.41	123.41
Variable Costs						
Facilities Operating Cost per Year [1000 dollars]	442.62	311.11	0.00	0.00	0.00	0.00
Unscheduled Maintenance Costs [dollars per mile]	0.30	0.25	0.35	0.30	0.14	0.12
Scheduled Maintenance Costs [dollars per mile]	0.18	0.18	0.15	0.15	0.19	0.19
Total Maintenance Costs [dollars per mile]	0.48	0.43	0.50	0.45	0.31	0.31
Fuel Economy [miles per gallon]	3.66	4.05	4.00	4.43	3.86	4.94
Gallons per Year per Bus	12,295	8,642	11,250	7,901	11,658	7,085
Fuel Costs (with Taxes) [dollar per gallon]	1.96	1.96	3.85	3.85	3.85	3.85
Fuel Costs (w/ Taxes and Credits) [dollar per gallon]	1.42	1.42	3.85	3.85	3.85	3.85
Yearly Operating Grants [1000 dollars]	0.00	0.00	0.00	0.00	0.00	0.00

Table 3-4 LCCM Outputs (continued)

Total Lifecycle Costs (Base Year Dollars)						
Purchase Scenario Number	**1**	**2**	**3**	**4**	**5**	**6**
Subtotals						
Vehicle Related Capital Costs	50,627,800	58,627,800	49,465,600	57,095,000	72,243,410	86,493,410
Other Capital Costs	2,544,180	2,544,180	-	-	140,740	140,740
Vehicle Unscheduled Maintenance Costs	16,200,000	10,500,000	18,900,000	12,600,000	6,480,000	5,040,000
Vehicle Scheduled Maintenance Costs	9,720,000	7,560,000	8,100,000	6,300,000	10,260,000	7,980,000
Fuel Costs	20,950,820	14,725,926	51,975,000	36,501,129	53,860,104	32,732,794
Other Variable Costs	5,311,475	3,733,333	-	-	-	-
Totals						
Total Capital	**53,171,980**	**61,171,980**	**49,465,600**	**57,095,000**	**72,384,150**	**86,634,150**
Total Variable	**52,182,295**	**36,519,259**	**78,975,000**	**55,401,129**	**70,600,104**	**45,752,794**
Total	**105,354,275**	**97,691,239**	**128,440,600**	**112,496,129**	**144,064,254**	**132,386,944**

For example, a 2009 NREL survey of CNG fleets used a CNG fuel price of $1.30 DGE, and another NREL survey used $1.81 DGE (Adams and Home 2010). The high, medium, and low default fuel prices for the LCCM are $1.50, $1.84, and $2.02, respectively. Table 3-5 provides the natural gas prices found in literature research, peer experience, and federal fuel-price sources.

Table 3-5 Natural Gas Prices per DGE

CNG Price	Source
$1.96	*Alternative Fuel Price Report,* October 2011
$0.60-$1.80	Peer experience
$1.50	LCCM low default
$1.84	LCCM medium default
$2.02	LCCM high default

When choosing a fuel, an agency must also consider the capital investment for vehicles and infrastructure. The CNG and hybrid scenarios each have higher capital costs as compared to the diesel purchase scenario. Most of the capital expenditure is the purchase cost of the vehicles; however, CNG requires significant fueling infrastructure, and hybrid vehicles require diagnostic equipment.

Additional costs associated with CNG are annual operating and maintenance costs. CNG fueling facilities have compressors powered by electricity or natural gas. These compressors require a significant amount of energy and ongoing maintenance. The cost of operating and maintaining the CNG fueling station is on the "other variable cost" line.

Figure 3-1 and Figure 3-2 provide the total LCC of each scenario. As discussed previously, both CNG scenarios have a lower LCC as compared to each of the other scenarios. The figures clearly show that variable costs (which include fuel) are lower in the CNG scenarios.

As seen in Figure 3-3, the total LCC per bus for each scenario ranges from just under $1 million to almost $1.5 million. Since each scenario includes a bus purchase of 100 vehicles, the difference between the scenarios in LCC per bus is similar to that of the total LCC.

Figure 3-4 provides the LCC per mile for each scenario. The cost per mile is driven by the total miles the fleet is expected to travel, divided by the LCC of the scenario. The scenarios traveling the most miles while maintaining the lowest cost have the lowest cost per mile. The scenario with the highest cost per mile is the hybrid-diesel 45-foot vehicle. The 45-foot scenarios have the lowest miles because of the operating characteristics of routes using 45-foot buses. The higher LCC is driven by the capital costs from each scenario.

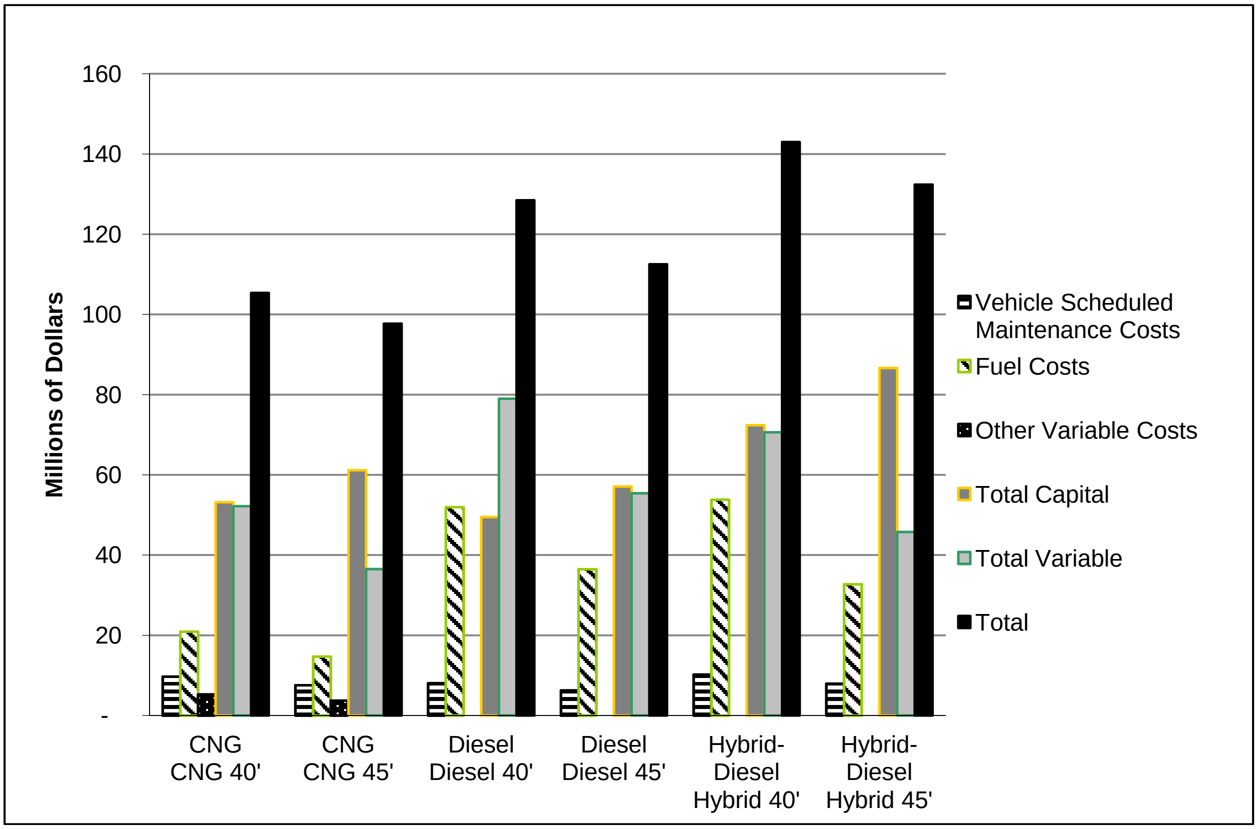


Figure 3-1 LCC Scenario Comparison

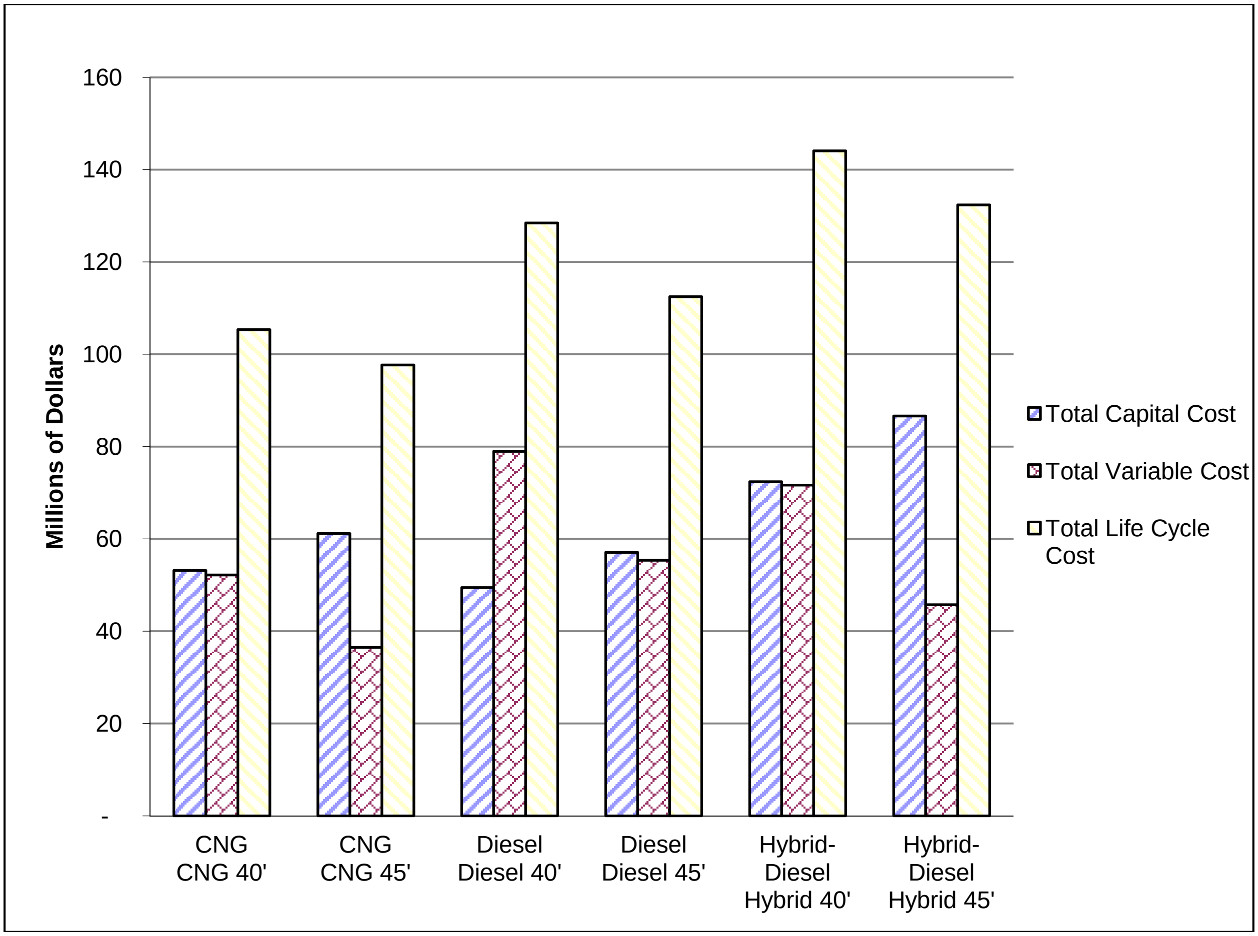


Figure 3-2 LCC Scenario Comparison II

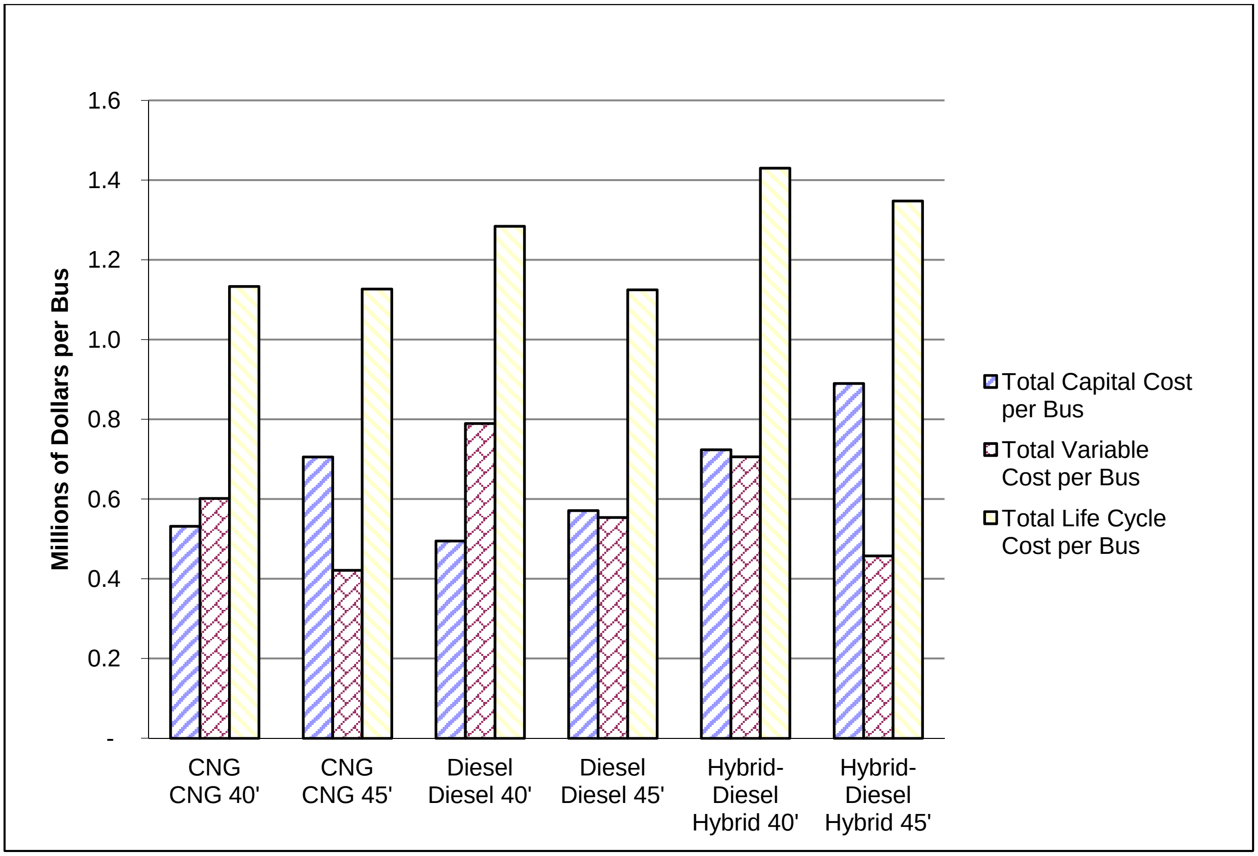


Figure 3-3 LCC per Bus

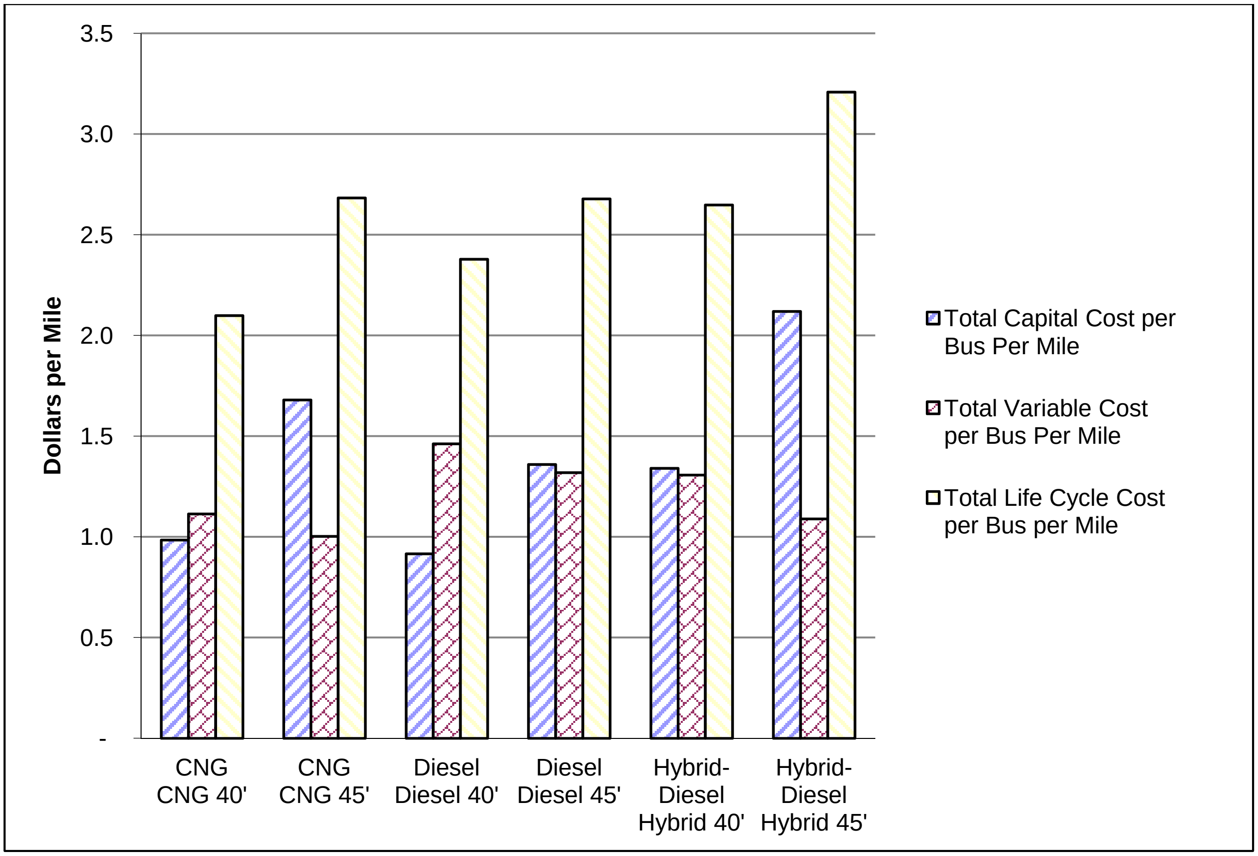


Figure 3-4 LCC per Mile

Key Findings

- The two CNG scenarios have a lower LCC than the diesel and hybrid scenarios. Table 3-6 provides each scenario's total LCC.

Table 3-6 LCC Totals

Scenario	Total LCC
CNG 40 foot	$105,354,275
CNG 45 foot	$97,691,239
Diesel 40 foot	$128,440,600
Diesel 45 foot	$112,496,129
Hybrid 40 foot	$144,064,254
Hybrid 45 foot	$132,386,944

- Without the tax credit the Total LCC for the CNG scenarios would be:
  - CNG 40ft – $113,321,488 (as compared to $105,354,275)
  - CNG 45ft - $103,291,239 (as compared to $97,691,239)
- Fuel economy and the price of fuel have major impacts on the output of the LCCM. Minor adjustments made to these variables lead to significant changes in the output.
- The cost of building, maintaining, and operating a CNG fueling facility is significant; however, the price advantage of natural gas outweighs the infrastructure costs.
- Fleet size matters—infrastructure cost per vehicle is reduced for each additional vehicle.

4. Financial Risks Associated with Implementing CNG

Inherent risks come with operating any type of fueled vehicles. This task identifies and analyzes the risks associated with implementing a CNG fueling program. The task includes the following sections:

- **Fuel-selection risk overview —**provides information on a variety of risks associated with fuel choice. The source of the information is *TCRP Report 146: Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements*.
- **Capital cost expenditures and cost recovery—**provides information on the payback period and rate of return when operating CNG vehicles. This section also provides an analysis of the fleet size and cost savings experienced.
- **LCC scenario considerations—**provides information on scenarios in which increases or decreases in high-impact cost variables would make CNG operation less attractive.

Fuel-Selection Risk Overview

TCRP Report 146 provides an overview of risks associated with fuel selection for transit vehicles. Agencies should consider five types of risk when selecting a fuel type:

- **Infrastructure risks—**the risk of loss that may occur because of the unavailability of one or more unique supply components necessary for effective operation of a system. In the case of transit fuel or technology, it can be an interruption in the supply or unavailability of fuel, fuel-specific equipment, maintenance services, warranty service, replacement of spare parts, etc., within a reasonable time and at a reasonable cost (Science Applications International Corporation 2011).
- **Technology risks—**risk from multiple factors associated with the introduction of a new technology, such as fuel cells, hybrid-electric vehicles, CNG and LNG systems, etc. The risks could include higher-than-expected costs, lower performance, higher maintenance and service costs, more service calls and downtime, safety issues, durability, infrastructure development and stability, trained personnel, etc., directly attributable to the novel technology (Science Applications International Corporation 2011).
- **Performance risks—**risks due to the loss that may occur from the inefficient operations of a component, subsystem, or the entire system. These inefficiencies may come from technological limitations, limitations due to configuration issues (e.g., higher weight of a CNG bus), more frequent failures (e.g., problems with LNG containment), inexperienced support personnel, inappropriate fuel quality, etc. (Science Applications International Corporation 2011).
- **Safety risks—**risks at the first level of impact including death, injury, and damage to property. Safety risks can also have severe secondary impacts, and in the case of transit buses, just the perception of a safety issue can ground a fleet and impose severe redesign, modification, insurance, and other costs. The factor of safety is a key risk consideration (Science Applications International Corporation 2011).

- **Fuel availability risks—**the risk of an agency experiencing a disruption in fuel supply. This risk exists for all types of fuel. However, when operating CNG, agencies typically have no on-site fuel storage. This makes the threat of disruptions much more serious for those agencies that operate CNG vehicles. As discussed previously, natural-gas suppliers provide fuel through a pipeline. If the pipeline becomes ruptured or disrupted in any way, the transit agency might not be able to fuel the vehicles. Agencies can store diesel and LNG on-site in large storage tanks. Agencies can purchase these fuels from multiple sources; therefore, the issue of fuel disruption is reduced. However, *TCRP Report 142* states, "CNG…when supplied by pipeline is an equal or more dependable source of fuel than diesel" (Science Applications International Corporation 2011). When discussing disruptions in fuel supply, the benefit of using natural gas over diesel is the fact that 80-90 percent of natural gas is produced domestically (U.S. Department of Energy 2011). While a disruption may occur in the pipeline supply to the agency, the possibility of the disruption lasting long term is very low. Two of the peer agencies, Sun Metro and Omnitrans, use LNG as a feedstock that they convert to CNG fuel. This process allows each agency to have fuel storage on-site.

Capital Cost Expenditures and Cost Recovery

As seen in the LCCM in the previous chapter, implementing a CNG fueling operation requires a significant capital investment. This section provides literature on the payback period, rate of return (ROR), and varying LCCM scenarios that could cause financial impacts on the use of CNG in a transit fleet.

Payback Period and Rate of Return

The payback period and rate of return on investments provide a way to measure the success of the investment. The definitions for payback period and rate of return are:

- **ROR—**the desired annual return on investment. When choosing a target ROR, many companies compare it to what they could make if they invested their money in another project with similar risk. Ten percent is a good baseline in the private sector because that is what the stock market has averaged over the long term. Municipal governments generally consider 6 percent the baseline because that is what it costs a government to raise money through bonds (Johnson 2010).
- **Payback period—**the period after which the investment has broken even and is starting to turn profits. At this point, an investment no longer carries the risk of losing money. Stable, progressive fleets can have a target payback period of seven years, while more risk-adverse fleets can require a three-year payback period (Johnson 2010).

Many agencies invest in a CNG fueling station for cost-savings benefits. The cost savings are highly dependent on the price of fuel. Other factors include the cost of maintenance of the vehicles and the fueling station. As seen in the LCCM, the cost of maintaining CNG vehicles is similar to the cost of maintaining diesel vehicles. The cost of maintaining and powering the CNG fueling station is on average $0.36 per DGE. To make CNG economically viable, natural gas must be priced to offset the higher capital and operating expenditures seen in CNG facilities and vehicles.

The report *Business Case for Compressed Natural Gas in Municipal Fleets*, by Caley Johnson with the NREL, provides information on the financial aspects of operating CNG in municipal fleets (Johnson 2010). Johnson developed a model that compares the use of CNG in varying municipal fleet types—such as refuse trucks, transit vehicles, and school buses. The model is called the CNG Vehicle and Infrastructure Cash-Flow Evaluation (VICE) model. In the analysis of determining the rate of return and payback period for CNG transit vehicles, the model inputs include the following variables (among others):

- Annual vehicle miles traveled—35,286.
- Average miles per gallon—for diesel 3.27, and for CNG 3.02.
- Average fuel price—for diesel $2.56, and for CNG $1.18.
- Station cost and operation—determined in the model by the number of vehicles and annual miles.
- Incremental costs of CNG vehicles—$50,502.

The VICE model also includes input variables for incentives and credits for purchasing and operating CNG fleets. The following list provides the incentives and credits used in the model:

- $0.55 tax credit per DGE.
- Credit to cover 80 percent of the incremental cost of a CNG vehicle.
- Credit of $50,000 for installing a CNG station.

The VICE model determined that when a transit agency has approximately 50 CNG vehicles, the agency can expect to see an ROR of about 30 percent, and when an agency has 200 CNG vehicles, the agency has an ROR of about 50 percent (Johnson 2010).

The payback period for a CNG station and vehicle investment is largely determined by the number of vehicles the agency operates. When an agency operates a CNG fleet of between 10 and 20 vehicles, the payback period may be in upwards of 15 years. However, when an agency has at least 30 vehicles, the payback period drops precipitously to around six to seven years. When an agency operates a fleet of 200 vehicles, the payback period drops to around three years (Johnson 2010). Johnson determined that in order for a transit agency to break even by reaching an ROR of at least 6 percent, the agency would need to operate at least 11 vehicles (Johnson 2010). Johnson also looked at what the payback period would be without the credits for a fleet of 100 vehicles. The results are provided in Table 4-1.

Table 4-1 Payback Period with and without Credits

Credit Scenario	All Credits	No Fuel Credit	No Vehicle Credit	No Station Credit	No Credits
Number of years	3.6	5.9	5.5	3.6	9.1

As shown in the table, the fuel credit has the largest impact, followed by the vehicle credit. Without any credits, the expected payback period is 9.1 years. Based on the results of the VICE model, the cost benefits/risks associated with implementing a CNG fleet are dependent on the available credits; however, without credits, the agency should see benefits within the normal 12-year life of the vehicle.

TTI researchers examined the LCCM to determine the required number of 40-foot CNG vehicles at a given facility needed to justify the capital investment for CNG. Researchers found that in order to implement a CNG fueling operation, the agency needs at least 10 CNG vehicles to have lower cost than that of diesel over a 12-year vehicle life. In this scenario, the capital costs of the CNG fueling station include capacity for only 10 vehicles, which is about $1.15 million. This scenario also does not include tax credits for either fuel. The price advantage of natural gas over diesel provides enough savings that a 10-vehicle CNG fleet is viable at any one facility. Table 4-2 provides purchase scenarios in increments of five vehicles. Based on the variables within the LCCM, the more vehicles purchased, the greater the cost savings.

Table 4-2 LCC of 40-Foot Bus Purchase Scenarios (No Credits)

Number of Vehicles	CNG 40-Foot	Diesel 40-Foot	Hybrid 40-Foot	% Difference Between CNG and Diesel
5	$6,658,045	$6,422,030	$7,454,155	-4%
10	$12,271,911	$12,844,060	$14,644,160	4%
15	$17,885,776	$19,266,090	$21,834,166	7%
20	$23,499,642	$25,688,120	$29,024,171	9%
25	$29,113,507	$32,110,150	$36,214,176	9%
30	$34,727,372	$38,532,180	$43,404,181	10%
35	$40,341,238	$44,954,210	$50,594,186	10%
40	$45,955,103	$51,376,240	$57,784,191	11%
45	$51,568,969	$57,798,270	$64,974,197	11%
50	$57,182,834	$64,220,300	$72,164,202	11%
55	$62,796,700	$70,642,330	$79,354,207	11%
60	$68,410,565	$77,064,360	$86,544,212	11%
65	$74,024,430	$83,486,390	$93,734,217	11%
70	$79,638,296	$89,908,420	$100,924,223	11%
75	$85,252,161	$96,330,450	$108,114,228	12%
80	$90,866,027	$102,752,480	$115,304,233	12%
85	$96,479,892	$109,174,510	$122,494,238	12%
90	$102,093,757	$115,596,540	$129,684,243	12%
95	$107,707,623	$122,018,570	$136,874,248	12%
100	$113,321,488	$128,440,600	$144,064,254	12%

Figure 4-1 provides the purchase scenarios in graphic form. The figure shows that as the agency purchases more vehicles, the gap widens between the LCC of diesel and the LCC of CNG grows.

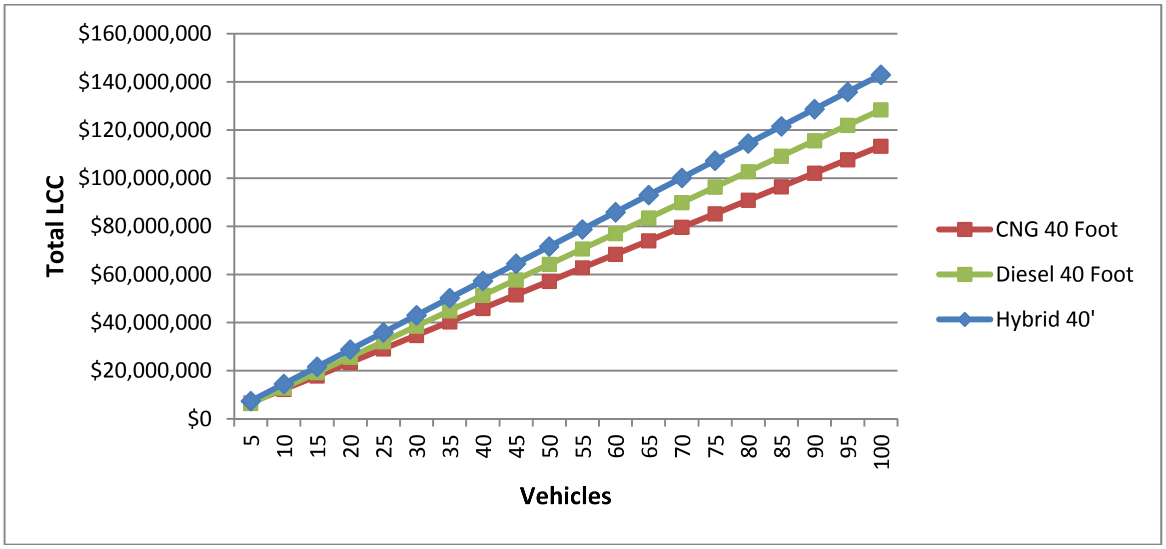


Figure 4-1 LCC of 40-foot Bus Purchase Scenarios

TTI researchers ran the same incremental test using the 45-foot bus scenarios. Table 4-3 provides the results of the incremental purchase scenarios. The results are similar to that of the 40-foot bus test. METRO would breakeven on an investment of 10 - 45-foot CNG vehicles. At 15 vehicles, METRO would begin to see savings over the diesel scenario.

Table 4-3 LCC of 45-Foot Bus Purchase Scenarios (No Credits)

Number of Vehicles	CNG 45 Foot	Diesel 45 Foot	Hybrid 45 Foot	% Difference Between CNG and Diesel
5	$6,156,533	$5,624,806	$6,870,290	-9%
10	$11,268,886	$11,249,613	$13,476,429	0%
15	$16,381,239	$16,874,419	$20,082,569	3%
20	$21,493,592	$22,499,226	$26,688,709	4%
25	$26,605,945	$28,124,032	$33,294,848	5%
30	$31,718,298	$33,748,839	$39,900,988	6%
35	$36,830,651	$39,373,645	$46,507,128	6%
40	$41,943,004	$44,998,451	$53,113,267	7%
45	$47,055,357	$50,623,258	$59,719,407	7%
50	$52,167,710	$56,248,064	$66,325,547	7%
55	$57,280,063	$61,872,871	$72,931,686	7%
60	$62,392,416	$67,497,677	$79,537,826	8%
65	$67,504,768	$73,122,484	$86,143,966	8%
70	$72,617,121	$78,747,290	$92,750,105	8%
75	$77,729,474	$84,372,096	$99,356,245	8%
80	$82,841,827	$89,996,903	$105,962,385	8%
85	$87,954,180	$95,621,709	$112,568,524	8%
90	$93,066,533	$101,246,516	$119,174,664	8%
95	$98,178,886	$106,871,322	$125,780,804	8%
100	$103,291,239	$112,496,129	$132,386,944	8%

Figure 4-2 provides the incremental purchase scenarios in graphic form.

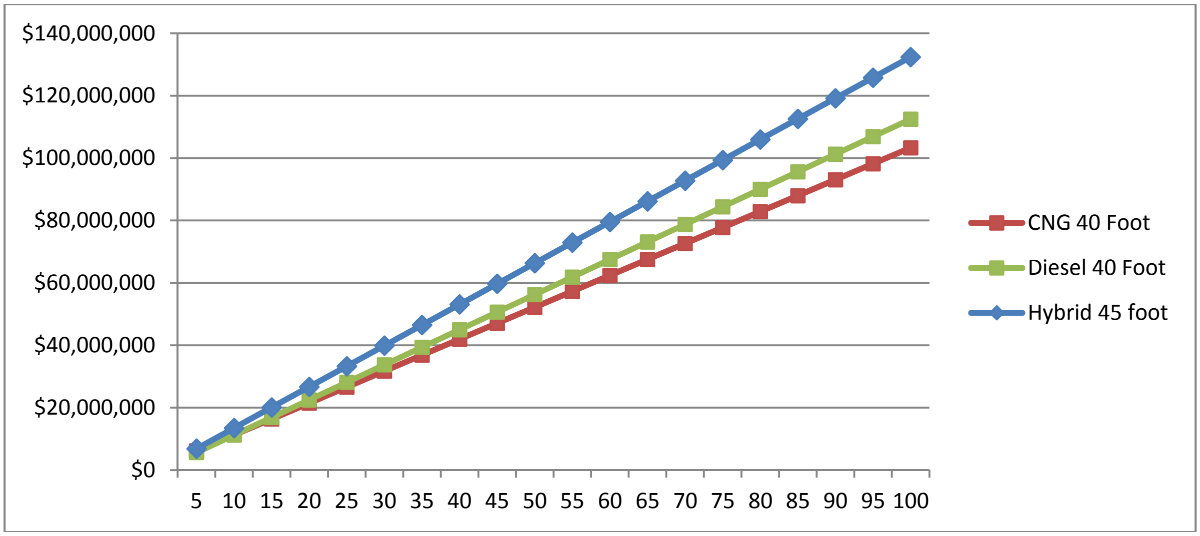


Figure 4-2 LCC of 45-foot Bus Purchase Scenarios

METRO is considering purchasing CNG vehicles beginning in 2014. Table 4-4 provides the possible procurement plan. The table displays METRO's plan to purchase additional hybrids and 60-foot articulated transit vehicles. METRO is considering purchasing 524 CNG vehicles between 2014 and 2020.

Table 4-4 METRO Procurement Plan

Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
45-Foot Hybrid	20										
45-Foot Hybrid				70							
40-Foot Hybrid	40										
40-Foot Hybrid	80										
40-Foot Hybrid		100									
60-Foot Artic			80								
60-Foot ARTICS				30							
45-Foot CNG							45				
45-Foot CNG								45			
45-Foot CNG									49		
45-Foot CNG										25	
40-Foot CNG					100						
40-Foot CNG						100					
40-Foot CNG							55				
40-Foot CNG								55			
40-Foot CNG									51		
40-Foot CNG										75	
40-Foot CNG											100
Total	**140**	**100**	**80**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

TTI researchers used the LCCM to run multiple procurement scenarios for each purchase year. The analysis included the proposed number of buses in each purchase year and accounted for the required infrastructure for each CNG purchase. The infrastructure costs for each purchase are calculated based on $1,000,000+ ($15,000 × the number of buses). Table 4-5 provides the results of the analysis.

Table 4-5 Bus Purchase Scenarios (No Credits)

Year	# of 40-foot	# of 45-foot	CNG	Diesel	Hybrid-Diesel
2014	100	0	$113,321,488	$128,440,600	$144,064,254
2015	100	0	$113,321,488	$128,440,600	$144,064,254
2016	55	45	$109,852,056	$121,265,588	$139,073,614
2017	55	45	$109,852,056	$121,265,588	$139,073,614
2018	51	49	$109,450,846	$120,627,809	$138,606,522
2019	75	25	$111,858,106	$124,454,482	$141,409,076
2020	100	0	$113,321,488	$128,440,600	$144,064,254
Total	536	164	$780,977,528	$872,935,267	$990,355,588

In each purchase, the model output shows the cost savings of CNG over diesel and hybrid-diesel. Based on the scenario, the agency can expect savings of about $92 million on the LCC for CNG over diesel.

LCC Scenario Considerations

To use the LCCM to assess the financial risk associated with implementing a CNG fleet, TTI researchers adjusted the high-impact variables within the model to determine when the LCCs for diesel and CNG are about equal. Researchers kept all variables constant with the exception of the high-impact variables, provided in Table 4-6. Researchers also assumed no credits are available. This test scenario compares a CNG 40-foot buses to a diesel 40-foot buses.

Table 4-6 LCC High-Impact Variables

Inputs	CNG 40-Foot	CNG 45-Foot	Diesel 40-Foot	Diesel 45-Foot	Hybrid 40-Foot	Hybrid 45-Foot
Size of Fleet	100	100	100	100	100	100
Annual Mileage per Vehicle	45,000	35,000	45,000	35,000	45,000	35,000
Fuel Economy (Miles per DGE)	3.66	4.05	4.00	4.43	3.86	4.94
Projected Fuel Costs (per DGE)	$1.96	$1.96	$3.65	$3.65	$3.65	$3.65
Unscheduled Maintenance	$0.30	$0.25	$0.35	$0.30	$0.14	$0.12
Scheduled Maintenance	$0.18	$0.18	$0.15	$0.15	$0.19	$0.19
Infrastructure	$2.5 million	$2.5 million	-		-	-
Annual O&M for Fueling Station	$442,620	$311,110	-		-	-

The fuel prices per DGE used in this LCCM scenario are $1.96 for CNG and $3.65 for diesel. With all variables staying constant including the price of diesel fuel, the price of CNG per DGE would need to average $2.99 to break even with the cost of diesel in the 40-foot bus scenario. This would represent a 53 percent increase in the cost of CNG per DGE. In the 45-foot bus scenario, CNG would need to increase 45 percent to $2.85 per DGE. From another perspective, if the price of CNG remains constant at $1.96 while diesel drops in price, the price of diesel would need to drop to $2.53 before the LCCs of 40-foot CNG and diesel scenarios break even. This represents a 31 percent decrease in the price of diesel. In the 45-foot bus scenario, diesel would need to decrease 27 percent to $2.68 per gallon. As seen in Figure 2-1, the prices of CNG and diesel tend to increase and decrease at the same time, so an increase in CNG price would result in an increase in diesel price as well. Table 4-7 and Table 4-8 provide the CNG and diesel scenarios used in the LCC analysis. The tables provide the breakeven fuel prices for CNG and diesel under the 40-foot and 45-foot LCC scenarios.

Table 4-7 CNG Breakeven Fuel Price with Diesel (No Credits)

Vehicle Type	Current Fuel Price	Breakeven	% + or -	Original LCC	LCC after Adjustment
CNG 40-Foot	$1.96	$2.99	53%	$113,321,488	$128,518,209
Diesel 40-Foot	$3.65	$3.65	0%	$128,440,600	$128,440,600
CNG 45-Foot	$1.96	$2.85	45%	$97,691,239	$112,520,869
Diesel 45-Foot	$3.65	$3.65	0%	$112,496,129	$112,496,129

Table 4-8 Diesel Breakeven Fuel Price with CNG (No Credits)

Vehicle Type	Current Fuel Price	Breakeven Price	% + or -	Original LCC	LCC after Adjustment
CNG 40-Foot	$1.96	$1.96	0%	$113,321,488	$113,321,488
Diesel 40-Foot	$3.65	$2.53	-31%	$128,440,600	$113,320,600
CNG 45-Foot	$1.96	$1.96	0%	$103,291,239	$103,291,239
Diesel 45-Foot	$3.65	$2.68	-27%	$112,496,129	$103,299,740

Table 4-6 provides the scheduled and unscheduled maintenance cost estimates for each LCC scenario. The total maintenance costs per mile range from $0.31 to $0.50. Each agency experiences varying costs associated with maintenance because maintenance costs are largely dependent on the operating conditions of the vehicle. To determine the cost in which maintenance on CNG vehicles would have to rise in order to break even with the cost of operating diesel vehicles, TTI researchers adjusted maintenance costs within the LCCM. All other variables in the model were held constant with the previous analysis conducted in this report. Table 4-9 provides the results of adjusting the cost of maintaining CNG vehicles.

Table 4-9 CNG Maintenance Breakeven Price with Diesel (No Credits)

Vehicle Type	Maintenance per Mile	Breakeven	% + or -	Original LCC	LCC after Adjustment
CNG 40-Foot	$0.48	$0.76	58%	$113,321,488	$128,441,488
Diesel 40-Foot	$0.50	$0.50	0%	$128,440,600	$128,440,600
CNG 45-Foot	$0.43	$0.75	74%	$103,291,239	$112,531,239
Diesel 45-Foot	$0.45	$0.45	0%	$112,496,129	$112,496,129

The table shows that CNG 40-foot maintenance costs would need to increase 58 percent to $0.76 per mile to have the same LCC as the diesel scenario. The CNG 45-foot maintenance costs would need to increase 74 percent to have the same LCC as the diesel scenario.

Key Findings

- The price of CNG per DGE would need to average $2.99 for the LCCs of 40-foot CNG and diesel to break even. This would represent an increase of about 53 percent in the cost of CNG per DGE.
- The price of diesel would need to drop to $2.53 for the LCCs of 40-foot CNG and diesel break even. This represents a decrease of 31 percent in the price of diesel.

- Maintenance costs for 40-foot CNG would need to increase 58 percent to $0.76 per mile for the CNG scenario to have the same LCC as the diesel scenario. Maintenance costs for 45-foot CNG would need to increase 74 percent to $0.75 per mile for the CNG scenario to have the same LCC as the diesel scenario.
- To implement a CNG fueling operation, the agency needs at least 10 CNG vehicles to break even with the cost of operating diesel vehicles over a 12-year vehicle life.
- When using the METRO bus purchase scenarios in the LCC, the purchase of CNG vehicles instead of diesel vehicles leads to about $92 million in savings over cumulative service lives of the vehicles.

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Appendix A: Bus-Fleet Inventory

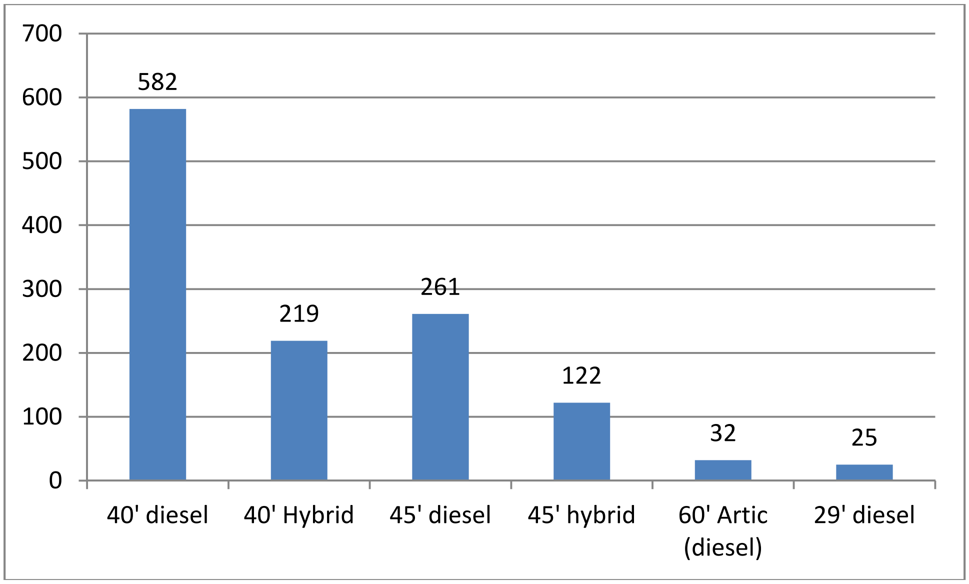

Figure A-1 Number of Vehicles by Type

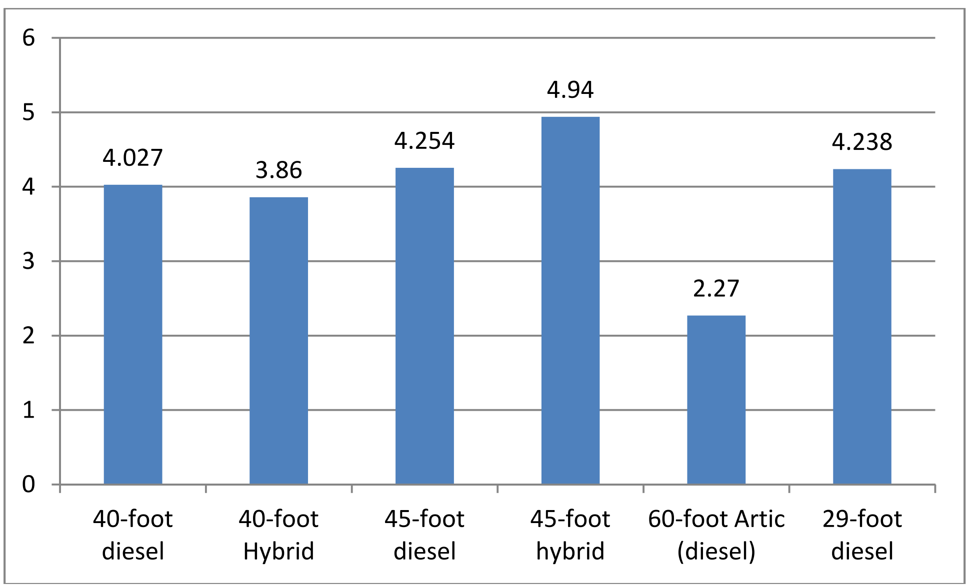

Figure A-2 Average Fuel Economy by Vehicle Type

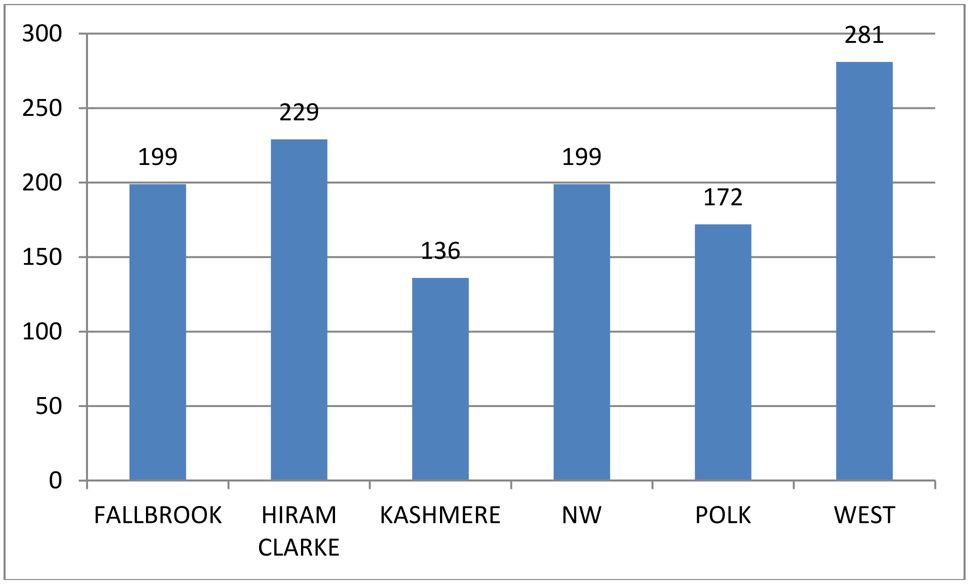

Figure A-3 Number of Vehicles by Facility

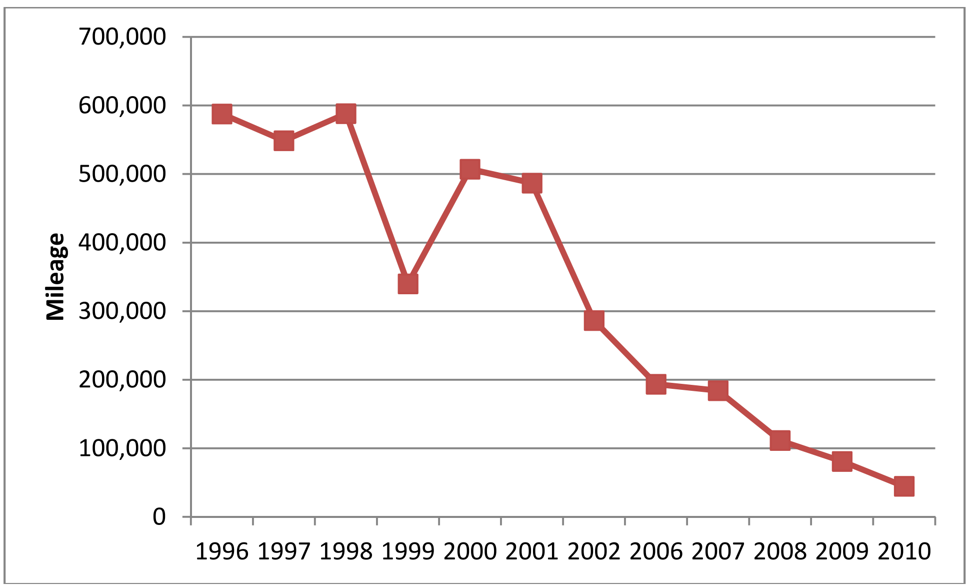

Figure A-4 Mileage by Vehicle Age

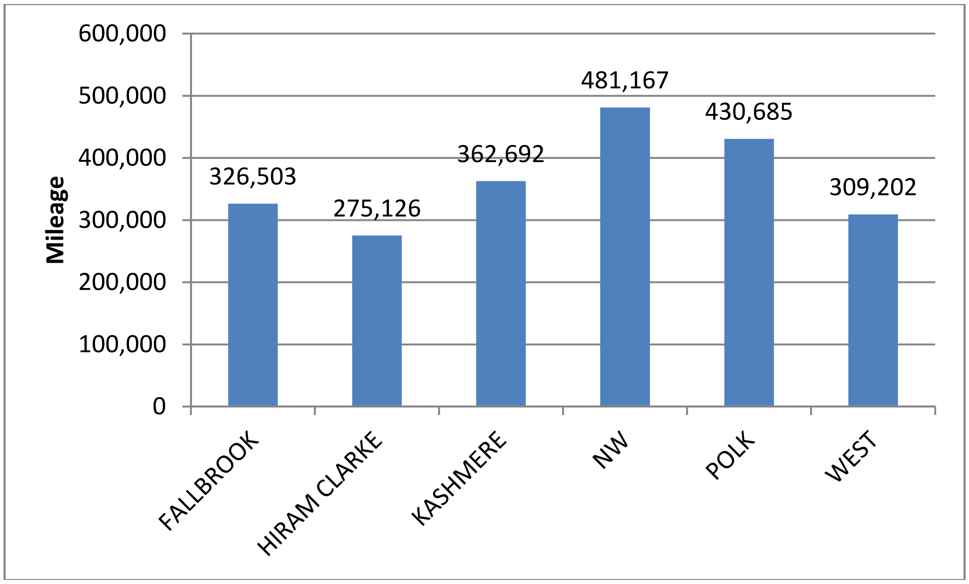

Figure A-5 Average Mileage by Facility