CALIFORNIA
NATURAL GAS VEHICLE PARTNERSHIP

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FOR IMMEDIATE RELEASE – July 26, 2005

Heavy-Duty Natural Gas Vehicles More Economical to Operate than Diesel, According to New National Report Released Today

– Crude Oil Price is a Key Variable: Over $31/barrel, Natural Gas Has the Advantage –

– Diesel Vehicle Costs Also Harder to Predict –

LOS ANGELES (July 26, 2005) — Heavy-duty natural gas powered vehicles (NGVs) that meet strict emissions standards are more cost-effective to own, operate and maintain over their lifetime than comparable diesel powered vehicles when the price of crude oil is more than $31 per barrel, according to a national report prepared by TIAX LLC, a leading product and technology development firm, for the California Natural Gas Vehicle Partnership. Oil prices have been well above $31 per barrel for some time.

"The findings of our report are significant," said Mike Jackson, Senior Director, TIAX LLC. "Transit, refuse, and short-haul fleet managers should carefully evaluate natural gas and diesel vehicle technologies that meet 2010 emissions standards. For these applications, our study indicates vehicles equipped with stoichiometric natural gas engines and three-way catalysts will have similar owning and operating costs compared to diesel engines equipped with advanced aftertreatment technologies, which enable both sets of vehicles, respectively, to meet new emissions standards.

"That said," Jackson added, "at oil prices above $31 per barrel, natural gas technologies are cheaper than the diesel alternatives and may well be the best overall option for fleet managers."

Projections of diesel vehicle costs have "a higher range of variation" than natural gas vehicle costs due to "uncertainty in the diesel engine technology and emission control equipment needed" to meet the performance demands of 2010 heavy-duty applications, according to the TIAX report.

Gunnar Lindstrom, chairman of the California Natural Gas Vehicle Partnership, a coalition of public- and private-sector interests that commissioned the report, welcomed its findings. "Diesel engines have had a significant cost advantage over natural gas up to now, but the costs of owning and operating comparable vehicles that meet 2010 emission standards, coupled with the price of petroleum, shifts the advantage to natural gas. What's more, natural gas vehicle manufacturers are now taking orders for vehicles that meet 2010 emission requirements, while uncertainties remain about diesel vehicle costs and technologies. This is solid justification to increase deployment of natural gas vehicles in California and across the country."

Lindstrom added that natural gas for U.S. transportation is primarily sourced domestically, so increased adoption of NGVs heightens the nation's energy security by decreasing reliance on foreign energy sources.

— more —

Todd Campbell, policy and science director for the Coalition for Clean Air and the environmental organizations' representative for the Partnership, has been closely involved in California issues related to mobile sources and air pollution. Commenting on the TIAX report, Campbell said, "With anticipated increases in population and vehicles on California's roads, reducing tailpipe emissions is more important than ever. We're hopeful that this report will encourage more fleet operators to deploy low-emission vehicles powered by natural gas. It's an important step to help assure clean air and a high quality of life for Californians."

More on the TIAX Report

The TIAX report, "Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies," estimated the life-cycle costs for heavy-duty diesel and natural gas vehicles that meet the stringent 2010 EPA and California Air Resources Board emission requirements. Refuse haulers, transit buses and short-haul trucks were analyzed.

The study is based on a life-cycle cost model that incorporates expected vehicle, fuel, operational and maintenance costs during a vehicle's lifetime, and then varied several factors independently. Among them were the cost of crude oil per barrel, the choice of diesel exhaust gas aftertreatment systems, the price of natural gas versus diesel, the price of liquefied natural gas versus compressed natural gas, engine costs and fuel economy. Copies of the TIAX report are available for download at: http://www.cngvp.org/HDDV_NGVCostComparisonFinalr3.pdf.

For more information on TIAX, visit www.tiaxllc.com.

More Information About Natural Gas Vehicles and the California Partnership

More natural gas powered vehicles are on the road around the world today than ever before, with their engines factory-built by the likes of American Honda Motor Company, Chrysler, Ford, General Motors, John Deere and Cummins Westport. More than 1,500 "filling" stations serve current demands for fuel in North America, with more being designed and constructed to meet future demand.

The California Natural Gas Vehicle Partnership believes that vehicle emissions and related issues need be addressed on a short- and long-term basis. Eventually, zero-emission fuel cell (hydrogen) powered vehicles will be developed and deployed on a large scale. NGVs are a vital "bridge" to hydrogen-powered vehicles, the Partnership believes, with an important role to play today and into the future.

The Partnership's members are from the public and private sectors, including government air quality, transportation and energy officials and agencies, together with vehicle and engine manufacturers, natural gas suppliers, fleet vehicle operators and environmental organizations. For more information, visit www.cngvp.org.

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Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies

Final Report

Report to the:
California Natural Gas Vehicle Partnership

South Coast Air Quality Management District

Southern California Gas Company

Date: July 15, 2005

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The authors wish to acknowledge the contributions to this report by the following:

Doug Horne – DBHORNE LLC
Kristine Isherwood – TIAX LLC
Erin Kassoy – TIAX LLC
Robert Weber – TIAX LLC
Michael D. Jackson – TIAX LLC

This report was prepared for the California Natural Gas Vehicle Partnership. Funding was provided for the Partnership by the South Coast Air Quality Management District and Southern California Gas Company. The report was reviewed by SCAQMD, California Natural Gas Vehicle Coalition, Cummins Westport and other interested stakeholders. The report's authors would like to thank the reviewers for their insightful and timely comments. Their comments have helped us improve the quality of this report.

Summary Findings

This report assesses the future life-cycle costs (LCC) of owning, operating and maintaining comparable emission diesel and natural gas heavy-duty engines for three heavy-duty applications. TIAX LLC estimated the LCCs for diesel and natural gas heavy-duty vehicles that meet the stringent 2010 EPA/CARB emission requirements. Applications analyzed were refuse haulers, transit buses, and short-haul trucks. The key findings of this report are highlighted below:

- The study shows that natural gas vehicles will be highly competitive with diesel LCCs when considering comparable vehicles that meet 2010 emission requirements
- The modeled future LCCs do not show a clear preference for one fuel choice over the other in the applications analyzed. This is significant finding, given that 2004 emission diesel engines have a significant cost advantage over natural gas currently.
- Post 2010, natural gas refuse haulers, transit buses, and short-haul trucks will have lower LCCs when oil prices are greater than $31 per barrel (2005$).
- Projections of diesel vehicle costs have a higher range of variation than natural gas vehicle (NGV) costs due to the uncertainty in the diesel engine technology and emission control equipment needed to meet the performance demands of 2010 heavy-duty applications.

The study results are predicated on the existence of 2010 natural gas and diesel technologies capable of meeting stringent 2010 EPA/CARB standards. Other sensitive parameters included the level of NGV market penetration, the cost of emission control technologies for both fuels, price ratio between compressed natural gas (CNG) and diesel, and the price ratio between liquefied natural gas (LNG) and CNG. All are explained more in the full report.

Executive Summary

Recently, there has been significant uncertainty surrounding the relative costs of 2010 technology heavy-duty diesel vehicles and their natural gas counterparts. Natural gas vehicles (NGVs) are generally considered more costly due to low production volumes and relatively expensive on-board fuel storage system. However, the California Energy Commission and the California Air Resources Board have postulated that future diesel engines may cost more due to the added cost of advanced emission control technologies required to meet 2010 Federal and California emission standards and the technologies' impact on fuel economy. [1]

To determine the relative costs between vehicles, TIAX LLC estimated the initial-owner life-cycle costs (LCCs) for 2010-technology diesel and natural gas heavy-duty refuse haulers, transit buses, and short-haul trucks. This report describes the LCC model, the study assumptions, a comparison of the natural gas vehicle costs with those of the diesel vehicles, and an analysis of the sensitivity of these costs as seen by the vehicle owner.

Through this study, we have found that 2010-technology NGVs are highly competitive with their diesel counterparts. The relative average annual cost (AAC) difference of owning, maintaining, and operating comparably equipped vehicles was found to be small over the range of expected fuel prices, vehicle technology costs and vehicle fuel economy. Section 3 of this report shows the results of the cost comparison in floating bar charts (Figures 3-1, 3-3 and 3-5) that represent significant overlap in expected prices for the vehicles considered in this study.

We found the most sensitive variables over the predicted industry average ranges to be the cost of crude oil, the percentage of NGVs sold compared to diesel new vehicle sales, the incremental cost of the required diesel exhaust gas aftertreatment (EGA) system to meet 2010 emission standards, the price ratio between compressed natural gas (CNG) and diesel, and the price ratio between liquefied natural gas (LNG) and CNG.

In the three applications analyzed, NGVs will have a significant advantage in life cycle costs when crude oil is priced at $60/bbl (in 2005$) on an average annual basis. The financial model predicts that the break-even points for a refuse hauler, transit bus, and short haul heavy-duty truck are $22/bbl, $31/bbl, and $28/bbl, respectfully, in 2010 world oil prices. These break even points are based on the example case vehicle scenarios for competing vehicles and assume the same oil price trend from the selected 2010 starting point. The price of diesel and natural gas in the transportation sector is forecasted as a function of the crude oil prices using EIA projections.

Break-even points of sensitive variables found from analyzing the example vehicle scenarios are:

- % of NGVs in fleet: Refuse – 12.5%, Short Haul – 12.5%
- Incremental cost of EGA system: Refuse – $3290, Transit – $2160, Short Haul – $4840
- CNG (DGE) /Diesel fuel price ratio: Refuse – 86%, Transit – 80%, Short Haul – 79%
- LNG/CNG (DGE) fuel price ratio: Refuse – 88%, Short Haul – 80%

[1] "California Strategies to Reduce Petroleum Dependency (AB2076)", California Energy Commission and the California Air Resources Board, December, 2001.

The life cycle costs for public transit buses are insensitive to the percentage of NGVs in fleet, because the most of the initial cost of buses are paid for by the government— 80% for diesel and natural gas buses and an additional 90% for the incremental capital costs of natural gas buses. In this application government subsidies wash out any vehicle price differences between diesel and natural gas technologies.

The ratios of CNG to diesel price and LNG to CNG price were studied separately because of the different factors that can influence the price ratios. For example CNG price will be affected by levels of imported natural gas and variations in future compression costs. Inherent price differences between LNG and CNG occur due to natural gas feedstocks, transportation, and fuel supply contracts to fleet owners.

Vehicle fuel economy and vehicle cost differentials, when independently varied over the expected industry average ranges, did not result in break-even points in any of the example scenario cases. Therefore, we found the financial model to be insensitive to these factors because these industry average ranges are fairly narrow. So, user specific values for fuel economy and cost differentials should be used to explore sensitivity to specific fleet applications which may have much different drive cycles and vocational capital costs

In summary, the study shows that the life-cycle costs of NGVs should be highly competitive over the initial owner life-time; given that the vehicle technology costs of 2010 emission level compliant diesel vehicles have less of a price advantage over NGVs in the same application. Other than some extreme price scenarios, which are examined in the sensitivity analysis, the modeled future costs do not show a clear preference for one fuel choice over the other in the applications that were analyzed.   This is a significant finding, when considering the distinct price advantages that diesel currently holds with the technologies needed that meet 2004 emission standards.

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Acronyms

AAC	Average annual cost
AEO 2005	Annual Energy Outlook 2005
ARB	California Air Resources Board
bbl	Barrel(s)
CEC	California Energy Commission
CI	Compression ignition (engine)
CIDI	Compressed-ignition direct-injection
CNG	Compressed natural gas
CO	Carbon monoxide
DGE	Diesel gallon equivalent
DOE	Department of Energy
EGA	Exhaust gas aftertreatment
EIA	Energy Information Administration
EPA	Environmental Protection Agency
HC	Hydrocarbons
HCCI	Homogeneous charge compression ignition
hp	Horsepower
LCC	Life-cycle cost
LNG	Liquefied natural gas
mcf	Thousands of cubic feet
MPG	Miles per gallon
MY	Model year
NG	Natural Gas
NGV	Natural gas vehicle
NPV	Net present value
NO_x	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
PM	Particulate matter
SCR	Selective catalytic reduction
SI	Spark ignition (engine)
Stoich	Stoichiometric
VMT	Vehicle miles traveled
yrs	Years

1. Introduction

Currently, there is significant uncertainty surrounding the relative costs of 2010 technology heavy-duty diesel vehicles and their natural gas counterparts. Natural gas vehicles are generally considered more costly due to low production volumes and fuel storage system costs. However, the California Energy Commission and the California Air Resources Board have postulated that future diesel engines may cost more due to the added cost of advanced emission control technologies required to meet 2010+ Federal and California emission standards.[2] They also postulated that future advanced emission control technologies will reduce fuel efficiency, leading to additional fuel costs.

To determine the relative costs between 2010 diesel and natural gas heavy-duty vehicles, TIAX LLC (TIAX) developed a life-cycle cost (LCC) model that takes into account the expected vehicle, fueling, and operations and maintenance (O&M) costs during the life of several heavy-duty vehicle applications. This model was used to estimate the relative initial owner LCCs of refuse haulers, transit buses, and heavy-duty short-haul trucks meeting the stringent 2010 emission standards for oxides of nitrogen (NO_x) and particulate matter (PM). This report describes the LCC model, the study assumptions, a comparison of the natural gas vehicle costs with those of the diesel vehicles, and an analysis of the sensitivity of these costs as seen by the vehicle owner.

This study estimates the costs of diesel and natural gas technologies in the 2010 timeframe. It does not attempt to build costs based on 2005 vehicle technologies and the changes that have to be made to achieve emission standards in 2007 and 2010. Instead, we have assumed that the 2010 technology is “relatively” mature and much of the learning needed to make 2010 technologies reliable and robust have already occurred during the transition to the 2010 standards. There will be short-term price fluctuations and reliability costs associated with new technologies entering the market place that the financial model does not take into consideration. There are also possible market segment irregularities that can be expected due to pre-buy strategies from fleets and near-term retrofit technologies that may enter the market place in select vocational segments. Therefore, the vehicle technologies within this report are referred to as 2010 technology and should not be confused with 2010 Model Year (MY) vehicles.

Because of the timeframe of the reported numbers, the financial model developed for this study uses expected industry average values for the technology costs including aftertreatment and fuel systems, fuel economy, fuel prices, and duty or drive cycle. In this way, the model is different than TIAX’s previous Transit Cost Tool.[3] That tool was developed to determine the life-cycle costs of various fuel and technology options in transit bus applications with user specific inputs. The results of this study should be used as inputs to the Transit Cost Tool when users would like to identify different options applicable to their fleet. For example, the Transit Cost Tool allows for the user to enter a fuel economy number that can significantly vary between users because of drive cycle. The industry average model developed for this report only looks at expected fuel

[2] “California Strategies to Reduce Petroleum Dependency (AB2076)”, California Energy Commission and the California Air Resources Board, December, 2001.

[3] U.S. DOE. Clean Cities Toolkit for Transit Buses as a Market Niche for Alternative Fuels. Developed by TIAX LLC. 2004. http://www.eere.energy.gov/afdc/apps/toolkit/transit_bus_toolkit.html

economy differences due to technology differences over the same drive cycle. Therefore, a small variation on the fuel economy numbers and engine technology costs associated with the example technology combinations are used in this study.

1.1 Final Report Content and Layout

Section 2 of this report describes the methodology and data assumptions incorporated into the LCC model. Of the many combinations of engine types, aftertreatment devices, fuels, and other parameters in the model, we selected the likely combinations and reported their relative average annual costs in Section 3 to demonstrate the range of expected average annual costs that a vehicle owner would incur in 2010. Section 4 describes the limitations and uncertainties of this LCC analysis and the sensitivity of the results to the various cost variables considered. Section 5 provides a summary and discussion of the reports findings.

1.2 Approach

This study was organized into five tasks, as described below.

1.2.1 Task 1 — Estimate 2010 Diesel Vehicle Technology Costs

In Task 1, TIAX obtained data on variables such as fuel prices, engine and vehicle system hardware and costs, and operation and maintenance costs. TIAX identified several applications with a niche natural gas fleet market to be considered in the analyses: refuse haulers, transit buses, and short haul class 7 & 8 trucks. Each of these applications has a different duty cycle and annual operation, which in turn affects the overall costing assessment.

Diesel fuel prices were estimated based on TIAX internal information and the Energy Information Administration's (EIA) projections.[4] Projections were performed only for Ultra-Low Sulfur Diesel fuel since this will be fully implemented by 2010.

Diesel engine and vehicle technology costs were estimated based on current research and development to meet 2010 low NO_x and PM standards. After determining the likely system configurations for each of the vehicle applications, we then estimated the component cost and then the total system costs including both hardware and software cost elements. These component costs were then compared to similar studies previous performed by Environmental Protection Agency (EPA) and the Department of Energy (DOE) on advanced engine technologies to confirm reasonableness in our estimates.[5,6]

TIAX also estimated O&M costs, including fuel consumption. Although it is anticipated that advanced diesel systems in 2010 will be less fuel efficient due to increased emissions control,

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[4] "Annual Energy Outlook 2005", Energy Information Administration, February, 2005. http://www.eia.doe.gov/oiaf/aeo/

[5] "Technology Roadmap for the 21st Century Truck Program", Department of Energy, December, 2000. http://www.osti.gov/bridge/

[6] U.S. Environmental Protection Agency, U.E.P., *Regulatory Impact Analysis for the Clean Air Nonroad Diesel Final Rule*. 2004. p. Chapter 6.

engine and vehicle manufacturers will also find ways of improving fuel economy by better integrating these technologies. Other possible O&M considerations include increased costs to maintain the aftertreatment systems. For example, PM filters will require cleaning after extended use. More frequent oil changes and/or more expensive oil formulations may also be required as a result of harder-working exhaust gas recirculation (EGR) systems. We identified these major maintenance cost elements and estimated the costs for maintaining the advanced technologies.

1.2.2 Task 2 — Estimate 2010 Natural Gas Vehicle Technology Costs

The objective of this task was the same as for Task 1 except that this task was completed for NGVs meeting the 2010 standards. This work was funded by NREL and performed by DBHORNE LLC. Projections for fuel prices, technology costs, and O&M costs relied on the experience with existing and prototype engines and vehicles. DBHORNE LLC used a similar methodology to estimate technology costs employed by TIAX in Task 1.

1.2.3 Task 3 — LCC Analyses

The results from Task 1 and 2 were used in Task 3 to estimate the LCC of the 2010 diesel and natural gas refuse trucks, transit buses, and short-haul trucks. TIAX updated its existing LCC models for the targeted fleet applications as well as for the newer diesel and natural gas technologies. LCC assumptions on vehicle life, discount rates, salvage value, and other factors were documented and incorporated in the LCC model. Fuel price scenarios, engine and vehicle costs, and O&M expenses were also incorporated into the model. Engine and vehicle costs were also incorporated into the model as well as O&M expenses. After finding the life cycle costs for pre-determined scenarios, a series of sensitivity analyses were performed. These sensitivity analyses were evaluated to identify the most dominant cost variables to better understand the tradeoffs between diesel and natural gas technologies for each application.

1.2.4 Task 4 — Comparative Analyses

The LCC analysis results were used in Task 4 to perform a comparative analysis between diesel and natural gas technologies. Factors such as differences in fuel prices, aftertreatment and engine capital costs, replacement intervals, and O&M costs affect how well or how poorly the technologies compete. All of these factors were identified and included in the comparison. Because we expect that there will not be a NO_x or PM benefit associated with either technology in 2010, technology costs will be the primary decision criteria used by fleets. However, other issues may also come into play such as the level of consumer confidence in newer technology, or cost/price estimates, or vehicle performance. In order to address these issues, TIAX identified and discussed several of these issues in the context of this comparative analysis.

1.2.5 Task 5 — Document Results

This report covers the efforts performed in Tasks 1 through 4. This document identifies the assumptions made in the analyses and bounds the expected LCC for diesel and natural gas heavy-duty vehicles.

2. Purpose of the Study

In order to estimate the relative cost difference of diesel versus natural gas heavy duty vehicles in the 2010 timeframe, TIAX modified an internal LCC model to estimate the annualized capital and operating expenses of heavy-duty vehicles over their lifetime in 2005 dollars. The model compares technology choices to meet the 2010 heavy-duty vehicle emission standards in three applications: refuse hauler, transit bus, and short haul truck. TIAX's previous Transit Cost Tool, developed to determine the life-cycle costs of various fuel and technology options in transit bus applications, provided the backbone for this model. [7] The current tool was expanded to include the other applications; allow for variations in fuel costs, fuel economies of diesel and natural gas engines, and the engine costs. It also allows the user to determine the rebuild/replacement period for the emission control system and enter a projected natural gas vehicle market penetration level. These are some of the factors used to identify the sensitivities in the projected cost estimates.

TIAX used several reports to provide input data. The majority of the cost values came from TIAX and Global Insights, Inc.'s recently released study "The Future of Heavy-Duty Powertrains" (referred to as HD Powertrains).[8] Cost estimates from this study were based on typical application cycles and included diesel engine costs, aftertreatment costs and fuel economy penalties, annual maintenance costs, application fuel economy and emission rates, and annual vehicle miles traveled. This was an extensive multi-client study that utilized drive cycle simulation tools and technology cost and efficiency models. These data were supplemented with information from the U.S. Department of Energy (DOE) sponsored report "Technology Roadmap for the 21st Century Truck Program" (referred to as 21st Century Truck) released December, 2000. [9] Projections of natural gas technology costs came from the California Energy Commission / Air Resources Board (CEC/ARB) report "California Strategies to Reduce Petroleum Dependency (AB2076)" (referred to as Petroleum Dependency), December, 2001. [10] In particular, the Attachment B report from Task 3 "Staff Reports on Petroleum Reduction Options" was used to predict differentials in future heavy-duty vehicle costs and efficiencies. Projected fuel costs were based on the forecasted prices by the EIA "Annual Energy Outlook 2005" (referred to as AEO 2005) report. [11]

Because this report is tasked with the comparison of future diesel and natural gas vehicle technologies and their associated costs, the focus was on relative differences in price and efficiency rather than in the absolute numbers. For example, relative fuel price differences between natural gas and diesel are more important than the actual prices in determining the comparative overall operating costs. It is also important to note that fuel price volatility means a range of actual costs are possible in the future. TIAX did not attempt to weigh any price points

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7 U.S. DOE. Clean Cities Toolkit for Transit Buses as a Market Niche for Alternative Fuels. Developed by TIAX LLC. 2004. http://www.eere.energy.gov/afdc/apps/toolkit/transit_bus_toolkit.html

8 "The Future of Heavy-Duty Powertrains", TIAX and Global Insight, Inc., December 2004.

9 "Technology Roadmap for the 21st Century Truck Program", Department of Energy, December, 2000. http://www.osti.gov/bridge/

10 "California Strategies to Reduce Petroleum Dependency (AB2076)", California Energy Commission and the California Air Resources Board, December, 2001.

11 "Annual Energy Outlook 2005", Energy Information Administration, February, 2005. http://www.eia.doe.gov/oiaf/aeo/

more heavily than others. While the LCC model provides annualized capital and operating costs, the projections of critical costs such as fuel, engine, and maintenance are relative estimates. The model is designed to illustrate sensitivities to the cost differentials of the two fuel choices, diesel and natural gas.

2.1 Applications, Fuels, Technology Options Studied

Table 2-1 summarizes the range of vehicle applications, engine and aftertreatment technologies, fuel type, maintenance options, and pricing assumptions included in the current study. The remainder of Section 2 discusses the assumptions used by the model to calculate costs.

Table 2-1. Vehicle, Fuel, and Maintenance Options

Vehicle Application Options	
Refuse Hauler	Refuse or garbage truck
Transit Bus	Intercity public transit bus
Short Haul	Class 7/8 suburban delivery vehicle

Vehicle Engine Technology	
Diesel	
CIDI	Compression-ignition direct-injection
HCCI	Homogenous charge compression ignition
Natural Gas	
Stoich	Advanced EGR Stoichiometric combustion engine

Emission Aftertreatment Options	
Diesel	
Option 1	Catalyzed PM trap, HC Selective Catalytic Reduction, Oxidation Catalyst
Option 2	Catalyzed PM trap, Urea Selective Catalytic Reduction, Oxidation Catalyst
Option 3	Catalyzed PM trap, Sulfur trap, NO_x trap, Oxidation Catalyst
Option 4	Continuously regenerated PM trap, HC Selective Catalytic Reduction, Oxidation Catalyst
Option 5	Continuously regenerated PM trap, Urea Selective Catalytic Reduction, Oxidation Catalyst
Option 6	Continuously regenerated PM trap, Sulfur trap, NO_x trap, Oxidation Catalyst
Option 7	4-way Catalyst (CIDI only)
Natural Gas	
3-way Cat	3-way Catalyst

Natural Gas Fuel Type	
CNG	Compressed natural gas
LNG	Liquefied natural gas

Replacement/ Rebuild Period of Emissions Control System	
435,000 miles	Owner chooses to replace aftertreatment devices and rebuild engine at 435,000 miles
10 years	Owner chooses to replace aftertreatment devices and rebuild engine at 10 years

Table 2-1. Vehicle, Fuel, and Maintenance Options (concluded)

Percentage of Natural Gas Vehicle Technology in the Production Fleet	
5%	5% of the annual production of a system (engine, aftertreatment) is for NG applications
12.5%	12.5% of the annual production of a system (engine, aftertreatment) is for NG applications
50%	50% of the annual production of a system (engine, aftertreatment) is for NG applications

Natural Gas Price Percentage with Respect to the Diesel Price (DGE)	
EIA estimate	Percentage is variable following EIA's projected yearly forecast
80% of Diesel	Percentage is fixed to 80% of diesel price in each year
90% of Diesel	Percentage is fixed to 90% of diesel price in each year

Liquefied Natural Gas Price Percentage with Respect to the Compressed Natural Gas Price (DGE)	
84%	Percentage is forecasted based on in-use numbers
79%	Percentage is varied by -5%
89%	Percentage is varied by +5%

2.2 General Assumptions: Vehicle Application Selection

Table 2-2 indicates the assumed values for the vehicle applications that TIAX studied. These values were determined to be representative of the application and drive cycles of the given applications. TIAX's HD Powertrain and DOE's 21st Century Truck reports were both used to compile this table. The characteristics, such as power rating, of the vehicles in each of the applications were found by looking at the current market leader in the classifications and assuming that they best define the market needs of that sector. Information about vehicle life, and vehicle miles traveled (VMT) were compiled during the research for the TIAX HD Powertrain study. Fuel economy and the percent variation values are from the drive-cycle model simulation completed during that study. The results of this simulation were compared to the findings in the 21st Century Truck report to find the appropriate drive cycle and load conditions applicable to this study. The fuel economy of refuse haulers assume that some hybridization has occurred for the 2010 timeframe. This is important because of the higher than average vocational work-load that occurs in this application. Therefore, the HD Powertrain report found a sharper increase in the industry average fuel economy for refuse haulers than in the other applications that were studied. Fuel economy for stoichiometric natural gas engines is 95% of the 2010 diesel engine. Vehicle chassis costs and annual maintenance costs are also a product of the HD Powertrain report and are assumed to be equivalent for the diesel and natural gas applications. Additional maintenance costs that were used in the model, but do not appear in this table are $700/year for PM trap maintenance on the diesel vehicles and $200/year for service checks on the liquefied natural gas (LNG) fuel systems and $500/year for spark-plugs on the stoichiometric engines. Fuel system costs were estimated based on Clean Vehicle Education Foundation's experiences with NGVs.[12]

[12] Conversation with Doug Horne on March 15, 2005.

Table 2-2. Vehicle Characteristics: Model Inputs

	Refuse Hauler	Transit Bus	Short Haul
Engine rating (hp)	325	285	470
VMT (miles)	24,860	46,600	55,920
First Owner Life (yrs)	6.5	12	10
Fuel Economy (MPG)	3.3	3.2	4.3
FE % variation[a]	±5.1%	±2.8%	±2.3%
Annual Maintenance	$25,830	$39,730	$27,400
Base Vehicle Costs			
Chassis	$115,880	$239,370	$132,480
Engine	$50/kW	$50/kW	$50/kW
Fuel System Cost			
Diesel	$150	$150	$150
Natural Gas	$9,000	$22,000	$9,500
Aftertreatment	based on selection (see section 2.4)		

[a] The variation shown is due to technology differences and is not drive cycle related

2.3 General Assumptions: Engine Technology Selection

Diesel engine costs were based on the assumption that the base engine cost of a 2010 compliant engine, without aftertreatment, is $50 per kilowatt. This base engine cost uses the CIDI engine, as shown in Table 2-3. Incremental diesel engine costs were taken from the technology cost analysis performed for the HD Powertrain report and are shown as percentage increases in the table. It is assumed that the Homogeneous Charge Compression Ignition (HCCI) engines that will be available in the 2010 timeframe are all mixed-mode HCCI engines with a maximum homogeneous charge capability in the range of 8-10 bar (modern diesel engines operate up to 20 bar). The natural gas engine costs were determined from the CEC/ARB's "California Strategies to Reduce Petroleum Dependency (AB2076)" Table 1E-3 *Component Cost Estimate of Emissions Compliance Technologies*.[13] Percentages of engine costs were calculated from the values in this table by removing the aftertreatment device cost and the chassis re-engineering costs, which we are covering separately in the life-cycle cost model. Table 2-3 shows the range of possible costs associated with the different options available in the model based on the CIDI engine base cost and are shown as the percent increase of the baseline engine. It is assumed the natural gas engines are EGR stoichiometric engines that take advantage of the advanced engine control technologies that have been developed for gasoline engines both in the light-duty and heavy-duty markets. These stoichiometric natural gas engines are assumed to be diesel engine-core variants, since the warranty and useful life requirements of engines in class 7-8 trucks are so demanding.

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[13] "California Strategies to Reduce Petroleum Dependency (AB2076)", California Energy Commission and the California Air Resources Board, December, 2001.

Table 2-3. Engine Cost: Model Inputs

	CIDI		HCCI		Stoich	
	Low	**High**	**Low**	**High**	**Low**	**High**
Refuse Hauler	Base Case	135%	102%	135%	125%	150%
Transit Bus		138%	102%	138%	117%	161%
Short Haul		125%	102%	125%	125%	139%

Another possible option for NG engines is lean-burn, which is the engine technology that exists in the market place today. These engines are typically variants of diesel engines, which have been redesigned to use either compressed natural gas (CNG) or LNG. Spark ignited, lean-burn engines are projected to have higher differential costs and require additional aftertreatment devices than the advanced EGR stoichiometric engines. High pressure, direct injected lean burn natural gas engines could also be developed but there are current uncertainties regarding costs and market acceptance. For these reasons, the natural gas industry plans to just produce the advanced EGR stoichiometric engines for the 2010+ market. Therefore, we did not consider the lean-burn NG engine option in any of the likely scenarios for this report.

2.4 General Assumptions: Aftertreatment Device Selection

The emission control devices themselves are highly engineered devices and are projected to add significantly to the cost of the powertrain either directly (the devices themselves) or indirectly (because of added complexity of engine control algorithms). Moreover, the installation and operation of emission control devices in the exhaust stream necessarily increases the fuel consumption and operating cost of the engine, partly because of the increased back pressure and partly from the additional fuel or other reagents required to reduce NO_x emissions. Current estimates range as high as 20-30% of the cost of the engine to install a complete system. The costs will decrease over time, as the systems evolve to use less precious metal and as production becomes more efficient with practice and production volume.

Choice of aftertreatment technology determines the price for the device and a multiplier for the fuel economy penalty. The device cost is derived from the engine's power rating compared to an assigned rating for medium-heavy and heavy duty applications. The costs are shown in Table 2-4. Fuel economy penalties due to back pressures in each of the aftertreatment devices, ranging from 1-3%, are assigned and multiplied together for system back pressure, depending on the selection of the options shown in Table 2-1.

The operating portion of the life cycle costs are duty cycle and vehicle dependent, and have been determined by vehicle operation and modeling using GT Drive[14] as part of TIAX's HD Powertrain study. Estimates of initial aftertreatment cost presented in Table 2-4 attempts to account for the evolution of the technologies along a learning curve, implying decreases in loadings of costly metals and higher throughput manufacturing. The costs of sensors and modifications to the engine control system were added to the estimates and are comparable to

[14] Gamma Technologies, Inc., "GT Drive" part of GT-Suite version 6.1.0

Table 2-4. Aftertreatment Costs: Model Inputs

Device	Med-heavy	Heavy
Catalyzed particulate trap (PM)	$ 1,300	$ 1,500
Continuously regenerated trap (PM)	$ 2,100	$ 2,400
Sulfur trap (S)	$ 1,560	$ 1,820
HC SCR (NO_x)	$ 790	$ 900
Urea SCR (NO_x)	$ 2,220	$ 2,520
NO_x trap (NO_x)	$ 1,300	$ 1,430
4-way catalyst (CO, HC, PM, NO_x)	$ 2,470	$ 2,860
3-way catalyst (CO, HC, NO_x)	$ 1,500	$ 1,300
Low temp oxidation catalyst (CO, HC)	$ 1,500	$ 1,300
Oxidation catalyst (CO, HC)	$ 540	$ 610

those estimated by the U.S. EPA[15]. Our costs are lower than EPA's in the cases of the hydrocarbon Selective Catalytic Reduction (SCR) and for NO_x traps because we have assumed improvements in the technology that reduce the amounts of expensive metals.

The choice of emission control technology will undoubtedly vary with application. When fuel cost is a critical aspect of vehicle operation, the operating cost of the powertrain/emission control system will be optimized. When the duty cycle of the vehicle is highly transient, e.g., low mileage utility vehicles, then flexibility of operation will be favored over the cost of the reagents or fuel dedicated to emissions control.

The model created for this life-cycle cost analysis assumes that all aftertreatment systems identified as viable solutions during the HD Powertrain study and modeling are effective at reducing pollutants to the required levels of 2010 heavy-duty standards. Modeling of the emission control effectiveness and the engine-out emission levels was not completed in this analysis. GT Drive modeling that was completed for the HD Powertrain study did calculate the annual amount of reductant needed in the SCR systems based on the NO_x levels of the diesel engine technologies over representative drive cycles. The cost of the required annual reductant needed was determined during that study and those values are used as constant inputs into this financial analysis.

There are considerable technology challenges to developing emission control systems to meet the very stringent 2010 NO_x and PM standards. These systems not only have to achieve the very low emissions but do so without substantial increases in fuel economy and over the useful life of the vehicle (435,000 miles for heavy, heavy duty applications). No production system exists today to achieve the standards so we studied several different options for each diesel vehicle. Uncertainty exists in the type of technology that will be employed for these applications. There

[15] U.S. Environmental Protection Agency, U.E.P., *Regulatory Impact Analysis for the Clean Air Nonroad Diesel Final Rule*. 2004. p. Chapter 6.

are indications that 4-way catalyst aftertreatment system option will not be available until several years after 2010. Therefore, interim or alternative solutions are likely to be needed.

2.5 General Assumptions: Other Cost Factors

Several additional cost factors were applied in this study. The vehicle, engine, and aftertreatment costs discussed above for natural gas technologies assume that these elements will be produced at the same annual volume as for the competing diesel vehicles and associated systems. Since this is historically not the case, the model has an economy of scale factor that is applied to natural gas component costs based on a percentage of NGVs within a heavy duty engine/vehicle line. Complete and accurate numbers to define the size of an engine/vehicle line are difficult to compile because the engines, aftertreatment devices, and fuel systems could be used in multiple applications in the 2010 timeframe, both in on-road and off-road vehicle segments. It is also possible that an aftertreatment device is used in new NGVs and as a retrofit on existing vehicles. For this report, we assume that the same economy of scale factor is applied equally to the natural gas engine, aftertreatment device and fuel system. Table 2-5 shows the economy of scale factors as a function of the percent market penetration of the entire heavy-duty vehicle fleet in 2010. These values are applied as a step function at the indicated vehicle percentage levels. Therefore, there is no difference in the financial model between a penetration rate of 12.5% and 25%--a factor of 1.25 will be applied in both cases. Equal volumes of diesel and NGVs (a market penetration rate of 50%) will give a one-to-one cost ratio, or no economy of scale cost penalty for the NGVs.

Table 2-5. Economy of Scale Factor: Model Inputs

NG Vehicle Percentage	Economy of Scale Multiplier [a]
50%	1
12.5%	1.25
5%	1.625

[a] TIAX estimate

Replacement costs of emission control devices and the cost of rebuilding an engine during the first-owner life were also included in the life-cycle cost analysis. To do this, TIAX opted for aftertreatment device replacement and engine rebuild interval periods of 10 years or 435,000 miles. This is based on expected 2010 warranty requirements of the emission control system for heavy-duty on-road vehicle applications. While it is not likely that all vehicles will replace the emission control devices as soon as the warranty period expires, there is reason to believe that regulations with respect to the in-use performance of the emission control devices will be in place by the time 2010 heavy-duty vehicles reach the end of their warranty life. It is at the end of the warranty period that the owner will first incur the full cost of replacing parts and rebuilding an engine that does not meet in-use emission standards. We also assumed that the owner will not replace and rebuild in the last year of a vehicle's life.

Because of the first-owner lifetime and the vehicle miles traveled (VMT), indicated in Table 2-2, there are cases where the emission control devices will not be replaced by the first owner. Therefore, the replacement and rebuild costs will not be incurred. Based on interviews with emission control manufacturers performed during TIAX's HD Powertrain study, we estimated the replacement cost of the aftertreatment devices to be three times that of the initial cost when purchased by the vehicle manufacturer. The cost to rebuild the engine, which is assumed to be done at the same time as the aftertreatment system replacement, is set to 100% of the initial engine cost to the manufacturer. Table 2-6 shows when the rebuild/replacement costs will be applied based on the selected interval period for each of the applications studied.

Related, but not equivalent to the useful life defined by the regulatory bodies, are value-lives in years that were separately assigned to the chassis, engine, aftertreatment system, and fuel system. Residual and scrap values for the vehicles at the end of the life of the first owner are calculated by dividing the age of sub-system, taking into account replacement of the aftertreatment or rebuild of the engine, by value-life and multiplying by 2/3. The value-life assigned to the sub-systems is defined in Table 2-7.

While an engine may be determined to have a rebuild period of 10 years, the value-life is assigned as 12 years, indicating there is some value of the engine before rebuild. 6.5 years is used for the value lifetime of the chassis and aftertreatment system on the refuse hauler, indicating the typical 'drive-to-scrap' lifetime of that application. Therefore, the scrap value of this vehicle is defined by the remaining value of the engine and fuel system. Residual values are found for the other two applications, indicating the projected value of the vehicle at the end of the first-owner life. While the vehicles may be used, on average, longer than the value-lives indicate for the sub-systems (i.e., 15 years for transit bus and short haul truck chassis), it was felt these value-lives should be used to determine the value of the various subsystems throughout their useful life.

After the residual or scrap values were found for the diesel and NG application, one further step was taken to normalize the value of these vehicles. Because it is likely that diesel vehicles will have the majority of the national market share in each of the applications studied and that the market for used NGVs and NGV parts might be limited to fleets that have previously adopted

Table 2-6. Emission Control Replacement, Engine Rebuild Decision Table

Replacement Period Selection	Refuse Hauler	Transit Bus	Short Haul
10 years	No Cost	Cost Incurred	No Cost
435,000 miles	No Cost	Cost Incurred	Cost Incurred

Table 2-7. Sub-system Value-Lives in Years: Model Inputs

	Refuse Hauler	Transit Bus	Short Haul
Chassis	6.5	15	15
Engine	12	12	12
Aftertreatment	6.5	10	10
Fuel System	15	15	15

NGV technologies, the NGV residual or scrap value was set to be no greater than that of the equivalent diesel vehicle. This has the effect of lowering the value of the NGV at the end of the first owner lifetime than when calculated as described above, since the initial capital cost of the NGVs is greater than the diesel equivalent in most cases.

2.6 Natural Gas Fuel Use Selection

TIAX studied both LNG and CNG fuels. For this analysis we assume that the Short Haul and the Refuse Haulers are LNG vehicles, while the Transit Bus is a CNG vehicle. These assumptions are consistent with current market trends and the needed range of the vehicles over the representative drive cycles. Future trends of vehicle scenarios could result in changes to these assumptions. For the model, all fuel prices and efficiencies are entered on a diesel gallon equivalent (DGE) basis.

2.6.1 Fuel Price Variation

The model uses fuel price forecasting from the Energy Information Administration's "Annual Energy Outlook 2005"[16] report. This report gives projected fuel prices for diesel and natural gas for use in the transportation sector. These costs include national average costs for taxes, delivery, storage, and compression — in the case of natural gas, giving a price for CNG. All fuel costs are given in 2005 dollars. All fuel prices assume use of a third party vendor who must recover capital and operating costs within the pump price of the fuel. Fueling infrastructure costs are not individually considered in this study.

The EIA forecasted range of fuel prices, given in high, base, and low cases, vary based on a 2010 average annual crude oil cost of $25/barrel (bbl) which increased to slightly over $29/bbl in 2022. TIAX decided that EIA's variation was not broad enough, considering the fact that cost of oil peaked above $50/bbl in the first half of 2005. This is a current high within the year and is not necessarily equivalent to the average annual cost. As a result, we generated high and low price scenarios for use in the model. For our high case, we choose a 2010 average annual oil cost of $60/bbl. For the low price scenario, we chose a 2010 average annual crude oil cost of $18/bbl. The crude oil price projections were converted to annual diesel prices using EIA's formula for calculating diesel price from crude oil. The results of these calculations are shown in Figure 2-1.

Similarly for natural gas, EIA provided estimated prices for CNG based on a 2010 average annual wellhead price of 3.64 dollars per mcf. These prices were increased by the same ratio of the high diesel price scenario to find the high case natural gas price scenario. An average annual wellhead price of 2.62 dollars per mcf for 2010 was used for the low case. We used EIA's formula for calculating CNG price from wellhead price over the given time period. The results of these calculations are shown in Figure 2-2. Figure 2-3 shows the price differential of diesel over CNG for the analysis time period. EIA's base case price ratio forecast is used for the three price scenarios and is shown in Figure 2-3.

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[16] "Annual Energy Outlook 2005", Energy Information Administration, February, 2005. http://www.eia.doe.gov/oiaf/aeo/

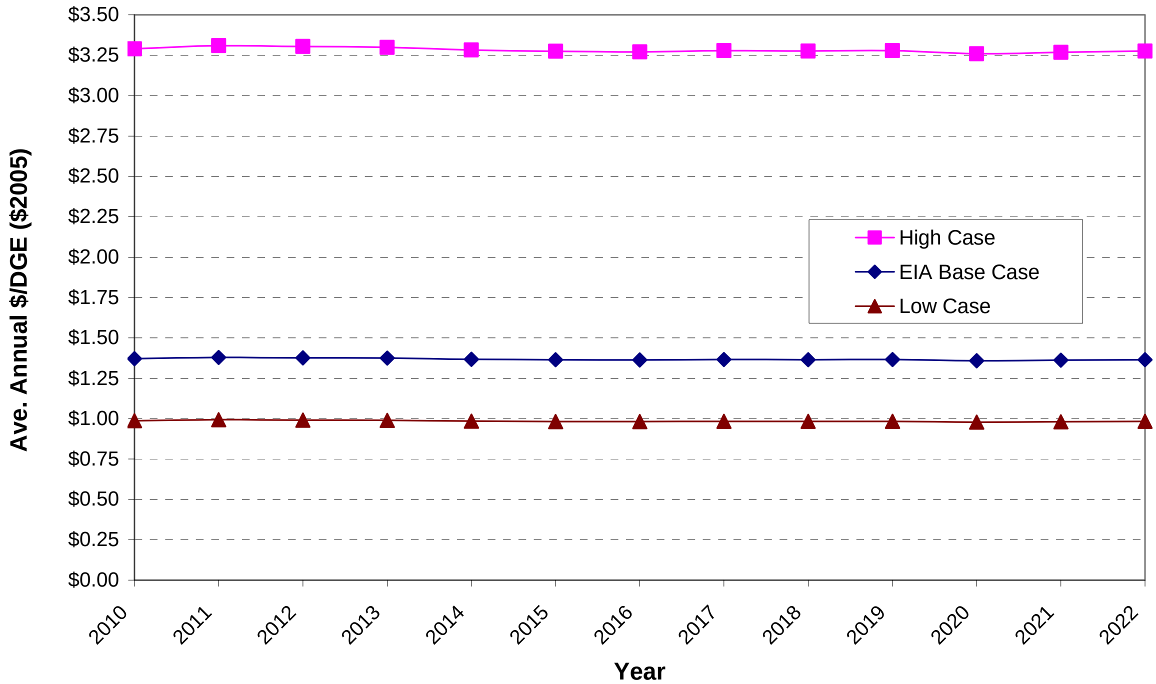


Figure 2-1. Diesel Price Range used in the Analysis

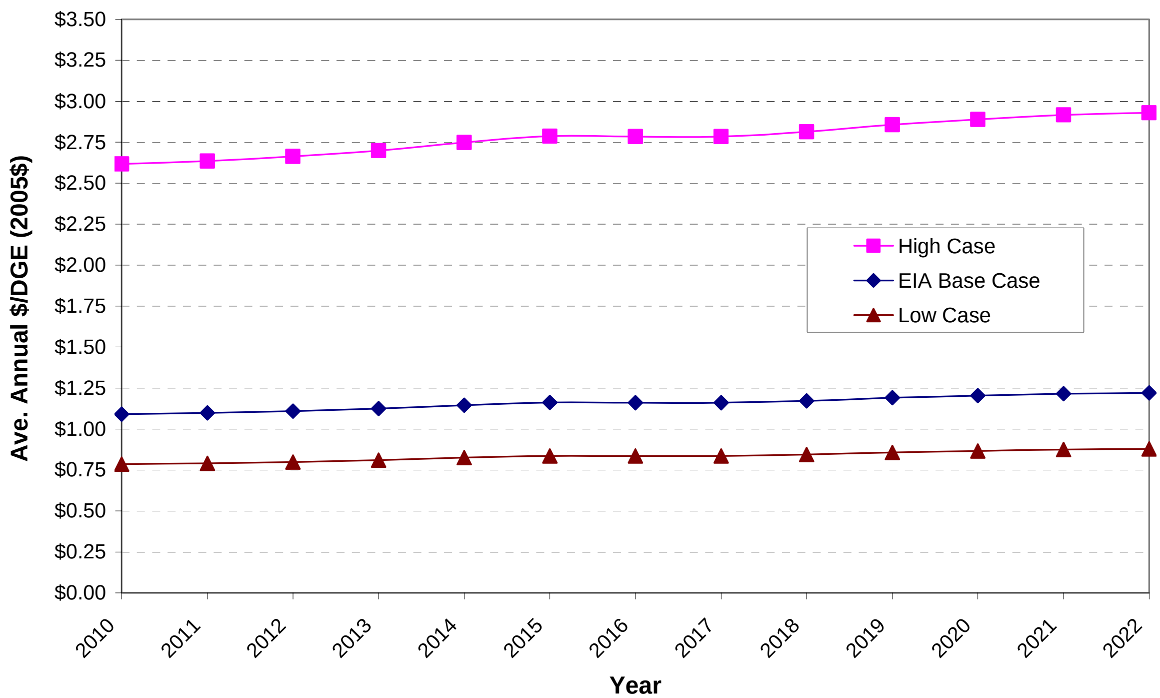


Figure 2-2. CNG Price Range used in the Analysis

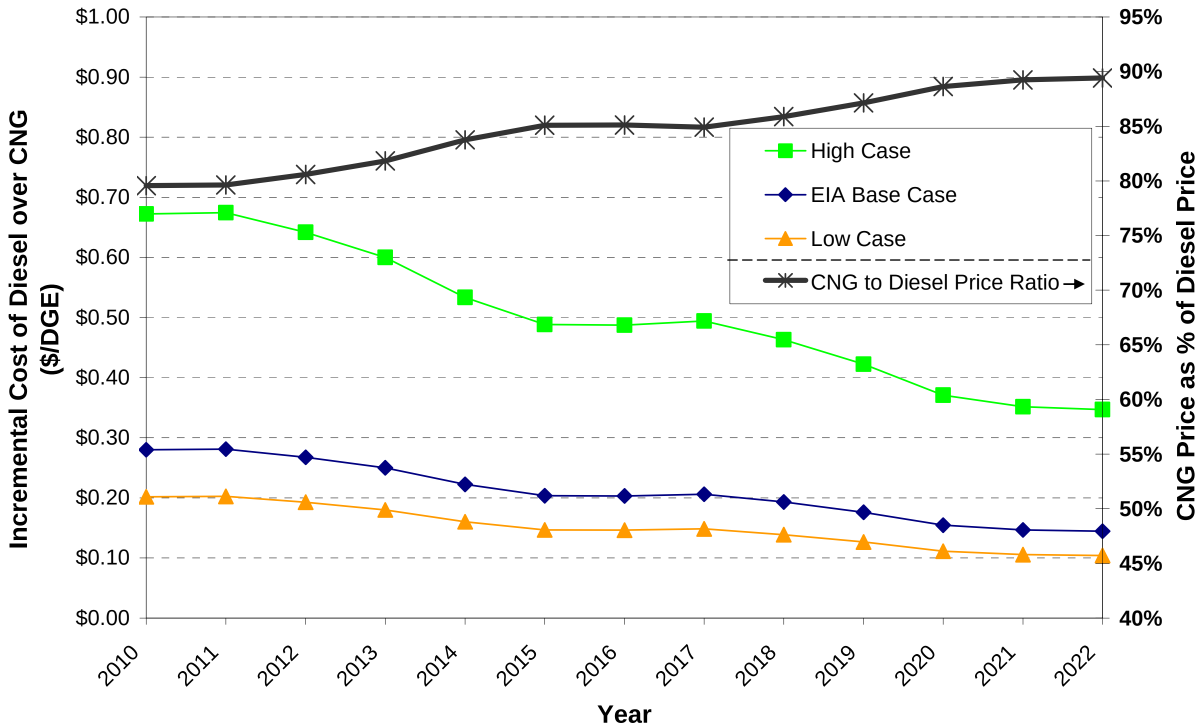


Figure 2-3. Incremental Cost of Diesel over CNG

For liquefied natural gas (LNG), we used a base assumption of 84% of the price of CNG for all fuel scenarios. This value was determined from in-use fleet experience.[17] The resulting prices used for LNG in the analysis are shown in Figure 2-4. Figure 2-5 shows the price differential and the price ratio of diesel over LNG for the analysis time period.

Because the base case presented by EIA includes all federal and state taxes, on a national average, and we increased the projection based on doubling the price of oil, we feel that the range of fuel prices provided will capture differences between the California market and the country's average. Therefore, we did not attempt to segment the additional taxes and market price increases that occur in California. In the case of the transit bus, the discounted fuel taxes are removed from the overall fuel price at $0.35/gallon for diesel and $0.16/DGE for CNG[18].

The three price scenarios discussed above continue to have the base case projected relationship between the assigned price of diesel and price of CNG– shown as CNG to Diesel Price Ratio in Figure 2-3. We also studied two other CNG cost options because many factors could have an effect on this relationship including: the level of imported natural gas; modifications to the fuel

[17] "Natural Gas Liquefaction", Idaho National Engineering and Environmental Laboratory, April 2004
[18] "Transportation Fuel Tax Rates for 2004" updated July 2004, California Energy Commission website http://www.energy.ca.gov/gasoline/fuel_tax_rates/html

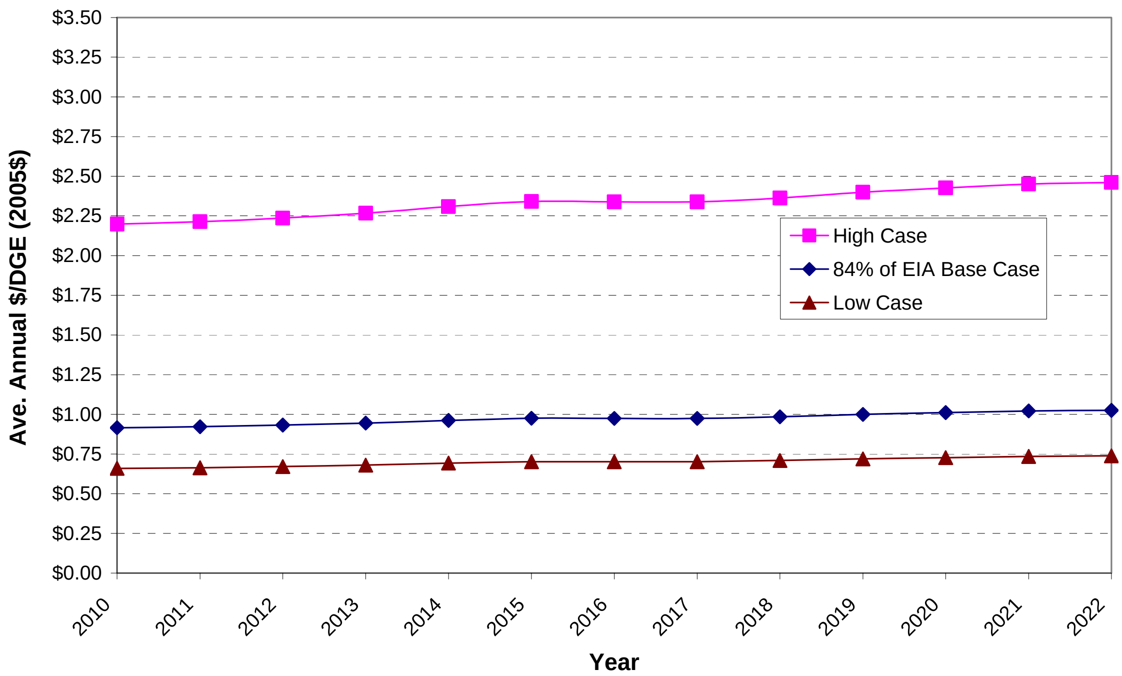


Figure 2-4. LNG Price Range used in the Analysis

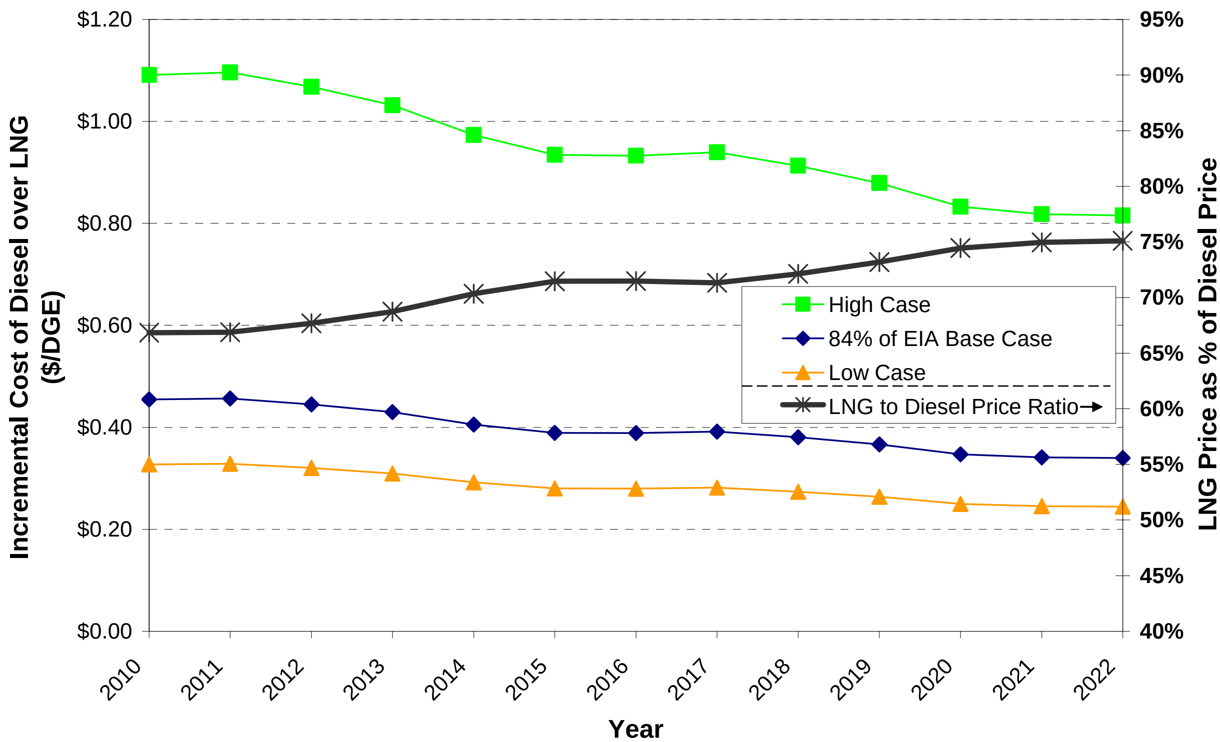


Figure 2-5. Incremental Cost of Diesel over LNG

storage, compression, and delivery system; fleets buying fuel in bulk; and the refining costs that will go into producing California's ultra-low sulfur diesel fuel. In order to analyze cases where CNG prices, relative to diesel, did not follow EIA's projection, TIAX also studied cases in which the CNG price was 80% and 90% of the diesel price, shown in Figure 2-6. These constant values were chosen because they are at the outer bounds of the EIA projections in the studied timeframe. The sensitivity analysis performed in section 4 looks at the effect of the CNG to diesel price ratio.

While it is likely that the prices of LNG and CNG will be closely linked in the future, there are inherent differences in the price of LNG because of the location of the user fleet and long term price contracts to fleet owners. With the typical means to transport and supply LNG to users, variations will continue to exist in the future. To analyze this effect, the sensitivity analysis varied the base assumption by ± 5% to study the effect of this variable on the overall life-cycle costs. Figure 2-7 shows the price differential for LNG to diesel that is used in the sensitivity analysis in Section 4.

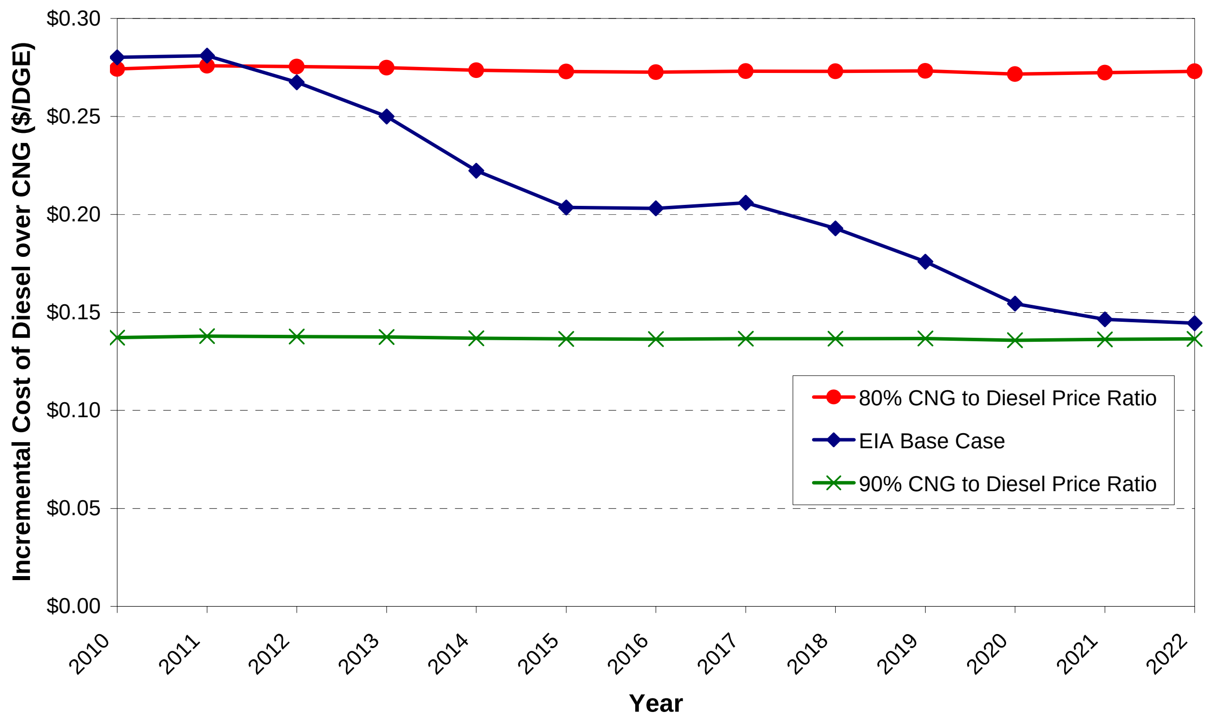


Figure 2-6. CNG Fuel Price Differential for Sensitivity Analysis

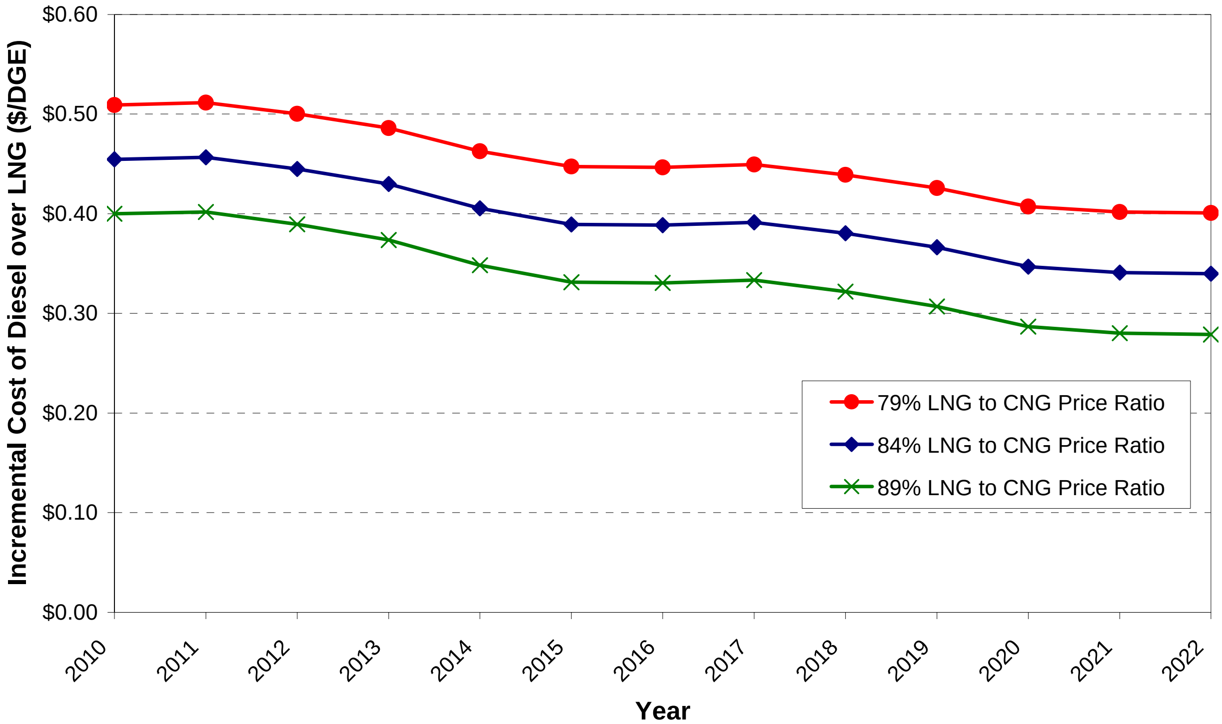


Figure 2-7. LNG Fuel Price Differential for Sensitivity Analysis

3. Results of Cost Comparisons

For our cost comparison of refuse haulers, transit buses, and short-haul heavy-duty trucks, we selected the most likely and/or the least expensive combinations of diesel and natural gas engine type and aftertreatment type. For each of these combinations, we calculated the average annual cost (AAC) of owning, maintaining, and operating the vehicle in 2005 dollars (2005$). We then compared the AAC within a given vehicle application, noting the impact of cost variation for different parameters on these results. The results of these comparisons are given below and the impact of cost variation is discussed in Section 4. The complete analysis results are tabulated in Appendix A.

The AAC for a given combination of technologies was calculated as the amortized capital cost for the vehicle over its lifetime in the fleet plus the 2005$ net present value (NPV) of all other expenses, averaged over the years in the owner's fleet. The amortized capital cost takes into account the initial capital costs, the residual value at the end of life in the fleet, vehicle useful life, and a 5% discount rate. The "other expenses" consist of O&M costs, fuel costs, and component replacement costs. In this study, the average NPV for "other expenses" was calculated according to equation 3-1 divided by the number of years in the fleet, using a discount factor of 5%.

$$\sum_{i=1}^{\text{Total years in fleet}} \left[(\text{"other expenses" for the year}) * (\text{discount factor})^{i} \right]_{i} = \text{NPV} \qquad (3\text{-}1)$$

For example, to calculate the NPV in the third year of ownership, the "other expenses" in that year would be multiplied by the NPV factor (*i.e.*, the discount factor raised to the power *i*), equal to $(1 - 0.05)^3$ or 85.7%. While, in the fourth year, the NPV factor would decline to 81.5%. The NPV factor, therefore, has the effect of discounting expenses in proportion to how far into the future they will be made, effectively making near-term expenses larger in comparison. Thus, in several cases, the study results show first year costs that are higher than average annual out-year costs.

3.1 Refuse Haulers

A high, low, and intermediate AAC was determined for each likely engine and aftertreatment combination; a summary of the intermediate AAC for refuse hauler combinations is provided in Table 3-1. The range of intermediate AAC shown in Table 3-1 bounds the most and least expensive refuse hauler combinations considered in this analysis. It was assumed that the owner would keep the refuse hauler for only 6.5 years, and would not incur the cost of an engine rebuild.

As shown in Table 3-1, a diesel refuse hauler with a CIDI engine and a 4-way catalyst for aftertreatment has the lowest intermediate AAC. Although 4-way catalysts are expected to become more common in heavy-duty applications sometime between 2010 and 2020, this combination is not considered a likely aftertreatment option for refuse haulers in 2010. It was included here to demonstrate the lower bound AAC.

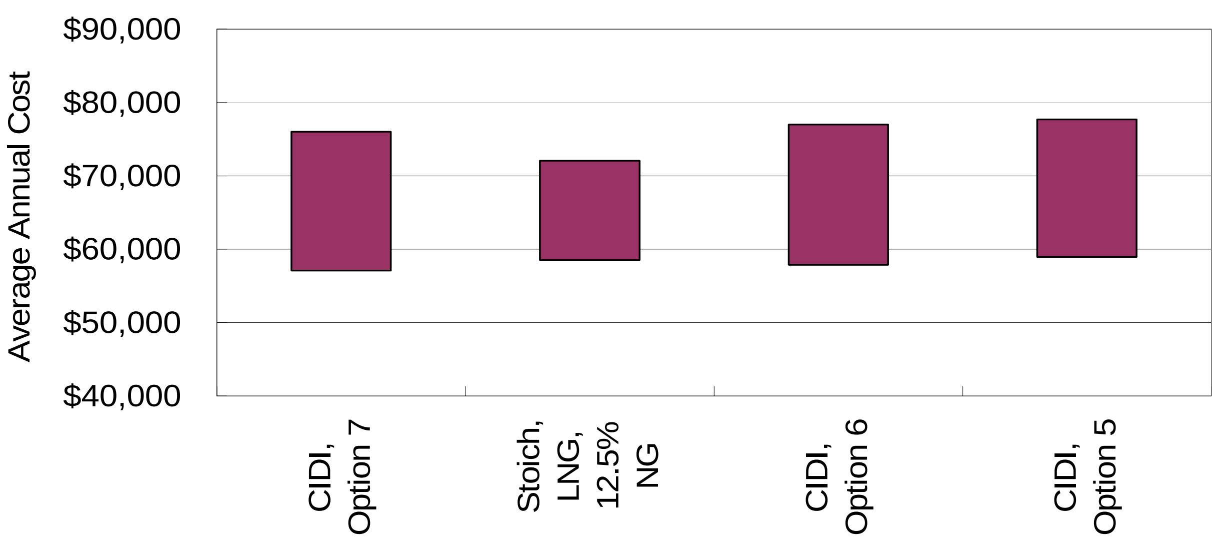
Table 3-1. Intermediate Average Annual Costs for Refuse Haulers in 2010

Engine/Fuel	Aftertreatment Option	Intermediate AAC (NPV, 2005$)[a]
CIDI / diesel	4-way catalyst (Option 7)[b]	$ 60,580
Stoichiometric / LNG	3-way catalyst	$ 61,050
CIDI / diesel	Regenerative PM trap, sulfur trap, NO_x trap, and oxidation catalyst (Option 6)[b]	$ 61,390
CIDI / diesel	Regenerative PM trap, urea-SCR, and oxidation catalyst (Option 5)[b]	$ 62,410

[a] To account for economy of scale in NGV production, the Intermediate AAC assumes that 12.5% of refuse haulers sold nationwide are natural gas engines by 2010

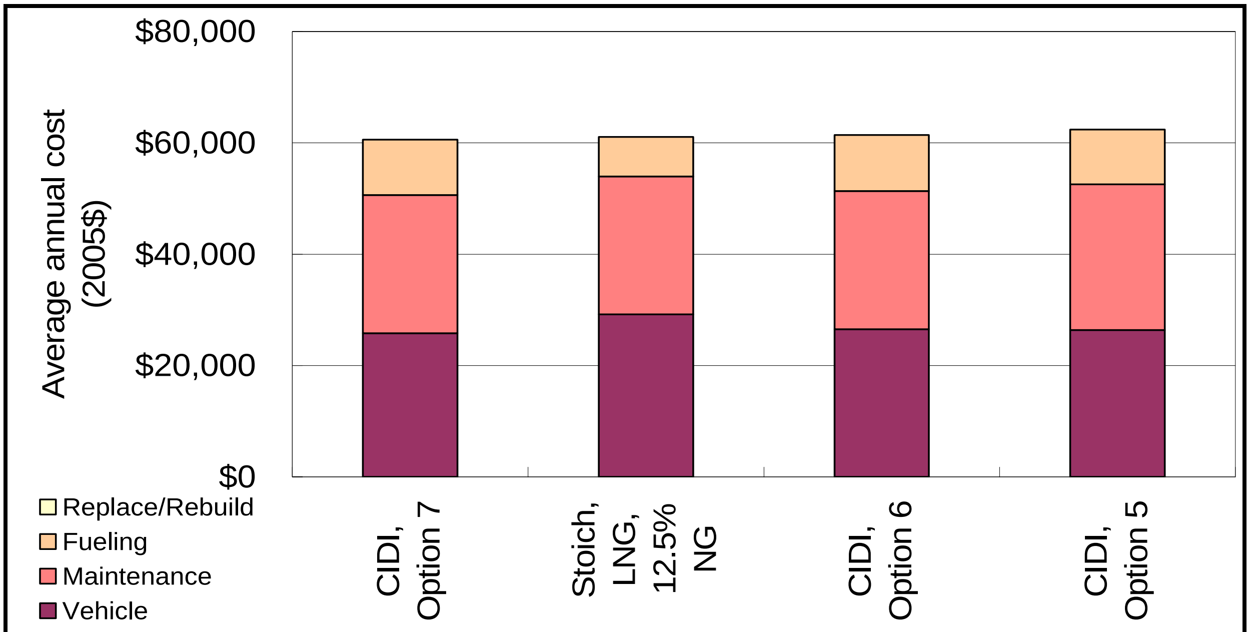
[b] "(Option #)" corresponds to number used to represent this aftertreatment combination in the ACC model

The diesel CIDI with 4-way catalyst has the lowest intermediate AAC of these combinations, and its AAC is 0.8% less than the LNG refuse hauler with a stoichiometric engine and 3-way catalyst. Among the likely diesel options, the diesel CIDI refuse hauler with a regenerative PM trap, sulfur trap, NO_x trap, and oxidation catalyst (option 6) has an intermediate AAC 0.5% greater than that of the LNG refuse hauler. The range of AAC for each of these refuse hauler combinations and a breakdown of intermediate AAC are shown in Figures 3-1 and 3-2, respectively.



NOTE: In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #5 consists of a regenerative PM trap, urea–SCR, and oxidation catalyst; Option #6 consists of a regenerative PM trap, sulfur trap, NO_x trap, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-1)

Figure 3-1. Range of Average Annual Cost for Refuse Haulers in 2010 (NPV, 2005$)



	CIDI Option 7 (2005$)	**Stoich. LNG, 12.5% NG (2005$)**	**CIDI, Option 6 (2005$)**	**CIDI, Option 5 (2005$)**
Average Annual Cost				
Replace/Rebuild	—	—	—	—
Fueling	9,960	7,060	10,060	9,870
Maintenance	24,800	24,800	24,800	26,170
Vehicle	25,820	29,180	26,520	26,370
1st year costs only				
Replace/Rebuild	—	—	—	—
Fueling	10,650	7,331	10,760	10,550
Maintenance	26,530	26,530	26,530	27,990
Vehicle	143,530	161,840	147,380	146,570

NOTE: In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #5 consists of regenerative PM trap, SCR-urea, and oxidation catalyst; Option #6 consists of a regenerative PM trap, sulfur trap, NO_x trap, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-1).

SCR reductant costs are included in the maintenance costs.

Figure 3-2. Example Cost Comparisons for Refuse Haulers in 2010

3.2 Transit Bus

As we did for the refuse hauler application, for transit buses we considered the high, low, and intermediate AAC for each combination; a summary of the intermediate AAC for transit bus combinations are provided in Table 3-2. As with the other applications, the range of intermediate AAC shown in Table 3-2 bounds the most and least expensive transit bus combinations considered in this analysis. Each of the combinations shown below is based on an engine rebuild and aftertreatment control device replacement interval of 10 years.

Table 3-2. Intermediate Average Annual Costs for Transit Buses in 2010

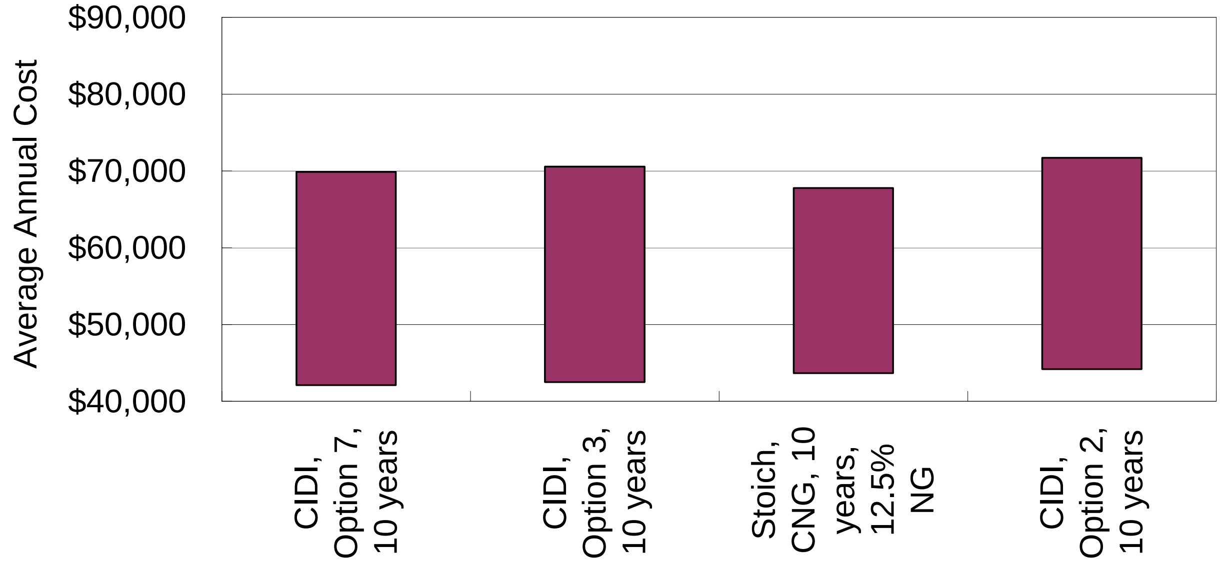
Engine/Fuel	Aftertreatment Option	Intermediate AAC (NPV, 2005$)[a]
CIDI / diesel	4-way catalyst (Option 7)[b]	$ 46,730
CIDI / diesel	Catalyzed PM trap, sulfur trap, NO_x trap, and oxidation catalyst (Option 3)[b]	$ 47,170
Stoichiometric / CNG	3-way catalyst	$ 47,720
CIDI / diesel	Catalyzed PM trap, SCR-urea, and oxidation catalyst (Option 2)[b]	$ 48,750

[a] AAC calculation assumes that 10% of transit buses sold nationwide are natural gas engines by 2010, for the economy of scale calculation. AAC calculation also assumes 80% Federal cost-share of the capital cost of diesel transit buses and 90% Federal cost-share for the incremental capital cost of alternative fuel transit buses (www.fta.dot.gov).

[b] "(Option #)" corresponds to number used to represent this aftertreatment combination in the ACC model

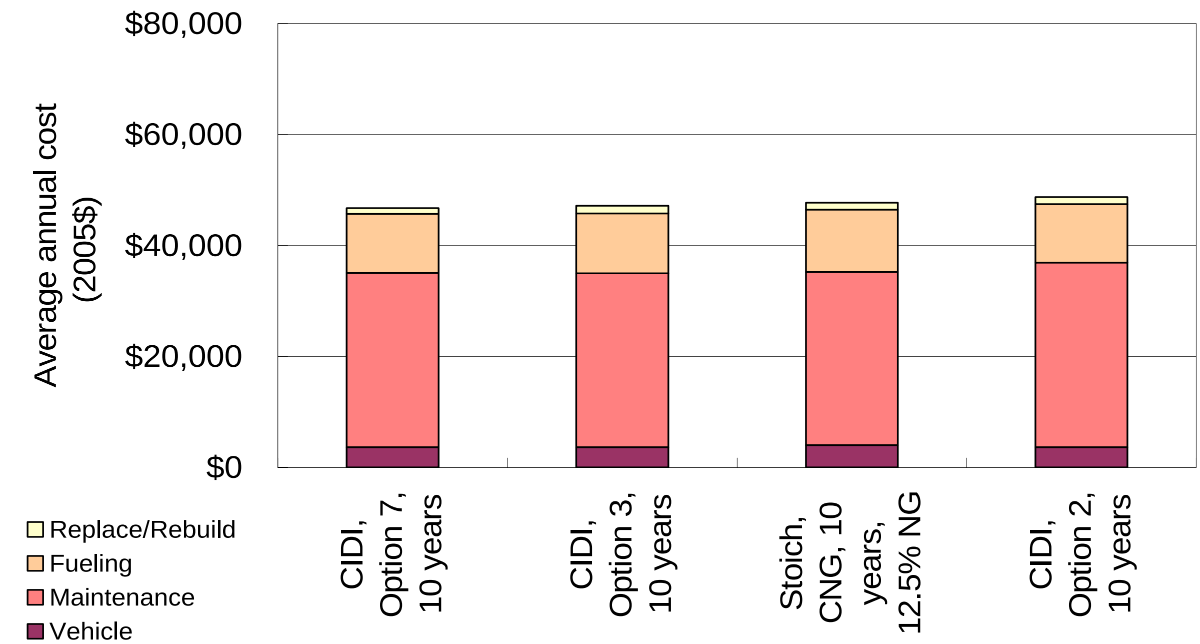
As shown in Table 3-2, the CIDI diesel transit bus with 4-way catalyst has the lowest intermediate AAC. The CNG transit bus with a stoichiometric engine and 3-way catalyst has a 2.1% larger AAC than the diesel CIDI with 4-way catalyst.

If 4-way catalysts are not available in 2010 for transit buses, the likely diesel technology with the lowest intermediate AAC is the CIDI diesel transit bus with a catalyzed PM trap, sulfur trap, NO_x trap, and oxidation catalyst. This intermediate AAC for this combination is only slightly less than the AAC combination for a stoichiometric CNG transit bus. Compared to this CIDI option, the stoichiometric CNG transit bus has a 1.2% larger AAC. For each of these transit bus combinations, the range of AAC and the breakdown of intermediate AAC are shown in Figures 3-3 and 3-4, respectively.



In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #2 consists of catalyzed PM trap, SCR-urea, and oxidation catalyst; Option #3 consists of catalyzed PM trap, sulfur trap, NO_x trap, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-3)

Figure 3-3. Range of Average Annual Cost for Transit Buses in 2010 (NPV, 2005$)



	CIDI Option 7 10 years (2005$)	**CIDI, Option 3 10 years (2005$)**	**Stoich., CNG, 10 years, 12.5% NG (2005$)**	**CIDI, Option 2 10 years (2005$)**
Average Annual Cost				
Replace/Rebuild	1,040	1,390	1,260	1,290
Fueling	10,670	10,780	11,260	10,570
Maintenance	31,360	31,360	31,200	33,240
Vehicle	3,660	3,640	4,010	3,640
1st year costs only				
Replace/Rebuild	—	—	—	—
Fueling	20,560	20,770	16,840	20,360
Maintenance	40,430	40,430	40,230	42,860
Vehicle	54,890	55,390	52,640	55,250

In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #2 consists of catalyzed PM trap, SCR-urea, and oxidation catalyst; Option #3 consists of catalyzed PM trap, sulfur trap, NO_x trap, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-3)

SCR reductant costs are included in the maintenance costs.

Figure 3-4. Cost Example Cost Comparisons for Transit Buses in 2010

3.3 Short-Haul Heavy-duty Trucks

As we did for refuse haulers, for short-haul heavy-duty trucks (short-haul), we considered the high, low, and intermediate AAC for each combination; a summary of the intermediate AAC for short-haul combinations are provided in Table 3-3. For these short-haul combinations, we also considered the effect of a smaller market penetration of NGVs compared with the other applications. The range of intermediate AAC shown in Table 3-3 bounds the most and least expensive short-haul combinations considered in this analysis.

Table 3-3. Intermediate Average Annual Costs for Short-haul Trucks in 2010

Engine/Fuel/ Replacement Interval[a]	Aftertreatment Option	Intermediate AAC (NPV, 2005$)[b]
CIDI / diesel / 10 years	4-way catalyst (Option 7)[c]	$ 56,800
HCCI / diesel / 10 years	Regenerative PM trap, HC-SCR, and oxidation catalyst (Option 4)c	$ 57,080
Stoichiometric / LNG / 10 years (5% NG market share)b	3-way catalyst	$ 57,110
HCCI / diesel / 435,000 miles	Catalyzed PM trap, urea-SCR, and oxidation catalyst (Option 2)[c]	$ 59,180
HCCI / diesel / 435,000 miles	Regenerative PM trap, urea-SCR, and oxidation catalyst (Option 5)[c]	$ 59,480
Stoichiometric / LNG / 435,000 miles (5% NG market share)[b]	3-way catalyst	$ 59,650

[a] "Replacement Interval" refers to the period after which engine and aftertreatment systems are replaced

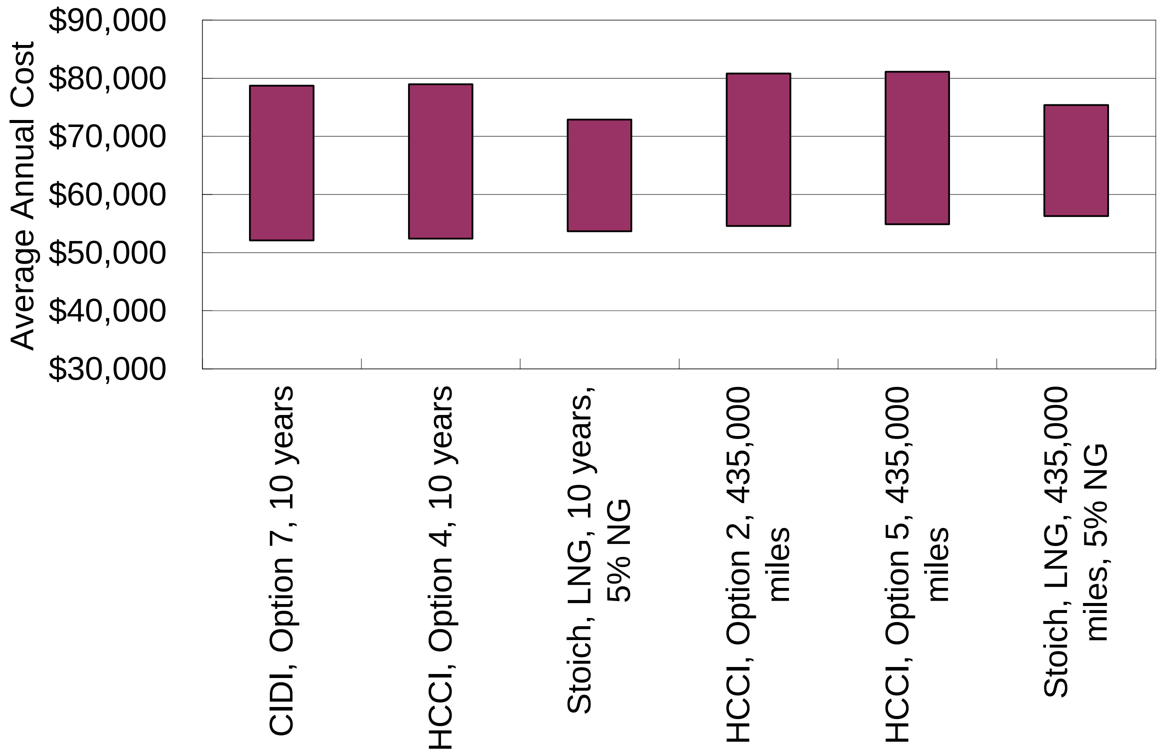
[b] In order to account for economy of scale in NGV production, the AAC calculation assumes that 5% of short-haul vehicles sold nationwide are natural gas engines by 2010

[c] "(Option #)" corresponds to number used to represent this aftertreatment combination in the ACC model

As shown in Table 3-3, for short-haul with a replacement interval of 435,000 miles, the engine and aftertreatment system are replaced by the original owner. The LNG short-haul with a 435,000-mile interval for aftertreatment replacement and engine rebuild has a 4.5% larger intermediate AAC than the same vehicle with a 10-year interval. Because we assumed that short-haul trucks are kept by the primary owner for 10 years, short-haul trucks with a 10-year replacement interval never require an engine rebuild or aftertreatment replacement during the primary ownership period.

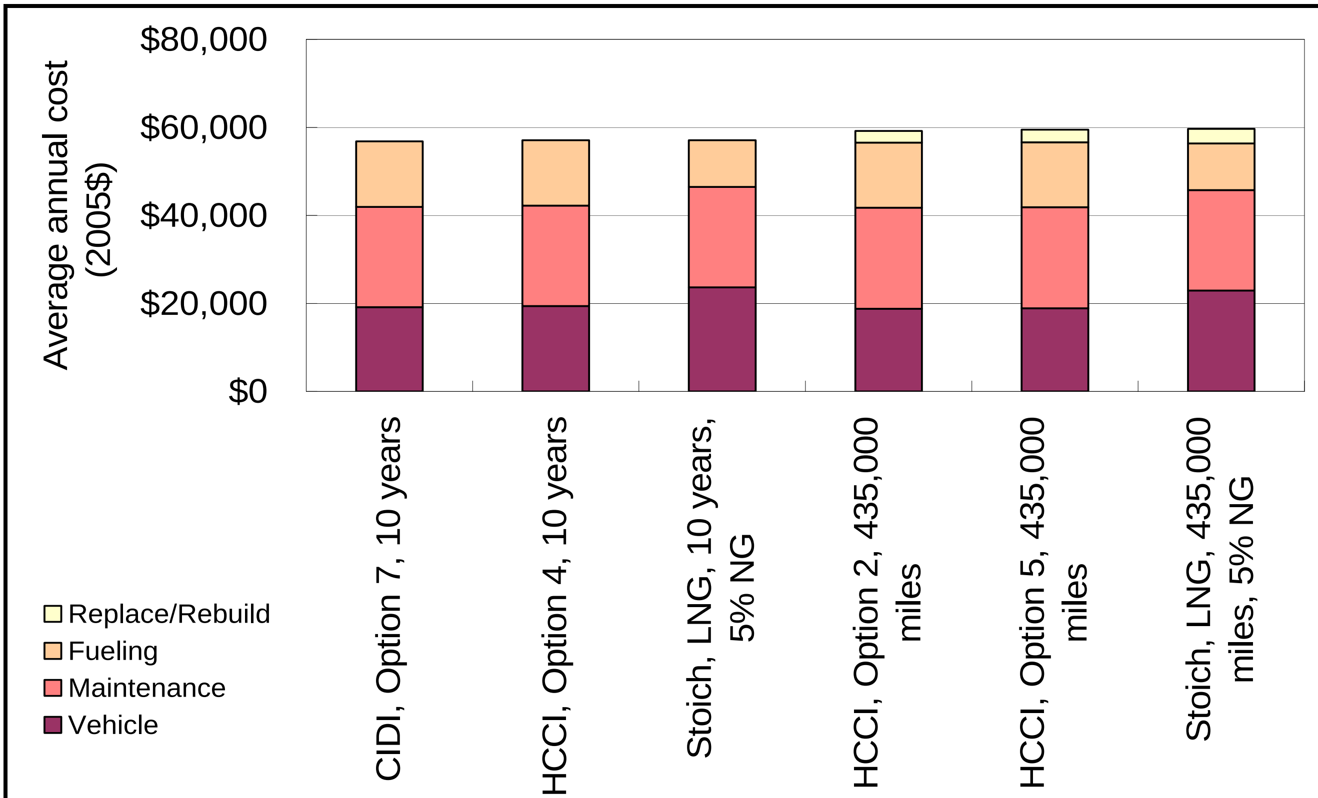
The diesel short haul with a CIDI, 4-way catalyst, and 10-year replacement interval has the lowest intermediate AAC of the combinations. The intermediate AAC for an LNG short-haul truck with a stoichiometric engine and 3-way catalyst is 0.5% larger than the lowest intermediate ACC, which is the same as the HCCI with a regenerative PM trap, HC-SCR, and oxidation catalyst. Both of these scenarios have a 10-year replacement interval.

For each of these short haul combinations, the range of AAC and the breakdown of intermediate AAC are provided in Figures 3-5 and 3-6, respectively.



NOTE: In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #2 consists of catalyzed PM trap, SCR-urea, and oxidation catalyst; Option #4 consists of regenerative PM trap, SCR-HC, and oxidation catalyst, Option #5 consists of regenerative PM trap, SCR-urea, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-2).

Figure 3-5. Range of Average Annual Cost for Short-haul Trucks in 2010 (NPV, 2005$)



	CIDI, Option 7 10 years (2005$)	HCCI, Option 4, 10 years (2005$)	Stoichiometric, LNG 10 years, 5% NG (2005$)	HCCI, Option 2, 435,000 miles (2005$)	HCCI, Option 5, 435,000 miles (2005$)	Stoichiometric LNG, 435,000 miles, 5% NG (2005$)
Average Annual Cost						
Replace/Rebuild	—	—	—	2,680	2,880	3,270
Fueling	14,870	14,880	10,670	14,730	14,730	10,670
Maintenance	22,790	22,800	22,790	22,960	22,960	22,790
Vehicle	19,140	19,410	23,650	18,810	18,910	22,920
1st year costs only						
Replace/Rebuild	—	—	—	—	—	—
Fueling	18,360	18,360	12,630	18,180	18,180	12,630
Maintenance	28,100	28,120	28,100	28,320	28,320	28,100
Vehicle	169,270	169,310	202,040	170,090	171,060	202,040

NOTE: In the figure above, "Option #" refers to aftertreatment combinations used in the ACC model. Option #2 consists of catalyzed PM trap, SCR-urea, and oxidation catalyst; Option #4 consists of regenerative PM trap, SCR-HC, and oxidation catalyst; Option #5 consists of regenerative PM trap, SCR-urea, and oxidation catalyst; and Option #7 consists of a 4-way catalyst (see Table 3-2).

SCR reductant costs are included in the maintenance costs.

Figure 3-6. Example Cost Comparisons for Short-haul Trucks in 2010

4. Sensitivity Analysis

A sensitivity analysis of the heavy-duty vehicle cost model was conducted for the three applications modeled – refuse hauler, transit bus, and short haul truck. Each of the following parameters was varied independently from two industry average cases for diesel and natural gas vehicles discussed in the previous results section (Section 3). The sensitivity analysis compares the Life Cycle Cost of diesel and natural gas technologies and indicates the differential on the x-axis. The diesel and natural gas cases are example cases of the technology combinations that may compete against one another in the market place. The parameters that were analyzed are as follows:

- Cost per barrel of crude, which ultimately drives fuel cost
- The percent of NGVs produced compared to diesel technologies, which is linked to engine, aftertreatment, and fuel system cost economies of scale
- Choice of diesel vehicle exhaust gas aftertreatment (EGA), the cost of which is highly variable due to the number of potential combinations
- Fuel price shift between LNG and CNG, where the transportation cost of LNG to fleets with varying distances from the wellhead is taking into account
- Fuel price shift between NG and diesel, whereby the CNG pump price on a DGE-basis is a fraction of the diesel pump price
- Varying engine cost differential between the diesel and what is effectively a NG variation of the diesel engine
- Fuel economy, which varies by application and fuel type due to the difference in energy content and method of combustion (SI vs. CI)

The results of the sensitivity analysis are pictured in Figures 4-1, 4-2, and 4-3. The results show the difference between the annualized vehicle cost for a NGV and diesel vehicle in the same application. The scale indicates when a diesel vehicle is less expensive than a NGV or if the NGV is less expensive and to what degree. The parameters tested in the sensitivity analysis are varied one-at-a-time around the selected "industry average" base case. The base case parameters that were modeled are indicated by the middle values in the figures. The example base case for the refuse hauler (results shown in Figure 4-1) compares a stoichiometric LNG vehicle with a 3-way catalyst and a CIDI diesel vehicle with a continuously regenerative PM trap, a sulfur trap, a NO_x trap, and an oxidation catalyst. There is no replacement interval for this application since the chassis is predicted to have a shorter life than the engine, aftertreatment, and fuel systems. The results shown in Figure 4-2 is for a stoichiometric CNG transit bus with a 3-way catalyst compared to a CIDI diesel bus with a catalyzed PM trap, a sulfur trap, a NO_x trap, and an oxidation catalyst. The replacement interval for this comparison is 10 years. For the short haul truck, Figure 4-3 compares a stoichiometric LNG vehicle with a 3-way catalyst with a HCCI diesel vehicle with a catalyzed PM trap, a urea SCR system, and an oxidation catalyst. The replacement interval is 435,000 miles.

Each of the example comparisons start with the EIA base case transportation sector fuel prices which correspond to a 2010 world oil price of $25 per barrel, and the associated compressed natural gas prices. The LNG price is assumed to be 84% of the CNG price on a DGE basis, as referenced in Section 2 of this report. All fuel prices are assumed to be gate prices, meaning that the fuel prices assume sale from a third party vendor who recovers all capital, operating costs,

4.1 Refuse Haulers

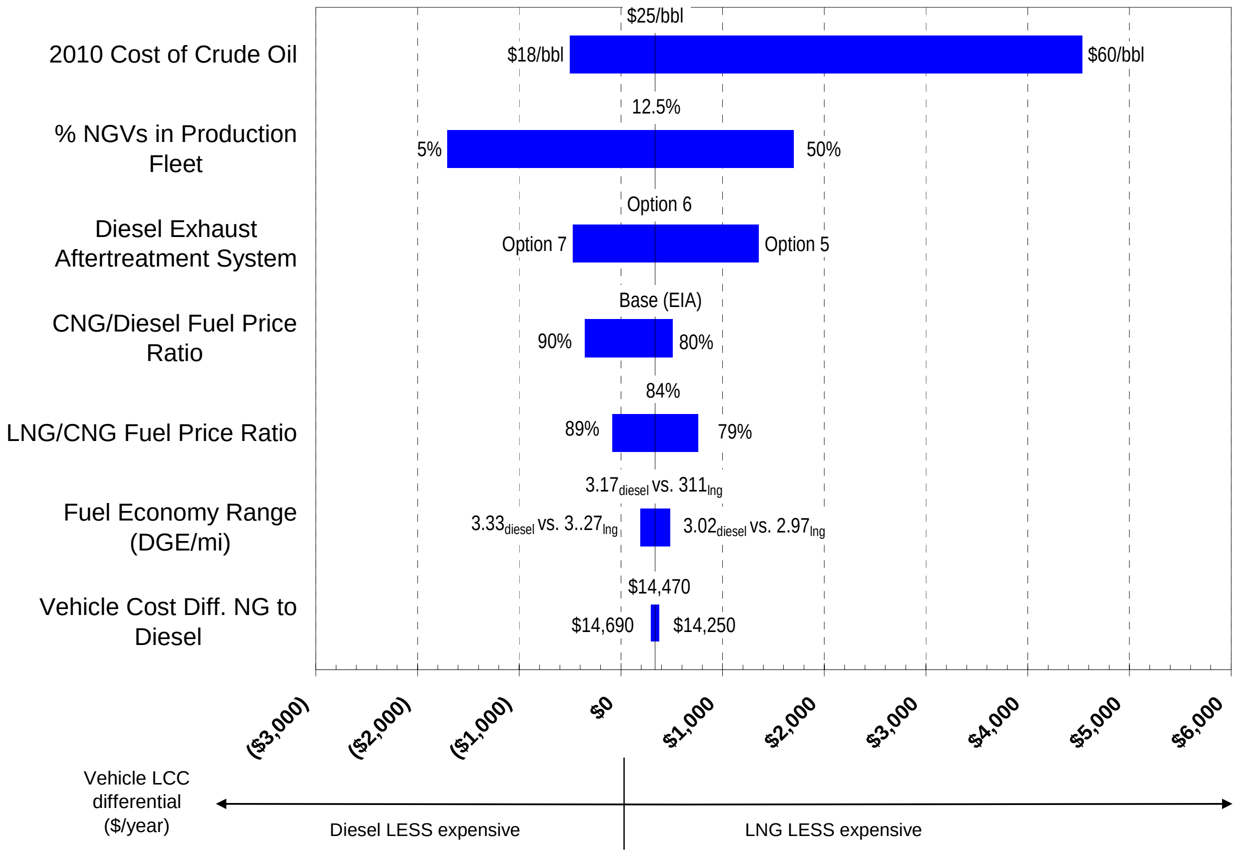


Figure 4-1. Refuse Hauler Application: LNG Compared to CIDI

and makes a reasonable profit associated with delivering the fuel to the end user. TIAX assumed a reasonable range of variation for fuel prices in order determine the financial model's sensitivity to the base case assumptions.

Again, each of the parameters are varied individually, so compounding effects such as CNG costing 80% of diesel on a DGE basis when oil prices are at $60 per barrel are not represented in this analysis. The vehicle LCC differential at the extremes of the sensitivity bars was found by entering the displayed parameters into the financial model. The figures do not attempt to predict values or conditions between the base case and the individually varied parameters. In most cases, there is not a linear relationship between the indicated parameters. For example, as indicated in Section 2.5, the economy of scale factors that result from the percentage of NGVs in the production fleet are used as a step function in the financial analysis

As illustrated in Figure 4-1, the annualized vehicle cost of the stoichiometric LNG refuse hauler is about $340 less expensive than the CIDI version. The breakdown of the costs associated with the examined cases highlighting the cost changes incurred for the individually varied parameters can be found in Appendix A, Table A-4. The refuse hauler application is most sensitive to oil price, NGV fleet size and diesel emission control cost. The results from the sensitivity analysis for this application can be summarized as follows:

- **Cost per barrel of crude:** If the annual average cost is $60 per barrel, then the LNG vehicle is less costly by over $4,500 per year, making the LNG vehicle a very attractive option. With all other factors held constant, the model tells us that the average annual per barrel crude cost needs to be only $22/bbl in 2010 for the NG refuse hauler to become less expensive than the diesel refuse hauler.

- **Percent of NGVs in the national fleet:** If the national LNG refuse hauler fleet approaches or exceeds 12.5%, then the annualized vehicle cost favors LNG. Otherwise, diesel is favored.

- **Diesel exhaust gas treatment:** The least expensive treatment option for CIDI engines is the 4-way catalyst (Option 7), but the probability that the catalyst will be available by 2010 is low according to TIAX's HD Powertrain study. The probability is higher that the more expensive Option 5 will be available in 2010. This shifts the vehicle cost in favor of the LNG refuse hauler.

- **Fuel price shift between NG and diesel:** Under the base case NG/diesel price ratio, an LNG vehicle is less expensive. Diesel vehicles will become more attractive in the refuse hauler application only if NG pump prices (on a DGE-basis) shift towards being on par with diesel fuel prices. The annual average price differential of LNG compared to diesel fuel is $0.34 when NG is 90% of diesel, and is $0.45 when NG is 80% of diesel. The LNG price is assumed to be 84% less than the NG price on a DGE-basis in this case.

- **Fuel price shift between LNG and CNG:** Only under the extreme case where LNG is 89% of CNG prices will the LCC of the diesel vehicle be better than the LCC of the LNG refuse hauler. This could be the case in remote or Northern California locations, where the cost of transporting the fuel outweighs other cost benefits. The annual average price differential of LNG compared to diesel fuel is $0.37 when LNG is 89% of CNG and $0.48 when LNG is 79% of CNG.

- **Fuel economy:** Fuel economy was analyzed over the estimated industry average based on drive cycle modeling of the vehicle technologies over representative drive cycles. The fuel economy range does not take into account possible user specific fuel economy differences due to variations in drive and duty cycles. In this study, annualized vehicle cost is insensitive to fuel economy differences associated with energy content differences between diesel and LNG.

- **Vehicle cost differential:** Vehicle capital-cost differential was analyzed over the estimated industry average for the technologies selected for this comparison. Vehicle LCC is insensitive to vehicle cost differences within the range that was evaluated.

4.2 Transit Bus

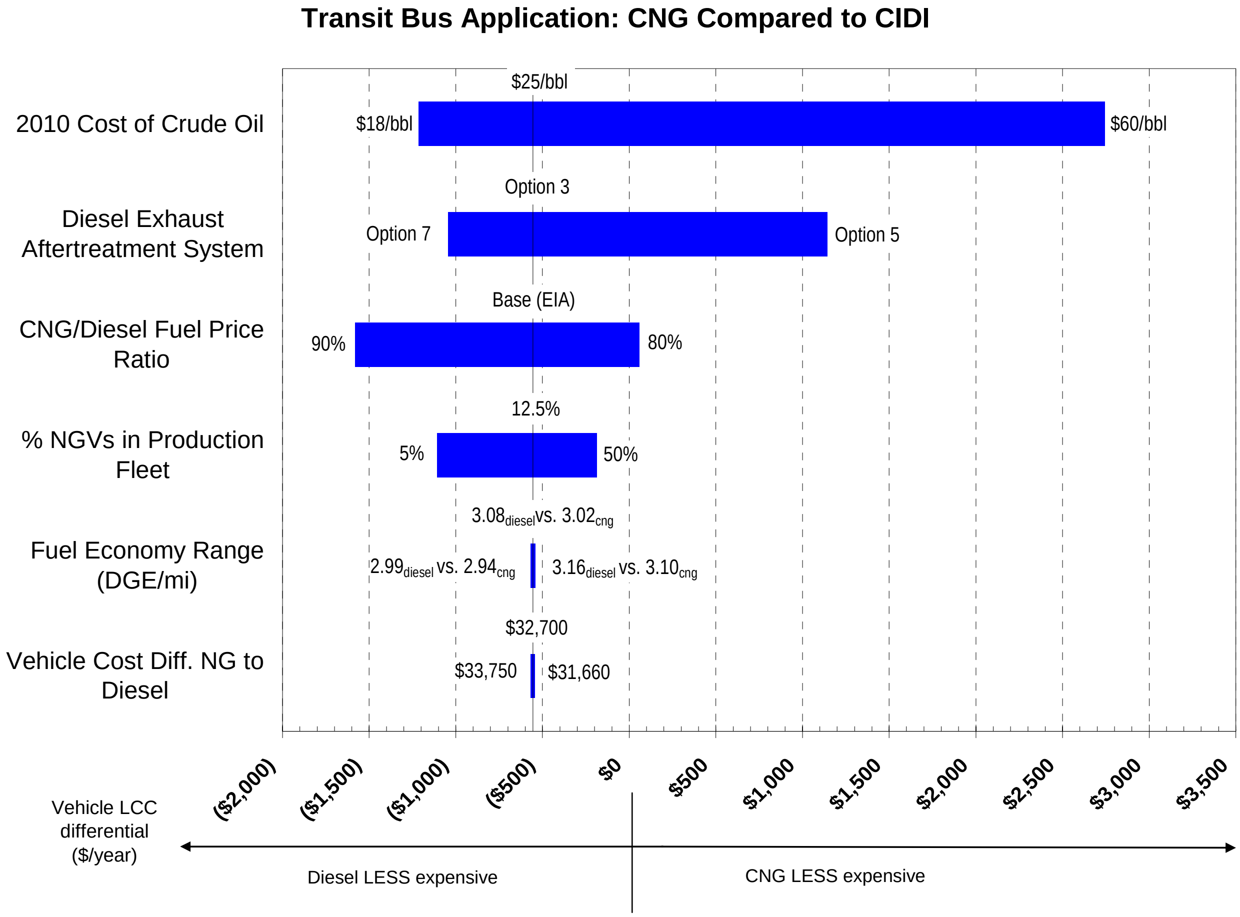


Figure 4-2. Transit Bus Application (local share of costs): CNG Compared to CIDI

As illustrated in Figure 4-2, the CIDI transit bus is roughly $560 less expensive than its stoichiometric CNG variant. The transit bus application is less sensitive than the other applications to the vehicle capital expenditures, including diesel, because the analysis considers the government subsidies of 80% for both diesel and natural gas buses and an additional 90% for the natural gas incremental capital costs. The parameters itemized below have the largest effect on the average annual costs are diesel exhaust gas treatment technology**,** the percent of NGVs in the national fleet, and the vehicle cost differential**.** The breakdown of the costs associated with this comparison for transit buses can be found in Appendix A, Table A-5. The analysis results by parameter can be summarized for a 10-year replacement interval as follows:

- **Cost per barrel of crude:** The most significant conclusion of this analysis is that the case of the high per barrel cost of crude oil makes the CNG transit bus less expensive than diesel. Given recent trends in the cost of crude, it seems unlikely that the cost per barrel will be $25 in 2010. With all other factors held constant, the model tells us that the average annual per barrel crude cost needs to be $31/bbl in 2010 for the NG bus to be less expensive than the diesel bus.

- **Diesel exhaust gas treatment:** Diesel vehicles are less expensive than NGVs unless the diesel vehicle is equipped with more expensive exhaust gas treatment packages. For the CIDI engine in a transit bus application, the most expensive treatment package (Option 5) includes a continuously regenerated PM trap, urea SCR for NO_x emissions, and a diesel oxidation catalyst for HCs and CO. However, NO_x traps (e.g., Option 3) are considered most likely technology type to be implemented to achieve the standards in 2010.[19].

- **Fuel price shift between NG and diesel:** A CNG to diesel price ratio of around 80% yields CNG transit buses that are economically attractive. This price ratio is lower than the EIA's projection. The annual average price differential of CNG compared to diesel is $0.27 when CNG is 80% of diesel, while the price differential is $0.14 when CNG is 90% of diesel.

- **Percent of NGVs in the national fleet:** Because of the transit cost share percentages, the capital costs associated with this application do not show much sensitivity. The national NGV fleet population would need to reach significantly high numbers to reduce the annualized vehicle cost. At a 50% NGV national fleet population, the LCC of the diesel vehicle is $190 cheaper.

- **Fuel economy:** Fuel economy was analyzed over the estimated industry average based on drive cycle modeling of the vehicle technologies over representative drive cycles. The fuel economy range does not take into account user specific fuel economy differences due to variations in drive and duty cycles. Annualized vehicle cost is insensitive to fuel economy differences associated with energy content differences between diesel and CNG within the range that was evaluated. The Transit bus application is particularly insensitive to fuel economy changes since the base case assumes that NG engine fuel economy is 95% of an equivalent diesel engine. This fuel economy penalty is cancelled out by the assumption that CNG is between 80% and 90% the cost of diesel fuel.

- **Vehicle cost differential:** Vehicle capital-cost differential was analyzed over the estimated industry average for the technologies selected in this case. Vehicle LCC is insensitive to vehicle cost differences within the range that was evaluated.

[19] Based on TIAX and Global Insight's joint study investigating the future of the heavy-duty powertrain.

4.3 Short-Haul Heavy-duty Trucks

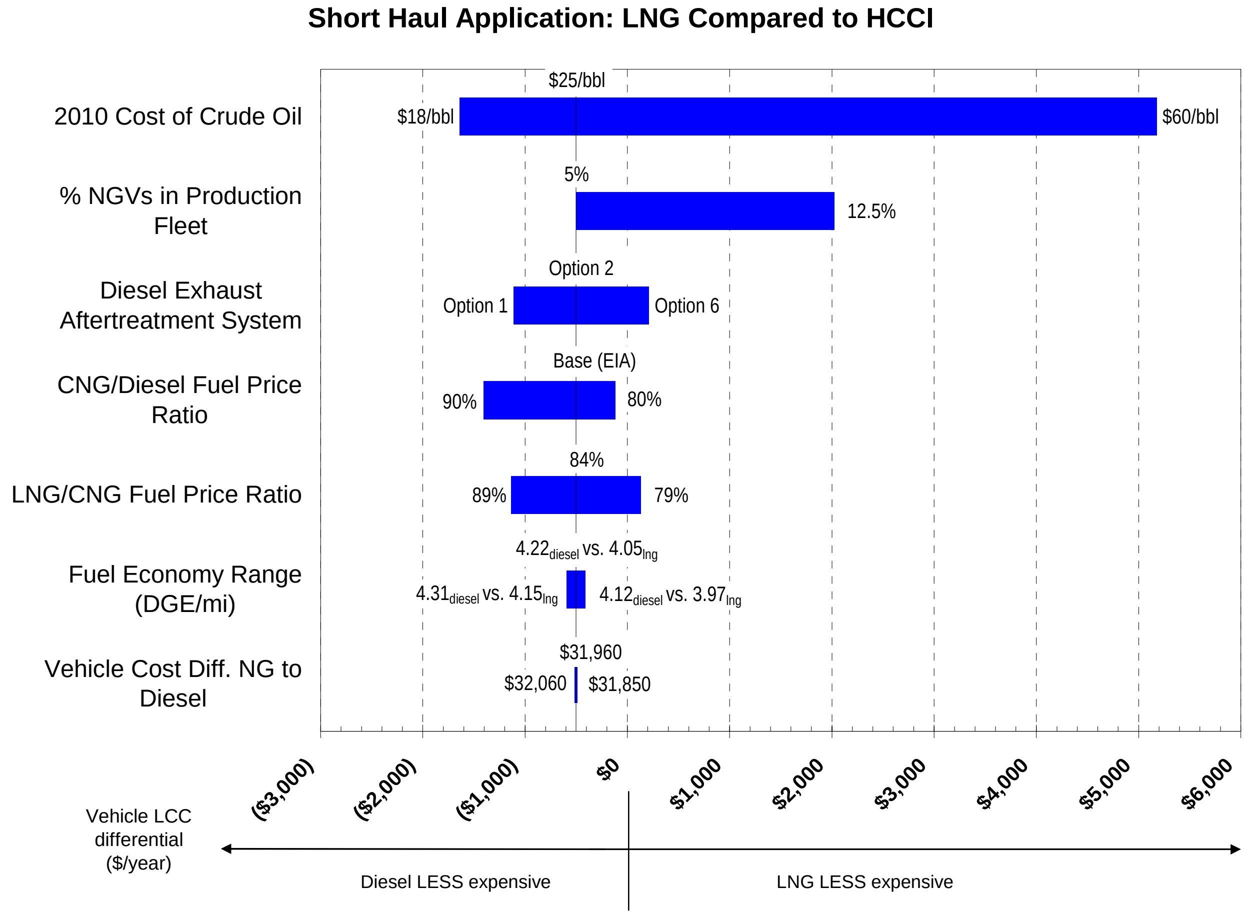


Figure 4-3. Short Haul Application: LNG Compared to HCCI

As illustrated in Figure 4-3, the annualized vehicle cost of a mixed-mode HCCI short haul truck is about $500 less than that of a stoichiometric LNG truck. As also illustrated in Figure 4-3, the short haul truck application is most sensitive to oil price and NGV fleet size. The breakdown of the costs associated with this case can be found in Appendix A, Table A-6. The results from this analysis can be summarized for a 435,000 mile replacement interval as follows:

- **Cost per barrel of crude:** Under the base scenario of $25 per barrel crude, the diesel truck is less expensive. However, with all other factors held constant, short haul NGVs are more attractive than diesel if the annual average cost of crude oil is $28/bbl or higher.

- **Percent of NGVs in the national fleet:** Unlike the other two applications, the example scenario for LNG short haul trucks is only 5% penetration into the national fleet. This is because it is expected that natural gas vehicles will have shorter range capability and this will limit its market penetration. However, this analysis shows that a LNG production rate of 12.5% yields over $2,000 in savings for an LNG short haul truck, with all other factors held constant.

- **Diesel exhaust gas treatment:** The base case scenario shows an advantage for the HCCI truck. This scenario uses a catalyzed PM trap, urea SCR and low temperature HCCI diesel oxidation catalyst (Option 2) which has a good probability of availability by 2010, according to TIAX's HD Powertrain study. The next most probable option (i.e., Option 1) uses HC SCR in lieu of urea SCR and is less expensive, making the diesel short haul even more attractive. With all other factors held constant, it is only the highest price diesel exhaust aftertreatment system that would give a LCC advantage to LNG.

- **Fuel price shift between NG and diesel:** NG price shift to 80% of diesel prices does not favor the NG vehicle, as a single variable. The annual average price differential of LNG compared to diesel is $0.33 when NG is 90% of diesel, while the price differential is $0.45 when NG is 80% of diesel. The LNG price is assumed to be 84% less than the NG price on a DGE-basis in this case.

- **Fuel price shift between LNG and CNG:** In the case where LNG is 79% of CNG prices, the LNG vehicle will be less expensive than diesel. This indicates that large fleets, who can buy NG in bulk, or those located close to LNG sources may be good candidates for a short haul LNG fleet. The annual average price differential of LNG compared to is $0.35 when LNG is 89% of CNG and $0.47 when LNG is 79% of CNG.

- **Fuel economy:** Fuel economy was analyzed over the estimated industry average based on drive cycle modeling of the vehicle technologies over representative drive cycles. The fuel economy range does not take into account user specific fuel economy differences due to variations in drive and duty cycles. Annualized vehicle cost is insensitive to fuel economy differences associated with energy content differences between diesel and LNG in the range that was evaluated.

- **Vehicle cost differential:** Vehicle capital-cost differential was analyzed over the estimated industry average for the technologies selected in the example cases. Vehicle LCC is insensitive to vehicle cost differences within the range that was evaluated.

5. Summary and Discussion

Given the projected costs of future technologies, fuel, and maintenance, this study has found that 2010 NGVs will be highly competitive with diesel vehicles in refuse hauler, transit bus, and short haul truck applications. A life-cycle cost model was used to analyze each of the three applications. The study shows that the expected higher capital-costs of NGV engine and fuels systems will be offset by lower emission control system and fueling costs over the life cycles of these vehicles.

The results shown in Section 3 show that NGVs are competitive over of the predicted range of AAC when the industry average range of costs and efficiencies are considered,. This study attempts to find the relative cost differences between diesel and natural gas technologies in a mature 2010 technology market, or in the 2010-2020 timeframe. It expresses the results in a range of values shown in floating bar charts, because of the uncertainty that exists in predicting costs in a future market and does not attempt to quantify the likelihood of one scenario over others. Of the example intermediate scenarios considered, the diesel vehicles that employ a 4 way catalyst were found to have lowest ACC for each of the vehicles. But since there are indications that the 4-way catalyst aftertreatment system option will not be available until several years after 2010 the sensitivity analysis considers the next best diesel technology choice, in terms of ACC.

We found the most sensitive variables over the expected range to be the cost of crude oil, the percentage of NGVs produced , the cost of the required diesel aftertreatment system that meet 2010 emission standards, and the price ratios between LNG, CNG and diesel. While this study did not attempt to forecast the cost of crude oil in the future, it did look at the EIA's projected numbers and added further variation to the cost of crude oil beyond that which was estimated by EIA. This was done to characterize a high fuel price scenario similar to the levels that California has experienced in 2005.

In the three applications analyzed, NGVs will have a significant advantage in life cycle costs when crude oil is priced at $60/bbl (in 2005$) on an average annual basis. Because the comparable equipped NGVs were found to have comparable ACC to diesel vehicles when fuel prices are low, and favorable ACC when fuel prices are high, there is less risk for fleet managers to invest in NGV technologies than currently exists. There are extreme scenarios where this might not be the case, so the sensitivity analysis attempts to identify some of the parameters that might increase the risk for individual owner/operators. However, the parameters are still only varied over industry average ranges and do not consider the much wider user specific values for fuel economy, fuel differential costs, or vehicle cost differentials.

The percentage of NGVs produced was a factor used to determine the price premium incurred for potentially low volume production runs for NG engines, aftertreatment, and fuel systems. This effect is largest in the class 7/8 short haul application, where the base scenario assumes that the penetration rate is relatively low at 5%. The low rate was select since natural gas trucks will have range limitations compared to diesel trucks. The transit bus is least effected by the percentage of NGVs produced when the analysis considers the currently available 80% federal price share for transit buses and an additional 90% price share for the incremental difference of the NG bus. If NGVs can reach enough volume in the applications analyzed to overcome the higher prices of small production volumes, they would have a distinct price advantage over diesel in the refuse hauler and short haul applications.

The cost of the diesel exhaust gas aftertreatment (EGA) system could give NGVs a price advantage in each of the applications, if diesel EGA system costs are on the high end of our predicted range. There remain significant challenges and uncertainties in producing a system that is able to comply with 2010 emissions standards, that lasts for the required useful life period, and that does not significantly reduce fuel economy. Nonetheless, it is more likely that the emission control systems selected for each application will be able to meet these challenges at a price point that keeps diesel competitive.

The price ratio of natural gas fuels to diesel fuel is a factor that can affect the price advantage of either fuel choice. This is, however, probably the most difficult variable to predict. There are many factors that affect the price difference between the fuels. While historic trends and predictions from EIA are used to identify cases within our analysis, changes in the volume of imported natural gas, the fuel storage, compression, and delivery methods, fleets buying fuel in bulk, and the refining costs that will go into producing California's ultra-low sulfur diesel fuel are just some of the influential factors. In the three applications that were analyzed, favorable natural gas price ratios with respect to diesel can give the NGVs slight life cycle cost advantages. Counting on a lower than predicted natural gas price ratio alone to justify the price advantages of NGVs is not wise, given the uncertainty and that the fuel price variations that occur within a year were not analyzed in this study. The separately varied cost of crude oil, with transportation fuel prices forecasted as a function of crude oil, has a bigger influence on the average annual cost and can quickly negate any price advantages of the fuel price ratio.

Because applications studied are typical markets for NGVs, the application drive cycles analyzed in this study were not greatly varied. With our assumptions, fuel economy was found to have little effect in the model when analyzed over the expected range for these applications. The model shows a trend that favors diesel over LNG as the fuel economy improves. Further analysis should be completed before applying results from this study to other applications with higher fuel economy, which have a smaller percentage of their annual budget attributed to fuel costs will therefore be less attractive for NGVs, or long range applications, which could require additional NG fuel storage than has been studied in this report.

In summary, this study projects that the relative cost of owning and operating 2010-technology NGVs to be much closer to, if not better than, the cost of owning and operating 2010-technology diesel vehicles in the analyzed applications. Currently, based on the vehicle technologies needed to meet 2004 heavy-duty emission levels, diesel has a distinct advantage when price parameters are varied over an industry average range and individual fleet requirements or local air quality rules and incentives are not considered.

Appendix A. Supporting Data

Table A-1. High Cost Scenario Calculation Results

Main inputs								2010 fuel price	Lifetime ave. fuel price (NPV)	Net fuel economy (miles per dge)	First year total fuel cost	fuel use over owner lifetime (NPV)	Vehicle capital costs						Engine/aftertr. replacement cost (NPV)		Maint. costs	Maintenance costs over lifetime (NPV)					Total lifetime operating costs	Average annual costs					Average annual costs (local share)
Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	% NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	high	high	high cost scenario	high	high	Engine (high)	Chassis	Aftertr.	Fuel system	**Total w/ tax (high)**	Residual value (high)	Engine (high)	Aftertr.	First year	Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	high	Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total (high)**	high
Refuse Hauler	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 3.08	3.06	$ 26,814	$ 162,975	$ 16,416	$115,882	$ 2,909	$ 150	$145,847	$ 5,073	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$ 324,181	$ 25,815	$ 9,962	$ 24,801	$ -	$ 76,027	$ 76,027
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 2.20	$ 2.12	2.97	$ 18,452	$ 115,576	$ 22,770	$115,882	$ 2,242	$ 11,250	$163,936	$ 5,073	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$ 4,253	$ -	$ 276,783	$ 29,184	$ 7,065	$ 24,801	$ -	$ 72,063	$ 72,063
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 3.08	3.02	$ 27,087	$ 164,637	$ 16,416	$115,882	$ 6,476	$ 150	$149,691	$ 5,073	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$ 325,843	$ 26,523	$ 10,064	$ 24,801	$ -	$ 76,990	$ 76,990
Refuse Hauler	Diesel	CIDI	Option 5	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 3.08	3.08	$ 26,556	$ 161,408	$ 16,416	$115,882	$ 5,726	$ 150	$148,883	$ 5,073	$ -	$ -	$ 27,993	$ 51,643	$105,310	$4,253	$ -	$ 8,871	$ 331,485	$ 26,374	$ 9,866	$ 26,166	$ -	$ 77,710	$ 77,710
Short Haul	Diesel	CIDI	Option 7	10 years	5%	EIA estimate	84%	$ 3.29	$ 2.67	4.08	$ 45,050	$ 365,016	$ 21,976	$132,476	$ 2,860	$ 150	$169,665	$31,914	$ -	$ -	$ 28,104	$ 177,269	$ 44,917	$5,675	$ -	$ -	$ 592,878	$ 19,144	$ 14,872	$ 22,786	$ -	$ 78,723	$ 78,723
Short Haul	Diesel	HCCI	Option 4	10 years	5%	EIA estimate	84%	$ 3.29	$ 2.67	4.08	$ 45,058	$ 365,087	$ 21,976	$132,476	$ 4,597	$ 150	$171,537	$31,914	$ -	$ -	$ 28,117	$ 177,269	$ 44,917	$5,675	$ -	$ 105	$ 593,055	$ 19,407	$ 14,875	$ 22,797	$ -	$ 78,983	$ 78,983
Short Haul	LNG	Stoich	3-way	10 years	5%	EIA estimate	84%	$ 2.20	$ 1.86	3.97	$ 31,001	$ 261,966	$ 39,461	$132,476	$ 2,113	$ 15,438	$204,172	$31,914	$ -	$ -	$ 28,104	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 489,828	$ 23,648	$ 10,674	$ 22,786	$ -	$ 72,887	$ 72,887
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 3.29	$ 2.67	4.12	$ 44,617	$ 361,508	$ 21,976	$132,476	$ 5,322	$ 150	$172,318	$41,368	$16,399	$11,914	$ 28,317	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 617,866	$ 18,811	$ 14,729	$ 22,959	$ 2,677	$ 80,814	$ 80,814
Short Haul	Diesel	HCCI	Option 5	435,000 miles	5%	EIA estimate	84%	$ 3.29	$ 2.67	4.12	$ 44,617	$ 361,508	$ 21,976	$132,476	$ 6,222	$ 150	$173,288	$41,728	$16,399	$13,929	$ 28,317	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 619,881	$ 18,908	$ 14,729	$ 22,959	$ 2,878	$ 81,112	$ 81,112
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 2.20	$ 1.86	3.97	$ 31,001	$ 261,966	$ 39,461	$132,476	$ 2,113	$ 15,438	$204,172	$41,728	$29,446	$ 4,729	$ 28,104	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 522,529	$ 22,921	$ 10,674	$ 22,786	$ 3,270	$ 75,377	$ 75,377
Transit Bus	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 2.55	3.02	$ 50,704	$ 406,387	$ 14,662	$239,374	$ 2,551	$ 150	$276,634	$41,442	$ 9,001	$ 4,697	$ 40,433	$ 208,464	$161,308	$6,514	$ -	$ -	$ 795,133	$ 28,433	$ 10,671	$ 31,357	$ 1,038	$ 94,869	$ 69,900
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 2.55	2.99	$ 51,221	$ 410,531	$ 14,662	$239,374	$ 4,853	$ 150	$279,115	$42,671	$ 9,001	$ 8,938	$ 40,433	$ 208,464	$161,308	$6,514	$ -	$ -	$ 803,518	$ 28,636	$ 10,780	$ 31,357	$ 1,392	$ 95,770	$ 70,577
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 2.62	$ 2.13	2.94	$ 41,538	$ 375,741	$ 21,447	$239,374	$ 2,038	$ 27,500	$312,861	$42,671	$13,166	$ 3,754	$ 40,233	$ 208,464	$161,308	$ -	$ 4,653	$ -	$ 765,252	$ 32,325	$ 11,256	$ 31,202	$ 1,257	$ 96,389	$ 67,769
Transit Bus	Diesel	CIDI	Option 2	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 2.55	3.05	$ 50,216	$ 402,481	$ 14,662	$239,374	$ 4,195	$ 150	$278,406	$42,320	$ 9,001	$ 7,727	$ 42,863	$ 208,464	$161,308	$6,514	$ -	$ 22,615	$ 816,872	$ 28,578	$ 10,568	$ 33,242	$ 1,291	$ 96,825	$ 71,696

Table A-2. Intermediate Cost Scenario Calculation Results

Main inputs								2010 fuel price	Lifetime ave. fuel price (NPV)	Net fuel economy (miles per dge)	First year total fuel cost	fuel use over owner lifetime (NPV)	Vehicle capital costs						Engine/aftertr. replacement cost (NPV)		Maint. costs	Maintenance costs over lifetime (NPV)					Total lifetime operating costs	Average annual costs					Average annual costs (local share)
Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	% NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	medium	medium	medium	medium	medium	Engine (medium)	Chassis	Aftertr.	Fuel system	**Total w/ tax (medium)**	Residual value (medium)	Engine (medium)	Aftertr.	First year	Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	medium	Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total (medium)**	medium
Refuse Hauler	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.20	$ 10,654	$ 64,753	$ 14,267	$115,882	$ 2,909	$ 150	$143,531	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$ 225,960	$ 25,815	$ 9,962	$ 24,801	$ -	$ 60,578	$ 60,578
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 20,829	$115,882	$ 2,242	$ 11,250	$161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$ 4,253	$ -	$ 207,127	$ 29,184	$ 7,065	$ 24,801	$ -	$ 61,050	$ 61,050
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$ 10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$ 226,620	$ 26,523	$ 10,064	$ 24,801	$ -	$ 61,387	$ 61,387
Refuse Hauler	Diesel	CIDI	Option 5	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.23	$ 10,551	$ 64,131	$ 14,267	$115,882	$ 5,726	$ 150	$146,567	$ 4,416	$ -	$ -	$ 27,993	$ 51,643	$105,310	$4,253	$ -	$ 8,871	$ 234,208	$ 26,374	$ 9,866	$ 26,166	$ -	$ 62,406	$ 62,406
Short Haul	Diesel	CIDI	Option 7	10 years	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.17	$ 18,355	$ 148,723	$ 19,750	$132,476	$ 2,860	$ 150	$167,267	$31,667	$ -	$ -	$ 28,104	$ 177,269	$ 44,917	$5,675	$ -	$ -	$ 376,586	$ 19,144	$ 14,872	$ 22,786	$ -	$ 56,803	$ 56,803
Short Haul	Diesel	HCCI	Option 4	10 years	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.17	$ 18,359	$ 148,752	$ 19,907	$132,476	$ 4,597	$ 150	$169,308	$31,684	$ -	$ -	$ 28,117	$ 177,269	$ 44,917	$5,675	$ -	$ 105	$ 376,720	$ 19,407	$ 14,875	$ 22,797	$ -	$ 57,079	$ 57,079
Short Haul	LNG	Stoich	3-way	10 years	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$ 12,631	$ 106,736	$ 37,485	$132,476	$ 2,113	$ 15,438	$202,044	$31,667	$ -	$ -	$ 28,104	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 334,599	$ 23,648	$ 10,674	$ 22,786	$ -	$ 57,108	$ 57,108
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$ 18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$170,089	$40,449	$14,855	$11,914	$ 28,317	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 403,652	$ 18,811	$ 14,729	$ 22,959	$ 2,677	$ 59,177	$ 59,177
Short Haul	Diesel	HCCI	Option 5	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$ 18,179	$ 147,294	$ 19,907	$132,476	$ 6,222	$ 150	$171,059	$40,809	$14,855	$13,929	$ 28,317	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 405,667	$ 18,908	$ 14,729	$ 22,959	$ 2,878	$ 59,475	$ 59,475
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$ 12,631	$ 106,736	$ 37,485	$132,476	$ 2,113	$ 15,438	$202,044	$40,809	$27,972	$ 4,729	$ 28,104	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 367,300	$ 22,921	$ 10,674	$ 22,786	$ 3,270	$ 59,651	$ 59,651
Transit Bus	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.11	$ 20,561	$ 128,049	$ 12,644	$239,374	$ 2,551	$ 150	$274,459	$40,321	$ 7,762	$ 4,697	$ 40,433	$ 208,464	$161,308	$6,514	$ -	$ -	$ 516,795	$ 28,433	$ 10,671	$ 31,357	$ 1,038	$ 71,499	$ 46,726
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$ 20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$276,940	$41,549	$ 7,762	$ 8,938	$ 40,433	$ 208,464	$161,308	$6,514	$ -	$ -	$ 522,341	$ 28,636	$ 10,780	$ 31,357	$ 1,392	$ 72,164	$ 47,167
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$ 16,845	$ 135,073	$ 18,461	$239,374	$ 2,038	$ 27,500	$309,644	$41,549	$11,333	$ 3,754	$ 40,233	$ 208,464	$161,308	$ -	$ 4,653	$ -	$ 524,585	$ 32,325	$ 11,256	$ 31,202	$ 1,257	$ 76,041	$ 47,723
Transit Bus	Diesel	CIDI	Option 2	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.14	$ 20,364	$ 126,818	$ 12,644	$239,374	$ 4,195	$ 150	$276,232	$41,199	$ 7,762	$ 7,727	$ 42,863	$ 208,464	$161,308	$6,514	$ -	$ 22,615	$ 541,208	$ 28,578	$ 10,568	$ 33,242	$ 1,291	$ 73,678	$ 48,746

Table A-3. Low Cost Scenario Calculation Results

Main inputs: Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	% NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	2010 fuel price: low	Lifetime ave. fuel price (NPV): low	Net fuel economy (miles per dge): low cost scenario	First year total fuel cost: low	fuel use over owner lifetime (NPV): low
Refuse Hauler	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.92	3.37	$ 7,297	$ 44,354
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.66	$ 0.64	3.27	$ 5,022	$ 31,454
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.92	3.33	$ 7,372	$ 44,806
Refuse Hauler	Diesel	CIDI	Option 5	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.92	3.40	$ 7,227	$ 43,928
Short Haul	Diesel	CIDI	Option 7	10 years	5%	EIA estimate	84%	$ 0.99	$ 0.80	4.27	$ 12,917	$ 104,661
Short Haul	Diesel	HCCI	Option 4	10 years	5%	EIA estimate	84%	$ 0.99	$ 0.80	4.27	$ 12,920	$ 104,681
Short Haul	LNG	Stoich	3-way	10 years	5%	EIA estimate	84%	$ 0.66	$ 0.56	4.15	$ 8,889	$ 75,113
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 0.99	$ 0.80	4.31	$ 12,793	$ 103,655
Short Haul	Diesel	HCCI	Option 5	435,000 miles	5%	EIA estimate	84%	$ 0.99	$ 0.80	4.31	$ 12,793	$ 103,655
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.66	$ 0.56	4.15	$ 8,889	$ 75,113
Transit Bus	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.76	3.19	$ 14,398	$ 72,510
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.76	3.16	$ 14,544	$ 73,249
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.79	$ 0.64	3.10	$ 11,795	$ 86,508
Transit Bus	Diesel	CIDI	Option 2	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.76	3.23	$ 14,259	$ 71,813

Application	Vehicle capital costs: Engine (low)	Chassis	Aftertr.	Fuel system	**Total w/ tax (low)**	Residual value (low)	Engine/aftertr. replacement cost (NPV): Engine (low)	Aftertr.	Maint. costs: First year
Refuse Hauler	$ 12,118	$115,882	$ 2,909	$ 150	$141,216	$ 3,759	$ -	$ -	$ 26,533
Refuse Hauler	$ 18,888	$115,882	$ 2,242	$ 11,250	$159,753	$ 3,759	$ -	$ -	$ 26,533
Refuse Hauler	$ 12,118	$115,882	$ 6,476	$ 150	$145,060	$ 3,759	$ -	$ -	$ 26,533
Refuse Hauler	$ 12,118	$115,882	$ 5,726	$ 150	$144,252	$ 3,759	$ -	$ -	$ 27,993
Short Haul	$ 17,524	$132,476	$ 2,860	$ 150	$164,868	$31,420	$ -	$ -	$ 28,104
Short Haul	$ 17,838	$132,476	$ 4,597	$ 150	$167,078	$31,454	$ -	$ -	$ 28,117
Short Haul	$ 35,510	$132,476	$ 2,113	$ 15,438	$199,915	$31,420	$ -	$ -	$ 28,104
Short Haul	$ 17,838	$132,476	$ 5,322	$ 150	$167,859	$39,529	$13,311	$11,914	$ 28,317
Short Haul	$ 17,838	$132,476	$ 6,222	$ 150	$168,829	$39,889	$13,311	$13,929	$ 28,317
Short Haul	$ 35,510	$132,476	$ 2,113	$ 15,438	$199,915	$39,889	$26,498	$ 4,729	$ 28,104
Transit Bus	$ 10,626	$239,374	$ 2,551	$ 150	$272,285	$39,200	$ 6,524	$ 4,697	$ 40,433
Transit Bus	$ 10,626	$239,374	$ 4,853	$ 150	$274,766	$40,428	$ 6,524	$ 8,938	$ 40,433
Transit Bus	$ 15,474	$239,374	$ 2,038	$ 27,500	$306,426	$40,428	$ 9,500	$ 3,754	$ 40,233
Transit Bus	$ 10,626	$239,374	$ 4,195	$ 150	$274,057	$40,078	$ 6,524	$ 7,727	$ 42,863

Application	Maintenance costs over lifetime (NPV): Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	Total lifetime operating costs: low	Average annual costs: Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total (low)**	Average annual costs (local share): low
Refuse Hauler	$ 51,643	$105,310	$4,253	$ -	$ -	$ 205,560	$ 25,815	$ 9,962	$ 24,801	$ -	$ 57,102	$ 57,102
Refuse Hauler	$ 51,643	$105,310	$ -	$ 4,253	$ -	$ 192,661	$ 29,184	$ 7,065	$ 24,801	$ -	$ 58,528	$ 58,528
Refuse Hauler	$ 51,643	$105,310	$4,253	$ -	$ -	$ 206,012	$ 26,523	$ 10,064	$ 24,801	$ -	$ 57,879	$ 57,879
Refuse Hauler	$ 51,643	$105,310	$4,253	$ -	$ 8,871	$ 214,004	$ 26,374	$ 9,866	$ 26,166	$ -	$ 58,960	$ 58,960
Short Haul	$ 177,269	$ 44,917	$5,675	$ -	$ -	$ 332,523	$ 19,144	$ 14,872	$ 22,786	$ -	$ 52,105	$ 52,105
Short Haul	$ 177,269	$ 44,917	$5,675	$ -	$ 105	$ 332,649	$ 19,407	$ 14,875	$ 22,797	$ -	$ 52,401	$ 52,401
Short Haul	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 302,975	$ 23,648	$ 10,674	$ 22,786	$ -	$ 53,689	$ 53,689
Short Haul	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 360,013	$ 18,811	$ 14,729	$ 22,959	$ 2,677	$ 54,597	$ 54,597
Short Haul	$ 177,269	$ 44,917	$5,675	$ -	$ 1,727	$ 362,028	$ 18,908	$ 14,729	$ 22,959	$ 2,878	$ 54,896	$ 54,896
Short Haul	$ 177,269	$ 44,917	$ -	$ 5,675	$ -	$ 335,677	$ 22,921	$ 10,674	$ 22,786	$ 3,270	$ 56,286	$ 56,286
Transit Bus	$ 208,464	$161,308	$6,514	$ -	$ -	$ 461,256	$ 28,433	$ 10,671	$ 31,357	$ 1,038	$ 66,696	$ 42,119
Transit Bus	$ 208,464	$161,308	$6,514	$ -	$ -	$ 466,236	$ 28,636	$ 10,780	$ 31,357	$ 1,392	$ 67,314	$ 42,513
Transit Bus	$ 208,464	$161,308	$ -	$ 4,653	$ -	$ 476,020	$ 32,325	$ 11,256	$ 31,202	$ 1,257	$ 71,701	$ 43,686
Transit Bus	$ 208,464	$161,308	$6,514	$ -	$ 22,615	$ 486,203	$ 28,578	$ 10,568	$ 33,242	$ 1,291	$ 68,920	$ 44,183

Table A-4. Refuse Hauler Sensitivity Calculation

Refuse Hauler sensitivity 2005July14 — Example Cases (all dollars in 2005$)

Main inputs													Initial vehicle capital costs						Engine/aftertr. replacement cost (NPV)		Maint. costs	Maintenance costs over lifetime (NPV)						Average annual costs						
Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	%NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	2010 fuel price	Lifetime ave. fuel price (NPV)	Net fuel economy (miles per dge)	First year total fuel cost	Fuel use over owner lifetime (NPV)	Engine	Chassis	Aftertr.	Fuel system	**Total w/ tax**	Residual value (medium)	Engine	Aftertr.	First year	Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	Total lifetime operating costs	Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total**	**Total local share**	**Total local share diff.**
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$29,184	$ 7,065	$24,801	$ -	$ 61,050	$61,050	$337
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 3.08	3.17	$25,830	$ 156,995	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$318,202	$26,523	$24,153	$24,801	$ -	$ 75,477	$75,477	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 2.12	3.11	$ 7,331	$ 110,212	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$271,418	$29,184	$16,956	$24,801	$ -	$ 70,941	$70,941	$4,535
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.92	3.17	$ 7,749	$ 47,099	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$208,305	$26,523	$ 7,246	$24,801	$ -	$ 58,569	$58,569	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.64	3.11	$ 7,331	$ 33,064	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$194,270	$29,184	$ 5,087	$24,801	$ -	$ 59,072	$59,072	($503)
Refuse Hauler	Diesel	CIDI	Option 6	10 years	50%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	50%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 16,663	$115,882	$ 1,793	$ 9,000	$ 154,448	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$27,824	$ 7,065	$24,801	$ -	$ 59,689	$59,689	$1,698
Refuse Hauler	Diesel	CIDI	Option 6	10 years	5%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 27,078	$115,882	$ 2,914	$ 14,625	$ 172,939	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$31,226	$ 7,065	$24,801	$ -	$ 63,091	$63,091	($1,704)
Refuse Hauler	Diesel	CIDI	Option 5	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.23	$10,551	$ 64,131	$ 14,267	$115,882	$ 5,726	$ 150	$ 146,567	$ 4,416	$ -	$ -	$ 27,993	$ 51,643	$105,310	$4,253	$ -	$8,871	$234,208	$26,374	$ 9,866	$26,166	$ -	$ 62,406	$62,406	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$29,184	$ 7,065	$24,801	$ -	$ 61,050	$61,050	$1,356
Refuse Hauler	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.20	$10,654	$ 64,753	$ 14,267	$115,882	$ 2,909	$ 150	$ 143,531	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$225,960	$25,815	$ 9,962	$24,801	$ -	$ 60,578	$60,578	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$29,184	$ 7,065	$24,801	$ -	$ 61,050	$61,050	($472)
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	80% of Diesel	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	80% of Diesel	84%	$ 0.92	$ 0.86	3.11	$ 7,371	$ 44,803	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$206,009	$29,184	$ 6,893	$24,801	$ -	$ 60,878	$60,878	$509
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	90% of Diesel	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	90% of Diesel	84%	$ 1.04	$ 0.97	3.11	$ 8,293	$ 50,403	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$211,609	$29,184	$ 7,754	$24,801	$ -	$ 61,740	$61,740	($353)
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	79%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	79%	$ 0.86	$ 0.83	3.11	$ 6,895	$ 43,188	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$204,394	$29,184	$ 6,644	$24,801	$ -	$ 60,630	$60,630	$757
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	89%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,523	$10,064	$24,801	$ -	$ 61,387	$61,387	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	89%	$ 0.97	$ 0.94	3.11	$ 7,768	$ 48,654	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$209,861	$29,184	$ 7,485	$24,801	$ -	$ 61,471	$61,471	($84)
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.02	$11,286	$ 68,597	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$229,804	$26,523	$10,553	$24,801	$ -	$ 61,877	$61,877	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	2.97	$ 7,688	$ 48,156	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$209,362	$29,184	$ 7,409	$24,801	$ -	$ 61,394	$61,394	$483
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.33	$10,238	$ 62,230	$ 14,267	$115,882	$ 6,476	$ 150	$ 147,376	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$223,436	$26,523	$ 9,574	$24,801	$ -	$ 60,897	$60,897	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.27	$ 6,975	$ 43,686	$ 20,829	$115,882	$ 2,242	$ 11,250	$ 161,844	$ 4,416	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$204,892	$29,184	$ 6,721	$24,801	$ -	$ 60,706	$60,706	$191
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 16,416	$115,882	$ 6,476	$ 150	$ 149,691	$ 5,073	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,861	$10,064	$24,801	$ -	$ 61,725	$61,725	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 22,770	$115,882	$ 2,242	$ 11,250	$ 163,936	$ 5,073	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$29,481	$ 7,065	$24,801	$ -	$ 61,347	$61,347	$378
Refuse Hauler	Diesel	CIDI	Option 6	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.28	3.17	$10,762	$ 65,414	$ 12,118	$115,882	$ 6,476	$ 150	$ 145,060	$ 3,759	$ -	$ -	$ 26,533	$ 51,643	$105,310	$4,253	$ -	$ -	$226,620	$26,185	$10,064	$24,801	$ -	$ 61,049	$61,049	
Refuse Hauler	LNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 0.92	$ 0.88	3.11	$ 7,331	$ 45,921	$ 18,888	$115,882	$ 2,242	$ 11,250	$ 159,753	$ 3,759	$ -	$ -	$ 26,533	$ 51,643	$105,310	$ -	$4,253	$ -	$207,127	$28,888	$ 7,065	$24,801	$ -	$ 60,753	$60,753	$296

Table A-5. Transit Bus Sensitivity Calculation

Transit Bus sensitivity 2005July6 — Example Cases (all dollars in 2005$)

Main inputs													Initial vehicle capital costs						Engine/aftertr. replacement cost (NPV)		Maint. costs	Maintenance costs over lifetime (NPV)						Average annual costs						
Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	%NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	2010 fuel price	Lifetime ave. fuel price (NPV)	Net fuel economy (miles per dge)	First year total fuel cost	Fuel use over owner lifetime (NPV)	Engine	Chassis	Aftertr.	Fuel system	**Total w/ tax**	Residual value	Engine	Aftertr.	First year	Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	Total lifetime operating costs	Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total**	**Total local share**	**Total local share diff.**
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,636	$10,780	$31,357	$ 1,392	$ 72,164	$ 47,167	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$524,585	$32,325	$11,256	$31,202	$ 1,257	$ 76,041	$ 47,723	($556)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 3.29	$ 2.55	3.08	$49,851	$ 399,554	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$792,541	$28,636	$33,296	$31,357	$ 1,392	$ 94,681	$ 69,684	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 2.13	3.02	$16,845	$ 365,694	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$755,206	$32,325	$30,475	$31,202	$ 1,257	$ 95,259	$ 66,942	$ 2,742
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 0.99	$ 0.76	3.08	$14,955	$ 75,318	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$468,306	$28,636	$ 6,277	$31,357	$ 1,392	$ 67,661	$ 42,664	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.64	3.02	$16,845	$ 88,952	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$478,464	$32,325	$ 7,413	$31,202	$ 1,257	$ 72,197	$ 43,880	($1,215)
Transit Bus	Diesel	CIDI	Option 5	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.14	$20,364	$ 126,818	$ 12,644	$239,374	$ 5,022	$ 150	$ 277,122	$ 41,639	$ 7,762	$ 9,248	$ 42,863	$208,464	$161,308	$ 6,514	$ -	$22,615	$542,730	$28,650	$10,568	$33,242	$ 1,418	$ 73,878	$ 48,865	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,639	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$524,585	$32,320	$11,256	$31,202	$ 1,257	$ 76,035	$ 47,720	$1,145
Transit Bus	Diesel	CIDI	Option 7	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.11	$20,561	$ 128,049	$ 12,644	$239,374	$ 2,551	$ 150	$ 274,459	$ 40,321	$ 7,762	$ 4,697	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$516,795	$28,433	$10,671	$31,357	$ 1,038	$ 71,499	$ 46,726	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 40,321	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$524,585	$32,402	$11,256	$31,202	$ 1,257	$ 76,118	$ 47,772	($1,046)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	80% of Diesel	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,636	$10,780	$31,357	$ 1,392	$ 72,164	$ 47,167	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	80% of Diesel	84%	$ 1.10	$ 0.85	3.02	$16,936	$ 127,711	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$517,223	$32,325	$10,643	$31,202	$ 1,257	$ 75,427	$ 47,110	$58
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	90% of Diesel	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,636	$10,780	$31,357	$ 1,392	$ 72,164	$ 47,167	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	90% of Diesel	84%	$ 1.23	$ 0.96	3.02	$19,053	$ 147,381	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$536,893	$32,325	$12,282	$31,202	$ 1,257	$ 77,066	$ 48,749	($1,582)
Transit Bus	Diesel	CIDI	Option 3	10 years	50%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,636	$10,780	$31,357	$ 1,392	$ 72,164	$ 47,167	
Transit Bus	CNG	Stoich	3-way	10 years	50%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 14,768	$239,374	$ 1,630	$ 22,000	$ 299,300	$ 41,549	$ 9,067	$ 3,003	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$521,567	$31,158	$11,256	$31,202	$ 1,006	$ 74,622	$ 47,355	($188)
Transit Bus	Diesel	CIDI	Option 3	10 years	5%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,636	$10,780	$31,357	$ 1,392	$ 72,164	$ 47,167	
Transit Bus	CNG	Stoich	3-way	10 years	5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 23,999	$239,374	$ 2,649	$ 35,750	$ 325,159	$ 41,549	$14,733	$ 4,880	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$529,111	$34,076	$11,256	$31,202	$ 1,634	$ 78,168	$ 48,275	($1,108)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.16	$20,200	$ 125,801	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$518,788	$28,636	$10,483	$31,357	$ 1,392	$ 71,868	$ 46,871	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.10	$16,382	$ 131,362	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$520,874	$32,325	$10,947	$31,202	$ 1,257	$ 75,731	$ 47,414	($543)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	2.99	$21,342	$ 132,908	$ 12,644	$239,374	$ 4,853	$ 150	$ 276,940	$ 41,549	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$525,895	$28,636	$11,076	$31,357	$ 1,392	$ 72,460	$ 47,463	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	2.94	$17,307	$ 138,784	$ 18,461	$239,374	$ 2,038	$ 27,500	$ 309,644	$ 41,549	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$528,295	$32,325	$11,565	$31,202	$ 1,257	$ 76,350	$ 48,032	($569)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 10,626	$239,374	$ 4,853	$ 150	$ 274,766	$ 40,428	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,461	$10,780	$31,357	$ 1,392	$ 71,989	$ 47,189	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 15,474	$239,374	$ 2,038	$ 27,500	$ 306,426	$ 40,428	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$524,585	$32,033	$11,256	$31,202	$ 1,257	$ 75,748	$ 47,733	($544)
Transit Bus	Diesel	CIDI	Option 3	10 years	12.5%	EIA estimate	84%	$ 1.37	$ 1.06	3.08	$20,771	$ 129,354	$ 14,662	$239,374	$ 4,853	$ 150	$ 279,115	$ 42,671	$ 7,762	$ 8,938	$ 40,433	$208,464	$161,308	$ 6,514	$ -	$ -	$522,341	$28,810	$10,780	$31,357	$ 1,392	$ 72,339	$ 47,146	
Transit Bus	CNG	Stoich	3-way	10 years	12.5%	EIA estimate	84%	$ 1.09	$ 0.89	3.02	$16,845	$ 135,073	$ 21,447	$239,374	$ 2,038	$ 27,500	$ 312,861	$ 42,671	$11,333	$ 3,754	$ 40,233	$208,464	$161,308	$ -	$4,653	$ -	$524,585	$32,618	$11,256	$31,202	$ 1,257	$ 76,333	$ 47,714	($568)

Table A-6. Short Haul Sensitivity Calculation

Short Haul sensitivity 2005July14 — Example Cases (all dollars in 2005$)

Main inputs														Initial vehicle capital costs						Engine/aftertr. replacement cost (NPV)		Maint. costs	Maintenance costs over lifetime (NPV)						Average annual costs						
Application	Fuel	Engine type	Aftertr. option	Engine and aftertr. life	%NG in national fleet	CNG price tracking with diesel	LNG price tracking with CNG	2010 fuel price	Lifetime ave. fuel price (NPV)	Net fuel economy (miles per dge)	First year total fuel cost	Fuel use over owner lifetime (NPV)	Engine	Chassis	Aftertr.	Fuel system	**Total w/ tax**	Residual value	Engine	Aftertr.	First year	Oil changes	Brakes	Aftertr. maint.	Other maint	SCR cons.	Total lifetime operating costs	Vehicle purchase	Fueling	Maint.	Replace/ rebuild	**Total**	**Total local share**	**Total local share diff.**
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$367,300	$22,950	$10,674	$22,786	$ 3,270	$ 59,680	$59,680	($503)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 3.29	$ 2.67	4.22	$43,630	$ 353,512	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$609,870	$18,811	$35,351	$22,959	$ 2,677	$ 79,798	$79,798	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 1.86	4.05	$12,631	$ 256,172	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$516,735	$22,950	$25,617	$22,786	$ 3,270	$ 74,623	$74,623	$5,175
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 0.99	$ 0.80	4.22	$13,089	$ 106,054	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$362,412	$18,811	$10,605	$22,959	$ 2,677	$ 55,053	$55,053	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.56	4.05	$12,631	$ 76,851	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$337,415	$22,950	$ 7,685	$22,786	$ 3,270	$ 56,691	$56,691	($1,639)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	12.5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	12.5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 28,835	$132,476	$ 1,625	$ 11,875	$ 188,359	$ 40,449	$21,517	$ 3,638	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$359,753	$21,177	$10,674	$22,786	$ 2,515	$ 57,153	$57,153	$2,024
Short Haul	Diesel	HCCI	Option 6	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.13	$18,542	$ 150,240	$ 19,907	$132,476	$ 6,950	$ 150	$ 171,843	$ 41,100	$14,855	$15,559	$ 28,104	$177,269	$ 44,917	$5,675	$ -	$ -	$408,516	$18,987	$15,024	$22,786	$ 3,041	$ 59,838	$59,838	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 41,100	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$367,300	$22,898	$10,674	$22,786	$ 3,270	$ 59,628	$59,628	$210
Short Haul	Diesel	HCCI	Option 1	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.17	$18,359	$ 148,752	$ 19,907	$132,476	$ 3,697	$ 150	$ 168,338	$ 39,799	$14,855	$ 8,276	$ 28,117	$177,269	$ 44,917	$5,675	$ -	$ 105	$399,851	$18,636	$14,875	$22,797	$ 2,313	$ 58,621	$58,621	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 39,799	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$367,300	$23,001	$10,674	$22,786	$ 3,270	$ 59,731	$59,731	($1,110)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	80% of Diesel	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	80% of Diesel	84%	$ 0.92	$ 0.75	4.05	$12,700	$ 102,902	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$363,465	$22,950	$10,290	$22,786	$ 3,270	$ 59,296	$59,296	($120)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	90% of Diesel	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	90% of Diesel	84%	$ 1.04	$ 0.84	4.05	$14,287	$ 115,764	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$376,328	$22,950	$11,576	$22,786	$ 3,270	$ 60,582	$60,582	($1,406)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	79%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	79%	$ 0.86	$ 0.73	4.05	$11,879	$ 100,383	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$360,946	$22,950	$10,038	$22,786	$ 3,270	$ 59,044	$59,044	$132
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	89%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,811	$14,729	$22,959	$ 2,677	$ 59,177	$59,177	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	89%	$ 0.97	$ 0.82	4.05	$13,383	$ 113,090	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$373,653	$22,950	$11,309	$22,786	$ 3,270	$ 60,315	$60,315	($1,138)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.12	$18,590	$ 150,626	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$406,984	$18,811	$15,063	$22,959	$ 2,677	$ 59,510	$59,510	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	3.97	$12,917	$ 109,150	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$369,714	$22,950	$10,915	$22,786	$ 3,270	$ 59,921	$59,921	($411)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.31	$17,768	$ 143,962	$ 19,907	$132,476	$ 5,322	$ 150	$ 170,089	$ 40,449	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$400,321	$18,811	$14,396	$22,959	$ 2,677	$ 58,843	$58,843	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.15	$12,346	$ 104,322	$ 37,485	$132,476	$ 2,113	$ 15,438	$ 202,044	$ 40,449	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$364,886	$22,950	$10,432	$22,786	$ 3,270	$ 59,438	$59,438	($595)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 21,976	$132,476	$ 5,322	$ 150	$ 172,318	$ 41,368	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$19,027	$14,729	$22,959	$ 2,677	$ 59,392	$59,392	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 39,461	$132,476	$ 2,113	$ 15,438	$ 204,172	$ 41,368	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$367,300	$23,152	$10,674	$22,786	$ 3,270	$ 59,882	$59,882	($490)
Short Haul	Diesel	HCCI	Option 2	435,000 miles	5%	EIA estimate	84%	$ 1.37	$ 1.11	4.22	$18,179	$ 147,294	$ 17,838	$132,476	$ 5,322	$ 150	$ 167,859	$ 39,529	$14,855	$11,914	$ 28,317	$177,269	$ 44,917	$5,675	$ -	$ 1,727	$403,652	$18,596	$14,729	$22,959	$ 2,677	$ 58,961	$58,961	
Short Haul	LNG	Stoich	3-way	435,000 miles	5%	EIA estimate	84%	$ 0.92	$ 0.77	4.05	$12,631	$ 106,736	$ 35,510	$132,476	$ 2,113	$ 15,438	$ 199,915	$ 39,529	$27,972	$ 4,729	$ 28,104	$177,269	$ 44,917	$ -	$5,675	$ -	$367,300	$22,747	$10,674	$22,786	$ 3,270	$ 59,477	$59,477	($516)