U.S. and Canadian Natural Gas Vehicle Market Analysis:

Comparative and Scenario Analysis

Executive Summary

Published by America's Natural Gas Alliance

Executive Summary

The Cost Advantages of Natural Gas

America's Import Bill is Growing

The United States' annual import bill for transportation fuel is nearing $350 billion, double the amount we spend on education. In 2010, vehicles consumed a total of 4.7 billion barrels of conventional fuel, far more than the 4.2 billion barrels we imported that year.[1,2]

As President Barack Obama explained, Americans have an over reliance on foreign sources of energy for our transportation needs:

Our dependence on foreign oil threatens our national security, our environment, and our economy. We must make the investments in clean energy sources that will put Americans back in control of our energy future, create millions of new jobs, and lay the foundation for long-term economic security.[3]

Societal Costs

Not only is over reliance of foreign sources of energy expensive, it keeps us dependant on our energy from geopoliticially unstable regions of the world. Increasing use of domestic natural gas as a clean alternative fuel will help prevent North America from relying on regions of the world whose interests run counter to our own. For every gallon of transportation fuel we purchase, we pay a calculated energy security premium of $0.46.[4] The costs of this premium are reflected in decreased national economic output, loss of national gross product, economic strain and volatility, supply shocks and prices spikes, supply disruption, and import costs. Each time a driver refuels, s/he is paying $8.31 for energy security, per vehicle, on top of an average of $54 to fill up the tank.[5]

For every gallon of transportation fuel we purchase, we pay a calculated energy security premium of $0.46.[4]

In addition, transportation fuel carries a societal cost based on impacts from criteria pollutant emissions. Another societal cost of our transportation fuel results from GHG emissions. Monetization of these societal costs provides a means to assess the societal benefits of the alternative fuels considered. Across multiple vehicle segments, the societal costs for NGVs are lower than those for conventional transportation fuels. The net savings (of direct and societal costs) exceed $50,000 for some high fuel use applications and are comparable to saving 15 percent of lifetime costs. The savings for other applications may be less but are still significant.

1 Energy Information Administration. "U.S. Primary Energy Flow by Source and Sector." 2009.
2 Energy Information Administration. "Imports by Area of Entry." 2009.
3 The White House, "Learn: Clean Energy Economy," http://m.whitehouse.gov/issues/energy-and-environment/new-foundation/learn, (October 3, 2011).
4 In 2010 U.S. dollars; U.S. EPA and NHTSA, "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis," EPA-420-R-10-009, April 2010.
5 Assuming an average tank size of 16 gallons and based on a U.S. average gasoline (regular grade) price of $3.417 per gallon from AAA, http://fuelgaugereport.opisnet.com/index.asp, October 3, 2011.

ES1 Energy Security Premium

The effect of overseas transportation fuel

Energy Security Premium[6] = $0.462 per gallon transportation fuel
Decreased economic output Loss of national gross product Economic strain and volatility Transportation fuel supply shocks and price spikes Supply disruption Import costs

ES2 Criteria Pollutants + GHG Costs

Our current total transportation portfolio bears societal costs

Air Pollution Costs[7,8,9,10] $9,072 per ton NO_x $270 per ton CO $7,401 per ton VOC $283,274 per ton $PM_{2.5}$	GHG Costs[11,12] $23.13 per ton GHG
Impacts from Criteria Pollutants	Impacts from GHG Emissions

All together, current societal costs of conventionally fueled vehicles are estimated to amount to $0.99 per day for each passenger car on the road.[13,14,15,16,17,18] Multiply that by 255 million to account for the U.S.'s on-highway vehicle population, and you see that the societal costs connected to consuming transportation fuel add up to upwards of $252 million dollars day.

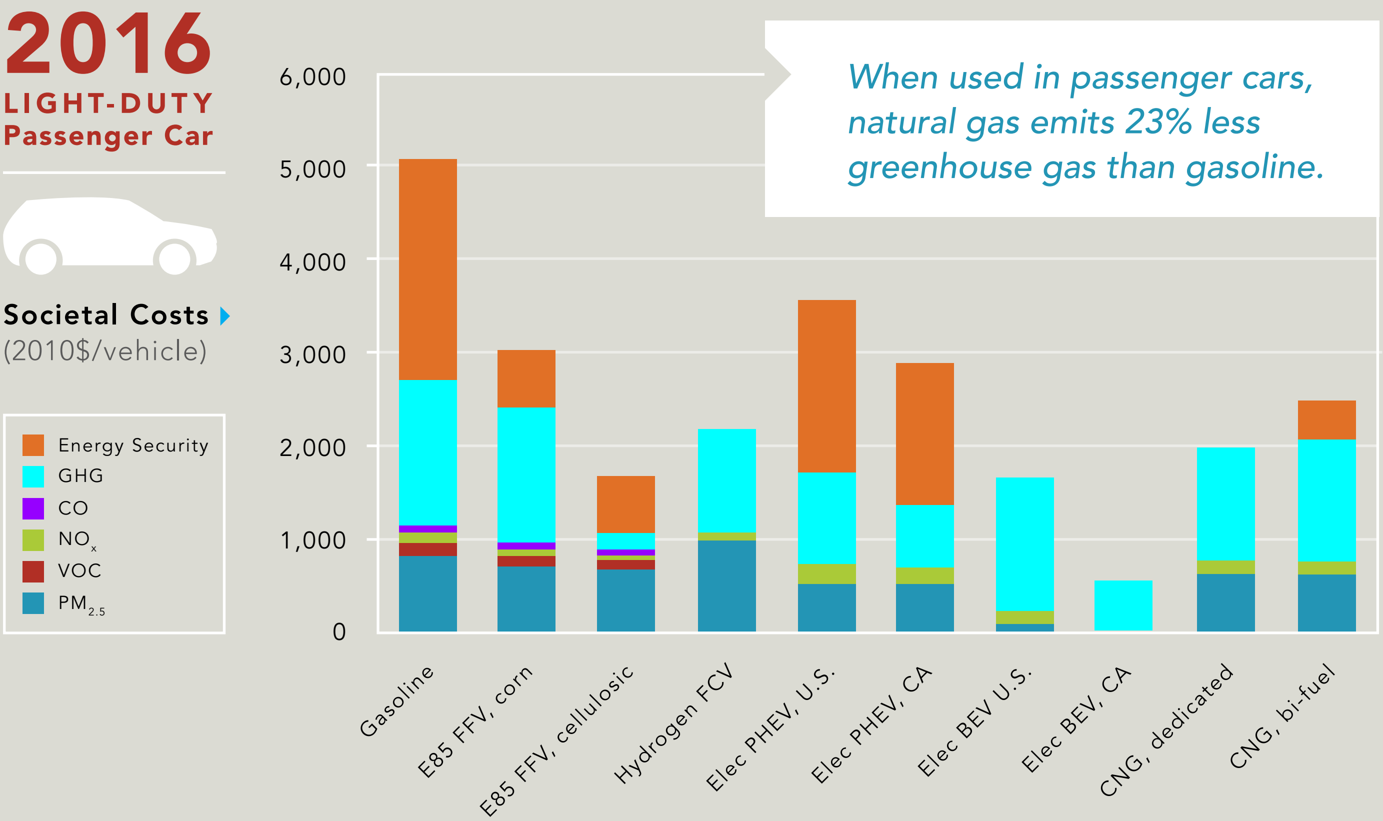
For the purposes of this report, light-duty vehicles are passenger cars. Medium-duty vehicles are vans and small trucks. Heavy-duty vehicles include tractors, semis, and utility vehicles such as garbage trucks.

The estimated indirect costs of a single conventionally-powered passenger car add up to $5,100 over its lifetime, while the indirect costs for a car that runs on a gasoline alternative range from $580 to $3,500.

The societal costs of natural gas vehicles are estimated across all vehicle sizes to be lower than those of conventionally fueled vehicles.

For medium-duty vans, hybrid package delivery vans, hybrid beverage trucks, transit buses, refuse haulers, and 18-wheeled tractor-trailers using conventional fuel, the costs are even higher. They can range from $18,000 to $95,000 per vehicle over its lifetime. In comparison, the indirect costs of running these vehicles on gasoline alternatives and/or diesel fuel range from $700 to as high as $88,000 per vehicle.

6 Costs for NOx and VOCs include both direct emissions of these pollutants and their indirect emissions (as precursors to PM); all costs are given in 2010 U.S. dollars.
7 U.S. EPA, NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009, p. 7-118. April 2010.
8 TIAX communication with N. Fann, EPA Office of Air Quality Planning & Standards, August/September 2010.
9 CEC. "Reducing California's Petroleum Dependence, Appendix A: Benefits of Reducing Demand for Gasoline and Diesel (Task 1)." P600-03-005A1, p. 3-27. September 2003.
10 U.S. Government. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis, Under Executive Order 12866," p. 39. Interagency Working Group. February 2010.
11 U.S. EPA, NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009, p. 7-128. April 2010
12 Research and Innovative Technology Administration, "Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances (2008)," http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html (October 6, 2011).
13 U.S. EPA, NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009, p. 8-16. April 2010.
14 Costs for NOx and VOCs include both direct emissions of these pollutants and their indirect emissions (as precursors to PM); all costs are given in 2010 U.S. dollars.
15 U.S. EPA, NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009, p. 7-118. April 2010.
16 TIAX communication with N. Fann, EPA Office of Air Quality Planning & Standards, August/September 2010.
17 CEC. "Reducing California's Petroleum Dependence, Appendix A: Benefits of Reducing Demand for Gasoline and Diesel (Task 1)." P600-03-005A1, p. 3-27. September 2003.
18 U.S. Government. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis, Under Executive Order 12866," p. 39. Interagency Working Group. February 2010.



Natural Gas is Safer and Environmentally Superior

Natural gas is what green energy proponents are searching for: a high octane, low carbon fuel. When used in passenger cars, natural gas emits 23% less greenhouse gas than gasoline, and that's only one part of its clean energy profile. It also has 46% fewer NOx emissions and virtually no sulfur dioxide, mercury, or particulate pollution. Natural gas has fewer drawbacks than current transportation/conventional fuel and it makes an ideal substitute.[19]

Like transportation fuel, compressed natural gas (CNG) is a flammable gas, but it has a narrow flammability range. This makes it an inherently safer fuel. Furthermore, CNG is nontoxic. In the event of a spill, CNG poses no threat to land or water. It disperses rapidly,[20] reducing the risk of ignition relative to gasoline.

Similarly, liquefied natural gas (LNG) readily evaporates if it is released in the air. If an LNG vehicle or station were damaged in a way that punctured fuel tanks, any spilled fuel would ultimately evaporate rather than pooling on the ground.

Natural Gas is Economical

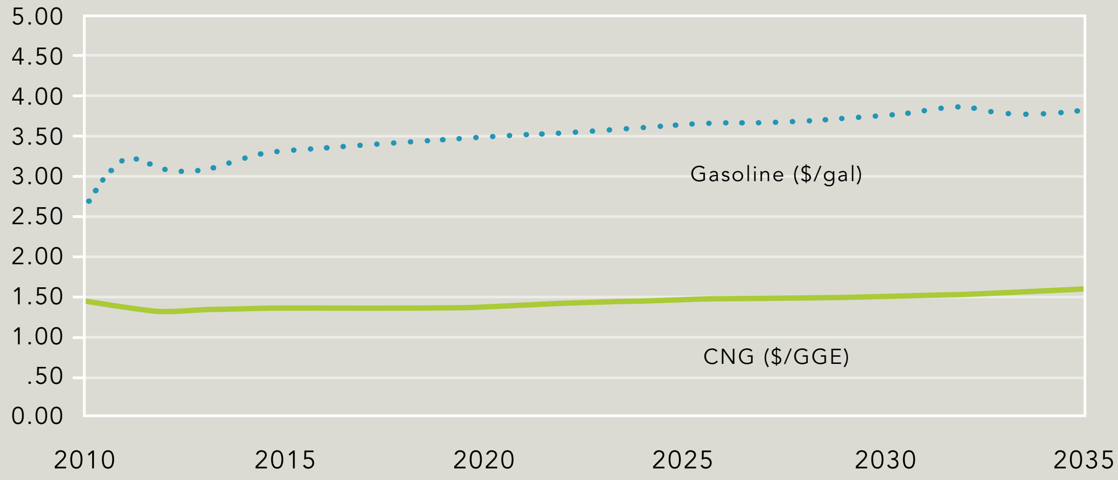
If you consider all of the alternative fuels that are feasible and available, natural gas offers the widest array of applications and is expected to be more economical than either gasoline or diesel—now and in the foreseeable future. As the following exhibit shows, natural gas is expected to become even cheaper relative to conventional fuels over the next 25 years. This may lead to fuel cost differentials between $1.00 and $2.00 per gallon gasoline equivalent (GGE) or even as much as $3.00 relative to diesel. The average North American fills up his or her tank weekly, and refueling with natural gas rather than gasoline works out to as much as $32 in saving every time. Over the course of a year, s/he would save $1,664.

19 ANGA, "Why Natural Gas: Clean," http://anga.us/why-natural-gas/clean, (October 3, 2011).
20 U.S. Department of Energy Energy Efficiency & Renewable Energy Vehicle Technologies Program. "Natural Gas Basics." http://www.afdc.energy.gov/pdfs/48126.pdf. April 2010.

ES4 Gasoline Prices vs CNG

Efficiency Adjusted Fuel Price

Notes
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes



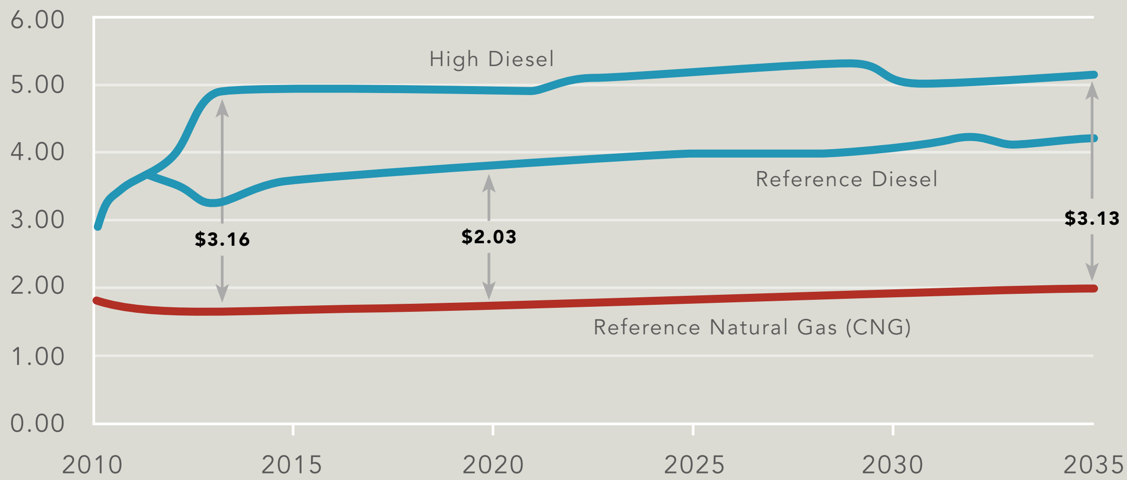
ES5 Diesel Prices vs CNG

DGE Fuel Price At Pump

(2010$ per DGE)

Notes
1) Fuel prices are derived from U.S. EIA "Annual Energy Outlook," 2012
2) Prices include federal and state taxes
3) Prices are adjusted for vehicle efficiency

Fuel price differentials at the pump of over $3 per equivalent gallon are possible in the near future.[21]



21 Energy Information Administration. "Annual Energy Outlook 2012." June 2012.

Growing Interest in Alternative Fuel Vehicles

End users are becoming more interested in alternative fuel vehicles. They want to increase our use of domestic alternatives and offset the harmful environmental consequences of conventional fuel consumption, but they have concerns about their purchase decisions.

Environmental Concerns and the Cost of Transportation Fuel are Driving Consumer Interest

Within the light-duty (passenger vehicle) segment, consumers are interested in hydrogen fuel cell vehicles (39% of consumers), hybrid gas and electric vehicles (40%), and natural gas vehicles (30%). Consumers are even willing to pay an average of $2,600 extra for more environmentally friendly vehicles.[22] However, today's limited vehicle selection, high prices, and a perceived lack of established fueling infrastructure holds them back.[23]

In the medium- and heavy-duty vehicle sectors, increasingly stringent emissions standards are making customers more interested in alternative fuel choices. For heavy-duty vehicles, creating the infrastructure for CNG or LNG offers returns on investment ranging from 8 to 31 percent.

Governmental Involvement

The government can also play a role in leveling the playing field relative to other alternative fuels and vehicles, allowing for more market based adoption and avoidance of picking alternative fuel winners and losers. If policy makers decide to continue to offer purchase incentives for alternative fueled vehicles, they should do so on a level playing field.

22 Kelley Blue Book. "All-New Eco Watch Study from Kelley Blue Book Marketing Research Tracks, Trends Shoppers' Opinions." http://mediaroom.kbb.com/all-new-eco-watch-study-kelley-blue-book-marketing-research- tracks-trends-shoppers-opinions. September 22, 2008.

23 Convenience Store News. "Study Shows Awareness, Use of Alternative Fuel Remains Low." http://www.allbusiness.com/retail-trade/food-stores/4489359-1.html. June 6, 2006.

U.S. and Canadian Natural Gas Vehicle Market Analysis:

Scenario Analysis

Final Report

Legal Disclaimer

This report was prepared by TIAX for America's Natural Gas Alliance on terms specifically limiting TIAX's liability. Our conclusions are the result of the exercise of our best professional judgment based in part upon materials and information provided to us by our subcontractors and others.

TIAX accepts no duty of care or liability of any kind whatsoever to any third party, and no responsibility for damages or loss, if any, suffered by any third party, as a result of decisions made, or not made, or actions taken, or not taken, based on this document.

This report may be reproduced only in its entirety and only with the prior written consent of TIAX.

Copyrighted items are the property of the respective copyright owners.

Table of Contents

Abbreviations
Lower Heating Value Energy Content Conversion Factors
Natural Gas Properties Comparison
Preface
Executive Summary

Chapter 1

Introduction

Chapter 2

Transportation Sector Today

Chapter 3

3 Methodology and Assumptions
3.1 Scenario Analysis Model
3.1.1 Overview
3.1.2 Light-Duty Vehicles
3.1.3 Heavy-Duty Vehicles
3.1.4 Fuel Prices
3.1.5 Station and Infrastructure Costs

Chapter 4

4 Light-Duty Scenarios
4.1 Scenario Projections
4.2 Economic Results
4.3 Market Analysis

Chapter 5

5 Heavy-Duty Scenarios
5.1 Scenario Projections
5.2 Economic Results
5.3 Market Analysis

Chapter 6

6 Industry-Level Actions
6.1 Bottlenecks
6.2 Opportunities

Abbreviations

CNG	Compressed natural gas
DGE	Diesel gallon equivalent (=131.7 cubic feet of natural gas)
EIA	Energy Information Administration
GGE	Gasoline gallon equivalent (=115.6 cubic feet of natural gas)
HD	Heavy-duty
LD	Light-duty
LNG	Liquefied natural gas (1 gallon LNG = 0.58 DGE)
NGV	Natural gas vehicle
NPV	Net present value
OEM	Original equipment manufacturer
scfm	Standard cubic feet per minute
VMT	Vehicle miles traveled

Lower Heating Value Energy Content Conversion Factors

Diesel	129,488 BTU/gal
Gasoline	113,602 BTU/gal
LNG	74,720 BTU/gal
Natural gas	983 BTU/cubic foot (=131.4 BTU/gal of volume)

Source: Argonne National Laboratory, "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," 1.8c

Natural Gas Properties Comparison

Property	Natural Gas	Gasoline	Diesel
Physical state	Vapor	Liquid	Liquid
Ignition temperature	1,080°F	540°F	410°F
Density	22 grams/cubic foot (lighter than air)	2,800 grams/gallon (lighter than water)	3,200 grams/gallon (lighter than water)
Spill behavior	Evaporates and disperses	Pools on surface	Pools on surface
Storage temperature	CNG: ambient temperature LNG: below -200°F	Ambient temperature	Ambient temperature
Storage pressure	CNG: 3,000 to 3,600 psi LNG: varies	Ambient pressure	Ambient pressure

Preface

Identifying the most productive and effective means to increase the use of natural gas vehicles

With the primary objective of identifying the most productive and effective means to increase the use of natural gas vehicles (NGVs) in the U.S. and Canada, the TIAX team has conducted a thorough and independent assessment of the NGV market. To highlight the major opportunities to spur the market's development and expansion, this assessment examines the key technical, economic, regulatory, social, and political drivers and challenges that shape this market. TIAX has partnered with The CARLAB, Clean Fuels Consulting, the Clean Vehicle Education Foundation, Jack Faucett Associates, the Natural Gas Vehicle Institute, and St. Croix Research to provide perspective and insights into the development of the future NGV market.

TIAX's overall approach relies on six key stages

- Segmentation of the vehicle market
- Identification of market decision drivers
- Assessment of market development actions
- Analysis of competing technologies
- Analysis of market scenarios
- Integration of overall market development opportunities

The market perspectives for which decision drivers and opportunities have been identified and assessed are: light- and medium-duty vehicle ownership and production; heavy-duty vehicle ownership and production; compressed natural gas infrastructure; liquefied natural gas infrastructure; and government.

Drawing on the respective expertise of each team member, TIAX presents an integrated assesment of the U.S. and Canadian NGV market in a collection of eight reports. Each report is capable of standing alone while integrating the data, ideas, and themes of the other seven reports. The collection of reports in this TIAX analysis of the NGV market is supported by America's Natural Gas Alliance and is intended to be transparent and accessible to a broad audience.

Executive Summary

Our transportation system must increase use of domestic alternative fuels

Building on the insights of individual decision makers, this assessment is intended to take a higher-level look at the natural gas vehicle (NGV) market. From an overall industry perspective, this report uses scenario analysis as a tool to show the ramifications for industry stakeholders of various levels of NGVs deployment. The scenarios, which are defined by a set of assumptions about how vehicle rollout will occur over the next 25 years, illustrate how total natural gas consumption across the transportation sector, natural gas fueling infrastructure expansion, lifecycle savings for vehicle purchasers, business economics for natural gas supply chain companies, and societal benefits enabled by government incentives are interrelated.

The contributions of three categories of stakeholders are assessed: end users, infrastructure developers, and government. For different NGV rollout scenarios, the investments and returns for these stakeholders are assessed to determine their respective business cases and the conditions under which investing in the NGV market makes sense. For end users, the business case hinges largely on the tradeoff between significant incremental vehicle costs over transportation fuel vehicles versus lifetime fuel savings. For infrastructure developers, the business case is determined by their fuel sales relative to their capital investment in fueling infrastructure. For government agencies and the general public they represent, the business case is the comparison between incentives granted to the NGV industry and the societal benefits that are gained by transitioning from conventional fuel to natural gas.

This scenario analysis is intended to tie together total NGV market potential and market potential for individual stakeholders. Accordingly, the methodology has two key components: projections of total NGV market size (as defined by vehicle population, fuel consumption, and station population) and modeling of stakeholder cash flow (as defined by investments and gains for end users, infrastructure developers, and government). Figure ES-1 shows that investments into the light-duty sector may offer an attractive business case for infrastructure developers, with a return on investment (ROI) of 13 percent, only if government incentives are available for the lifetime of the station; otherwise, the ROI may be 1 percent.

The compelling business case for NGV market stakeholders lies in the heavy-duty sector. For both compressed natural gas (CNG) and liquefied natural gas (LNG) in the heavy-duty sector, end users and infrastructure developers may see favorable business cases with and without government incentives. Depending on the level of incentives, for CNG infrastructure developers, the ROI may range from 10 to 31 percent. For LNG infrastructure developers, the ROI may range from 8 to 23 percent. The ROIs calculated in this analysis are primarily a function of fuel throughput at the stations. If throughput is higher than the annual fuel sales assumed in this assessment (either through higher fuel consumption per vehicle or greater density of vehicles per station), the business cases offered by the light- and heavy-duty sectors may be even more favorable.

For the near-term market penetration of NGVs, there must be adequate infrastructure to sustain both CNG and LNG fleets and a level playing field among government incentives for the incremental costs of the vehicles to entice end users to switch to natural gas. In the beginning, it is likely that if government incentives are extended, government incentives will exceed the societal benefits since economies of scale have not yet been attained. As the market develops and NGVs become more prevalent, the proven performance of natural gas in transportation will enable the NGV market to be self-sustaining. As shown in Figure ES-2, current production capacities of station equipment, engine, and tank suppliers will only be able to support the initial growth of the NGV market. Foreseeing these issues and making investments to alleviate potential capacity bottlenecks will enable the long-term development of the NGV market as it expands.

Figure ES-1

Heavy-duty NGVs provide a compelling business case for infrastructure developers with and without government incentives.

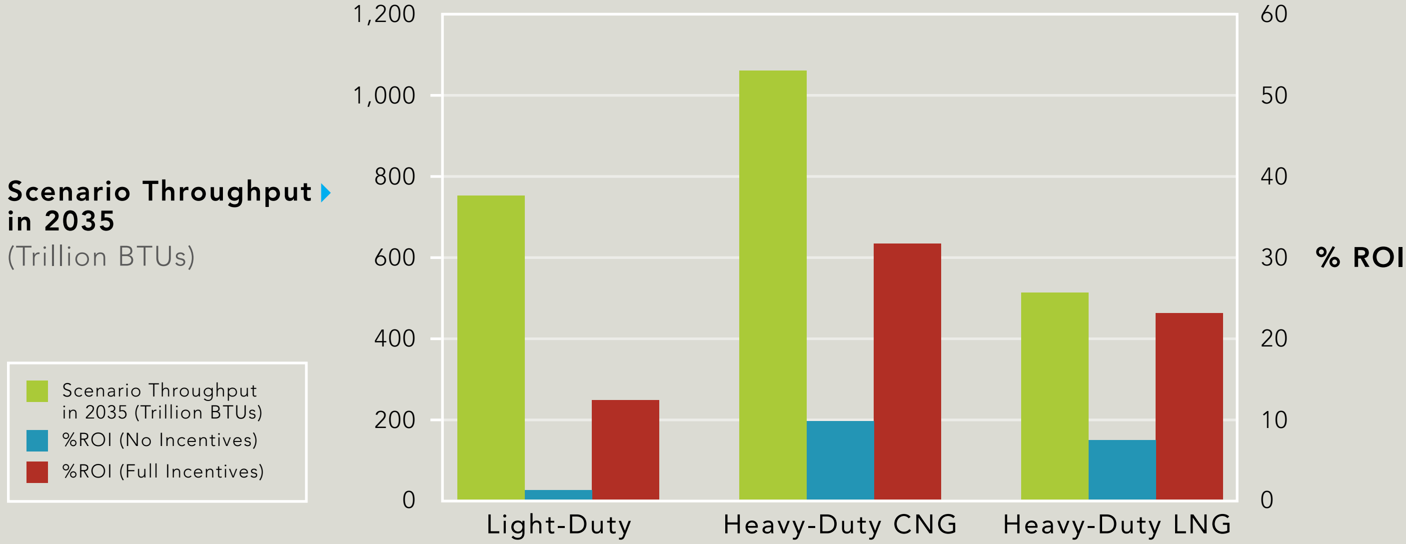
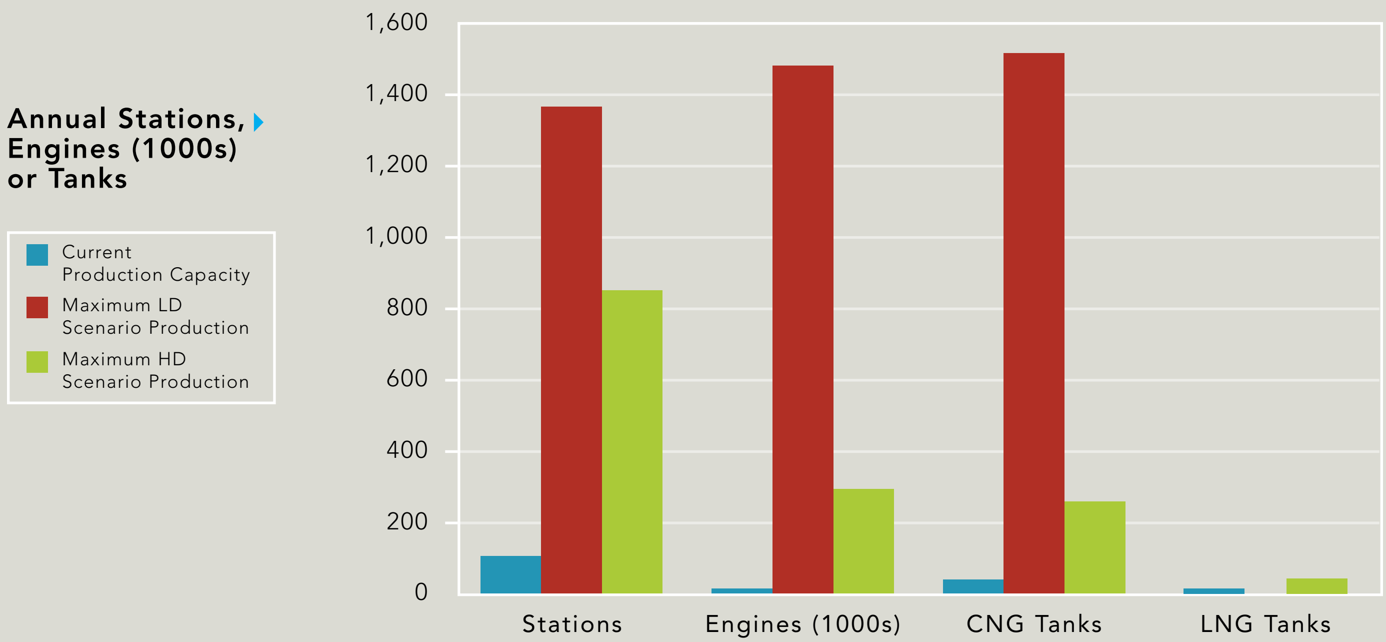


Figure ES-2

Potential bottlenecks in current production capacities of station equipment, engines, and natural gas storage tanks need to be addressed to enable the long-term growth of the NGV market.



1 Introduction

This assessment uses scenario analysis as a tool to investigate how various NGV rollout scenarios will affect natural gas vehicle (NGV) industry stakeholders. The implications for natural gas consumption and infrastructure development and the business cases for vehicle purchasers, infrastructure developers, and government are examined.

In the market development reports of the overall TIAX assessment, the specific drivers and challenges of individual decision makers in the NGV market have been examined in detail. These decision makers include vehicle purchasers and manufacturers, fueling infrastructure developers and equipment suppliers, and government policymakers. The market development reports have highlighted each of their individual requirements and opportunities to expand the North American NGV market.

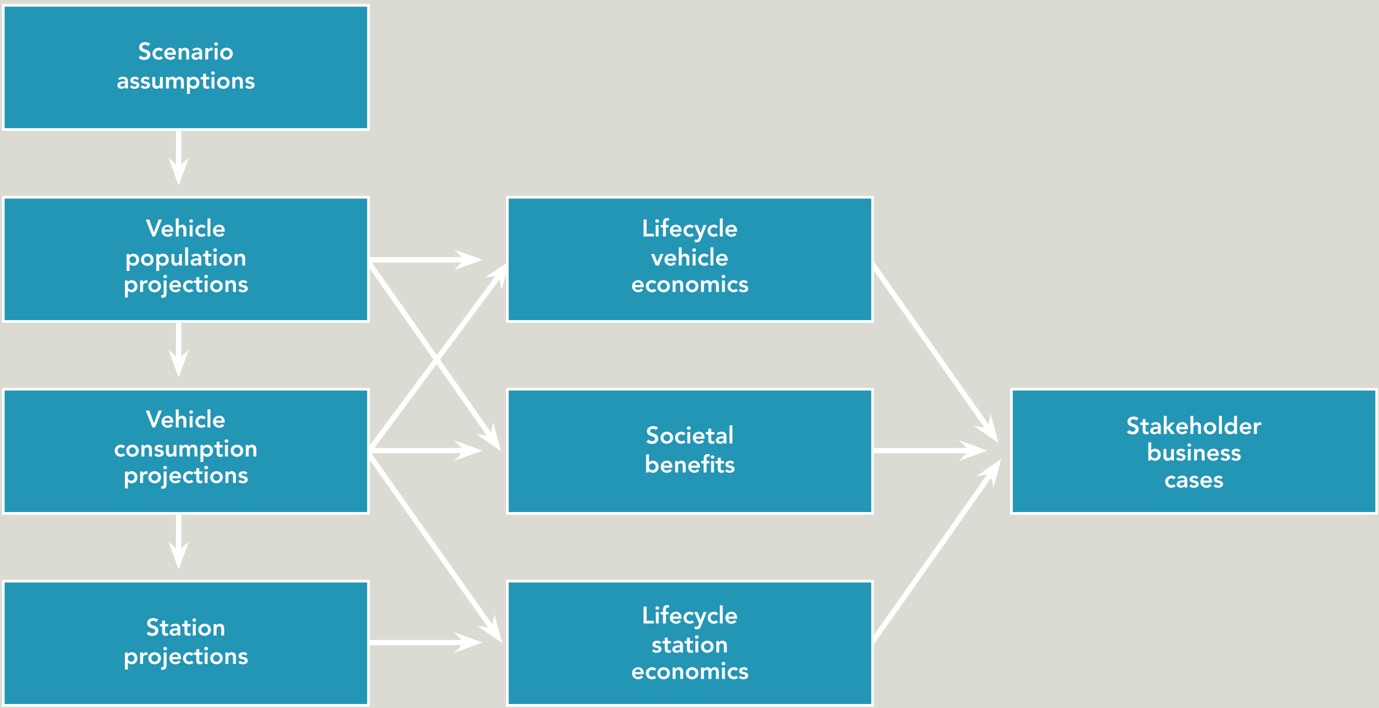
Building on the insights of individual decision makers, this assessment is intended to take a higher-level look at the NGV market. From an overall industry perspective, this report uses scenario analysis as a tool to show the ramifications for industry stakeholders of various levels of NGVs deployment. The scenarios, which are defined by set of assumptions about how vehicle rollout will occur over the next 25 years, illustrate how total natural gas consumption across the transportation sector, natural gas fueling infrastructure expansion, lifecycle savings for vehicle purchasers, business economics for natural gas supply chain companies, and societal benefits enabled by government incentives are interrelated. The scenarios are derived from U.S. Energy Information Administration (EIA) projections for the NGV market and are used to provide insight on the types of considerations and actions potentially needed by stakeholders to move beyond the business-as-usual case (Figure 1-1).

In particular, the contributions of three categories of stakeholders are assessed: end users, infrastructure developers, and government. As established in the market development reports, each plays a pivotal role in the development of the North American NGV market. For different NGV rollout scenarios, the investments and returns for these stakeholders are assessed to determine their respective business cases and the conditions under which investing in the NGV market makes sense. For end users, the business case hinges largely on the tradeoff between significant incremental vehicle costs over transportation fuel vehicles versus lifetime fuel savings. For infrastructure developers, the business case is determined by their fuel sales relative to their capital investment in fueling infrastructure. For government agencies and the general public they represent, the business case is the comparison between incentives granted to the NGV industry and the societal benefits that are gained by transitioning from conventional fuel to natural gas.

This report begins with the Section 2 summary of the roles and requirements of each major stakeholder category in the NGV market. Section 3 provides an overview of the methodology and assumptions used to develop NGV rollout scenarios and projections. In Section 4, projections for light-duty vehicles are presented and discussed in the context of the business cases for end users, infrastructure developers, and government. Section 5 mirrors Section 4, presenting the cases for heavy-duty vehicles. The report concludes in Section 6 with industry-level bottlenecks and opportunities for the NGV market.

Figure 1-1

This assessment uses scenario analysis as a tool to discuss the business cases for end user, infrastructure developers, and government stakeholders to invest in the NGV market.



2 Transportation Sector Today

2.1 Conventional Fuel Use in Transportation

Four major categories of NGV industry stakeholders have complementary roles in the development of the NGV market. The actions and investments of each affect those of the others, and this assessment aims to capture the interrelated nature of their roles in the market.

End users include personal-use vehicle owners and private- or public-sector fleets. In general, personal-use vehicle owners purchase light-duty vehicles (e.g., passenger cars, SUVs, and light trucks) for commuting, recreational and utility purposes. Fleets purchase light-, medium-, and heavy-duty vehicles (e.g., taxicabs, cargo vans, utility trucks, package delivery vans, buses, refuse haulers, and tractor-trailers) for a wide variety of transportation purposes. For all end users, lifecycle economics for vehicle ownership will drive the purchase decision (Figure 2-1), albeit to various degrees for various end users; their motivations are discussed in greater details in the Market Segmentation, Light- and Medium-Duty Vehicle Ownership and Production, and Heavy-Duty Vehicle Ownership and Production reports of the overall TIAX assessment.

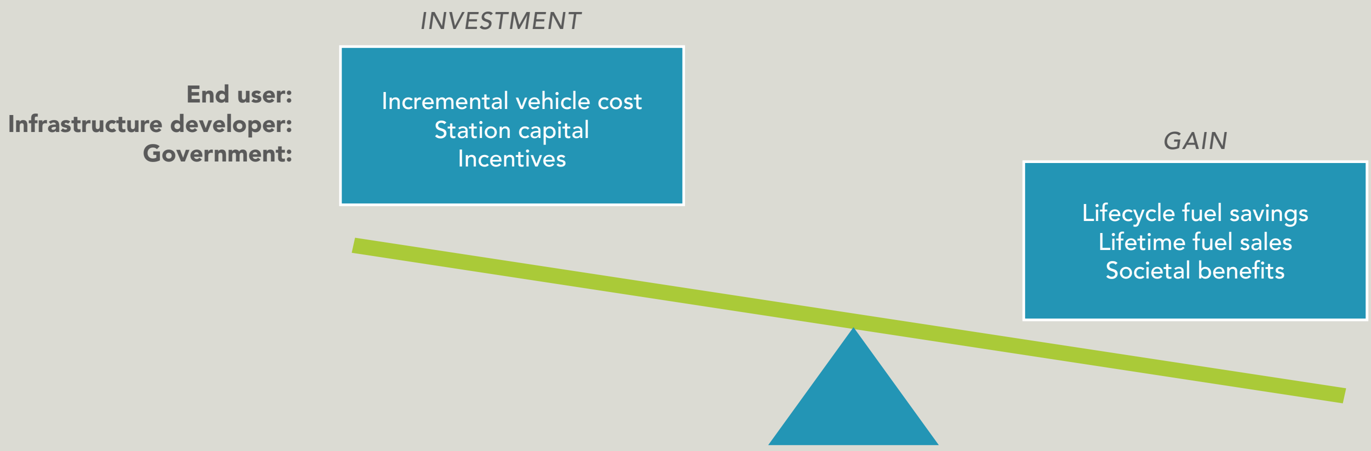
Infrastructure developers include all entities along the natural gas supply chain, from wellhead to fuel dispenser. They include gas producers, pipeline distributors, local distribution companies, stations owners, and station operators; in some case, some of these entities may have multiple roles along the supply chain. For infrastructure developers, their capital return on investment capital for producing and distributing natural gas, building fueling infrastructure, and operating fueling stations determines whether the NGV market is a viable business for them. The decision drivers and economics for infrastructure developers are discussed further in the Compressed Natural Gas (CNG) Infrastructure and Liquefied Natural Gas (LNG) Infrastructure reports of the overall TIAX assessment.

Government includes local, state/province, and federal level policymakers. Assuming that one key role of government is to ensure the wellbeing of society as a whole where individual actions and free markets may not, government investments into the NGV market, in the form of incentives, may be justified by the magnitude of the societal benefits resulting from adoption of NGVs. Further discussion of government's role in this market can be found in the Comparative Analysis report of the overall TIAX assessment.

Vehicle and equipment suppliers include original equipment manufacturers and small volume manufacturers of NGVs, as well as compressor manufacturers/suppliers/packagers and station engineering and construction companies. These stakeholders provide other stakeholders with the necessary vehicles and fueling stations. This assessment assumes that by being in the business of selling these products, the vehicle and equipment suppliers must have an acceptable business case. Otherwise, there would be no reason for them to produce the products that they do. This business case is largely independent of the state of the overall NGV market; that is, vehicle and equipment suppliers generally operate to meet the current and near-term demands of their customers, but they do not necessarily seek to drive the expansion of the NGV market. As such, this assessment assumes that their needed return on investment is built into their prices to the other stakeholders and therefore is an output of, rather than an input into, the scenarios modeled here. Their drivers are discussed in greater details in the Light- and Medium-Duty Vehicle Ownership and Production, Heavy-Duty Vehicle Ownership and Production, CNG Infrastructure, and LNG Infrastructure reports of the overall TIAX assessment.

Figure 2-1

The business case for major stakeholders in this scenario analysis hinges on their respective gains relative to their investments and describes the conditions under which investing in the NGV market makes sense for each stakeholder.



3 Methodology and Assumptions

3.1 Scenario Analysis Model

3.1.1 Overview

Scenario analysis is an important tool to determine the investment potential of natural gas as a transportation fuel and to identify and overcome possible bottlenecks to development.

Before delving into the scenario projections and their implications for NGV stakeholders, this section provides background on the methodology and assumptions used in this assessment. Light- and heavy-duty NGV scenarios are analyzed to identify: 1) the potential for natural gas as a mainstream transportation fuel and 2) possible bottlenecks to the development of NGV market.

This scenario analysis is intended to tie together total NGV market potential and market potential for individual stakeholders. Accordingly, the methodology has two key components: projections of total NGV market size (as defined by vehicle population, fuel consumption, and station population) and modeling of stakeholder cash flow (as defined by investments and gains for end users, infrastructure developers, and government). The first component, projections of total NGV market size, is derived from historical market penetration by similar alternative fuel vehicles and EIA estimates of NGV adoption in the U.S. over the next 25 years under business-as-usual and incentivized scenarios. Further details about these projections for light- and heavy-duty vehicle sectors are discussed individually in the next two sections.

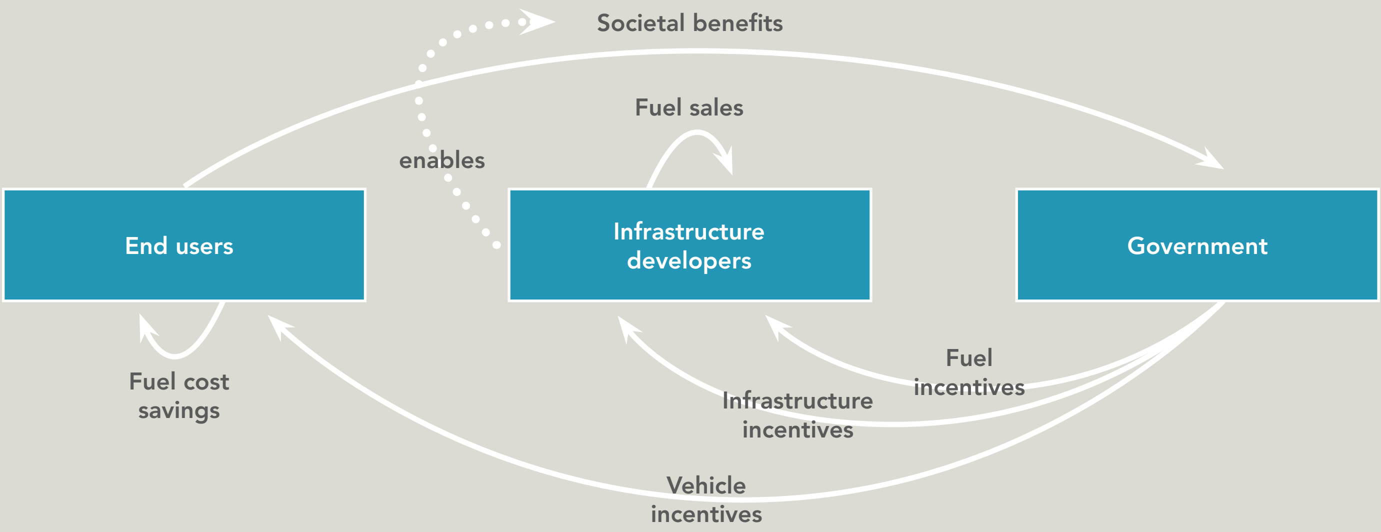
The second component of the methodology is the cash flow model (Figure 3.1.1-1). Based on the projections of vehicle population, fuel consumption, and station population, this model determines the total cost of infrastructure and cash flow from natural gas sales. The cash flow model focuses specifically on infrastructure developers and is used to examine the business case for gas producers and station owners. One of the key results of the model is the stakeholder return on investment (ROI). The ROI calculated here is defined by the formula in Figure 3.1.1-2. All monetary values in this report are reported in 2010 U.S. dollars. The net cash flow, in net present value (NPV), is the total sales of natural gas fuel minus all operations and maintenance costs; the cost of the uncompressed pipeline natural gas is included in the operations and maintenance costs. The investments, also in NPV, are the total capital investments, including, as applicable, CNG or LNG stations, liquefaction plants, and distribution tanker trucks.[1] This assessment presents the ROI as annual returns averaged over the lifetime of the infrastructure.

The cash flows of the other two major stakeholders considered in this assessment are calculated based on the simple economics and quantifications detailed in the Light- and Medium-Duty Vehicle Ownership and Production, Heavy-Duty Vehicle Ownership and Production, and Comparative Analysis reports of the overall TIAX assessment. For end users, the cash flow is defined by their upfront incremental vehicle costs and fuel price savings over the vehicles' lifetimes. Simple cash flow is used instead of discounted cash flow to capture the end user decision making process. For government, the cash flow is defined by the value of the incentives provided to the NGV industry and the quantifiable benefits to society. The full value of the societal benefits is used since benefits today should be equivalent to those in the future.

1 CNG infrastructure requires only stations, while LNG infrastructure requires stations, liquefaction plants, and distribution tankers.

Figure 3.1.1-1

The cash flows among the key stakeholders of the NGV market are interdependent and determine the business case for stakeholder investments.



Figue 3.1.1-2

ROI is an important determinant of the investment potential that the NGV market offers to stakeholders and is used in this assessment to establish a business case for infrastructure developers.

$$\textbf{Return on investment} = \frac{\text{Net cash flow} - \text{Investments}}{\text{Investments}}$$

Net cash flow = Natural gas fuel sale – operations and maintenance costs

Investments = Capital infrastructure investments (e.g., stations, liquefaction plants, distribution tanker trucks)

3 Methodology and Assumptions

3.1 Scenario Analysis Model

3.1.2 Light-Duty Vehicles

The light-duty NGV scenarios assume that market penetration of bi-fuel passenger cars will follow that of hybrid passenger cars to date and market penetration of dedicated passenger cars and bi-fuel light trucks will be limited primarily to market innovators.

Light-duty NGV scenarios are performed by combining individual market penetration assumptions for bi-fuel passenger cars, dedicated passenger cars, and bi-fuel light trucks. Where there are significant tradeoffs in vehicle attributes, alternative fuel vehicles have not historically achieved significant market penetration in the North American light-duty sector. In these cases, adoption of these alternatives is limited primarily to market innovators rather than mainstream consumers. In contrast, light-duty hybrid vehicles have been a relative success story, largely because they are fueled and operated identically to conventional gasoline vehicles.

For the bi-fuel passenger car scenario, it is assumed that there are no major range or fueling infrastructure limitations and a payback period similar to that of today's hybrid passenger cars (approximately ten years) can be achieved by bi-fuel NGVs. If so, bi-fuel passenger cars may be viewed by consumers in the same way as hybrid cars and thus may have a similar market penetration profile (Figure 3.1.2-1).[2] For the dedicated passenger car scenario, the range and fueling infrastructure limitations of NGVs are assumed to hinder mainstream consumer adoption, and therefore, market penetration of dedicated passenger cars is assumed to reach, at maximum, 2.5 percent of the light-duty market, which reflects an "innovator" market (Figure 3.1.2-2).[3] Unlike the mainstream market, the innovator market consists of end users who are willing to take economic losses for non-economic objectives, such as achieving environmental and political goals. For the bi-fuel light truck scenario, market penetration is similarly assumed to be limited to the innovator market, due to vehicle unavailability and consumer unfamiliarity with NGVs.

A fleet turnover model, Argonne National Laboratory's VISION model,[4] is used to convert market penetration to quantity of vehicle sales and fleet inventory, which determine natural gas fuel consumption. The VISION model incorporates EIA's 2010 Annual Energy Outlook, which projects annual vehicle sales through 2035. The model accounts for fleet turnover rates to calculate total fleet size and fuel consumption based on sales, vehicle age, fuel economy by year purchased, and vehicle miles traveled (VMT) by vehicle age. For this assessment, the VISION model is modified with the market penetrations shown in Figure 3.1.2-1 starting in 2014 to project vehicle sales, fleet size, and annual fuel consumption.

The reference case for the light-duty scenarios is the business-as-usual outlook for natural gas in transportation, with no bi-fuel vehicles in the market and small numbers of CNG vehicles using existing infrastructure.

---

2 It is important to note that, in reality, NGVs, including bi-fuels vehicles, do have range and fueling infrastructure limitations, which will likely decrease their market penetration relative to that expected for hybrid vehicles.

3 Ulli-Beer, S., et al. "Citizens' Choice: Modeling Long Term Technology Transition in the Automobile Industry." The 26th System Dynamics Conference Proceedings, Athens, Greece. July 20-24, 2008.

4 http://www.transportation.anl.gov/modeling_simulation/VISION/download.html

Figure 3.1.2-1

Light-duty bi-fuel passenger cars are assumed to follow the same market penetration profile as hybrid cars to date. Dedicated passenger cars and bi-fuel light trucks are assumed to be adopted only in innovator markets.

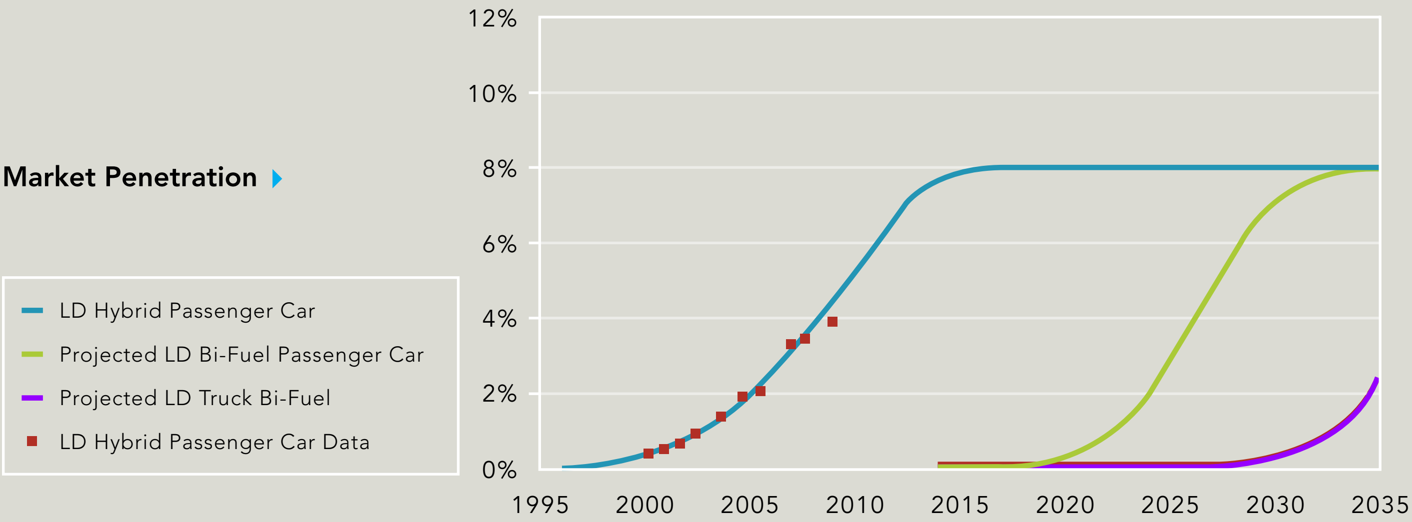
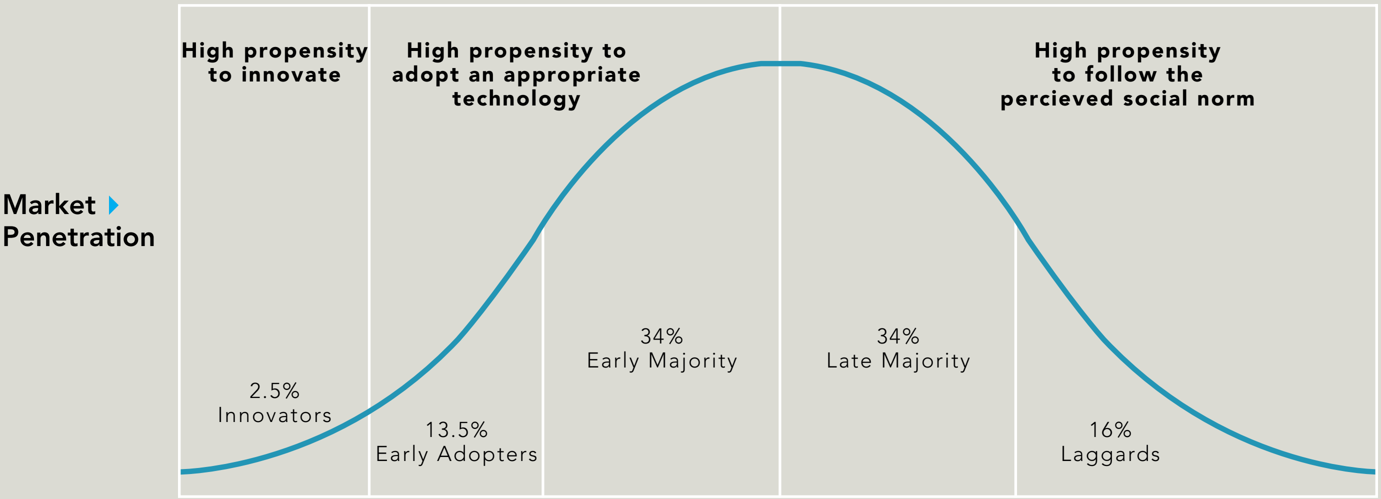


Figure 3.1.2-2

The innovator market assumed for dedicated passenger cars and bi-fuel light trucks is characterized by end users who are willing to adopt a new technology despite potential economic risks or losses.[5]



5 Figure adapted from Ulli-Beer, S., et al, 2008.

3 Methodology and Assumptions

3.1 Scenario Analysis Model

3.1.3 Heavy-Duty Vehicles

The heavy-duty scenarios are derived from EIA's 2010 Annual Energy Outlook projections of NGV market penetration under varying incentives support from government.

Unlike the light-duty scenarios where market penetration profiles were developed based on those of similar alternative technologies, the scenarios for heavy-duty NGVs are based on incentive cases developed by EIA in its 2010 Annual Energy Outlook. EIA developed a number of heavy-duty incentive scenarios to determine potential vehicle sales and fuel consumption for natural gas. Its "Reference Case" and "2027 Phaseout Case," illustrated in Figure 3.1.3 1, have been chosen to bound this analysis, as they represent the business-as-usual and maximum potential market in the EIA projections.

The 2027 Phaseout Case assumes incentives that partially or completely offset incremental vehicle costs, station capital costs, and natural gas costs (comparable to those proposed in the NAT GAS Act[6]) and expire at the end of 2027. EIA assumes that long-term incentives will encourage additional vehicle segments to transition to natural gas, beyond those using natural gas today, as in the Reference Case. EIA's heavy-duty scenarios do not include transit fleets as these fleets are currently incentivized by the Federal Transit Administration, and transit fleets are accounted for separately in this analysis.

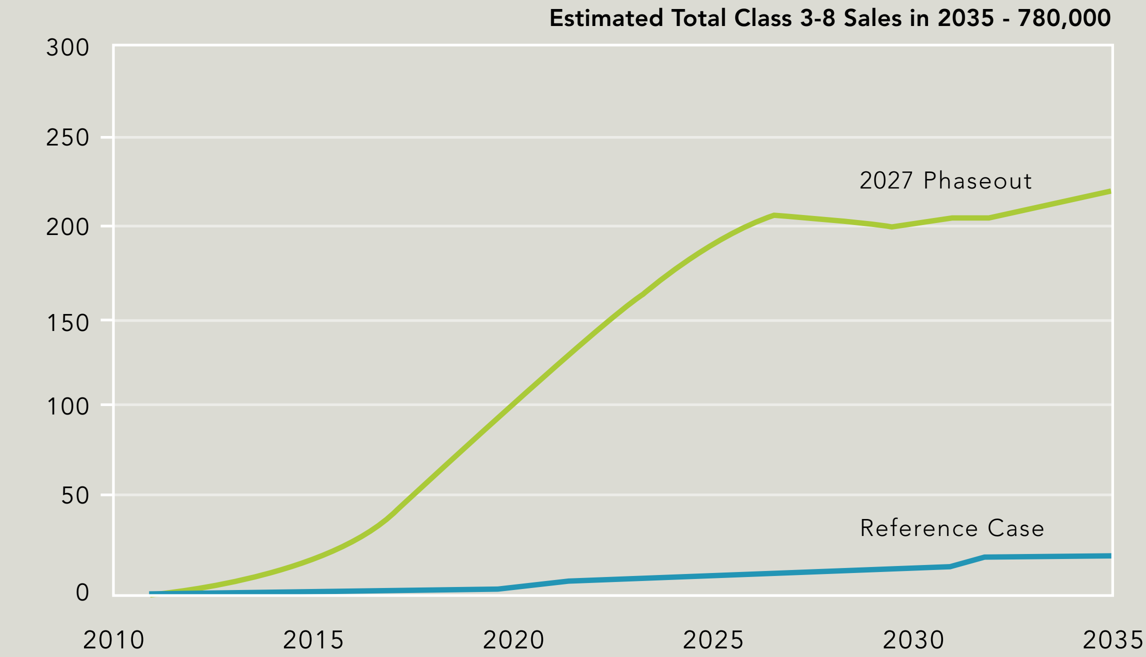
EIA projections group all NGV populations and fuel consumption together, without distinguishing by vehicle segment, fuel type (CNG vs. LNG), or fueling station type (public vs. private). This assessment disaggregates the projections in three ways. First, vehicle segments are separated by the levels of incentives granted toward incremental vehicle costs, which are different for different vehicle segments. Second, all vehicles in Classes 3 through 6 are assumed to use CNG. Using data from the Vehicle Inventory and Use Survey,[7] vehicles in Classes 7 and 8 that travel fewer than 200 miles per trip are assumed to use CNG, and those that travel more than 200 miles per trip are assumed to use LNG.[8] Finally, vehicles in each segment were assumed to fuel at public and/or private stations according to their reported fueling habits using data from the Vehicle Inventory and Use Survey.[9]

6 See the Comparative Analysis report of the overall TIAX assessment for descriptions and discussions of NAT GAS Act incentives.
7 U.S. Census Bureau. "Vehicle Inventory and Use Survey." 2002.
8 Vehicles in Classes 3 through 6 include utility trucks and package delivery vans, and vehicles in Classes 7 and 8 include refuse trucks, transit buses, and tractor-trailers. For more information about vehicle segments and classifications, see the Market Segmentation report in the overall TIAX assessment.
9 U.S. Census Bureau, 2002.

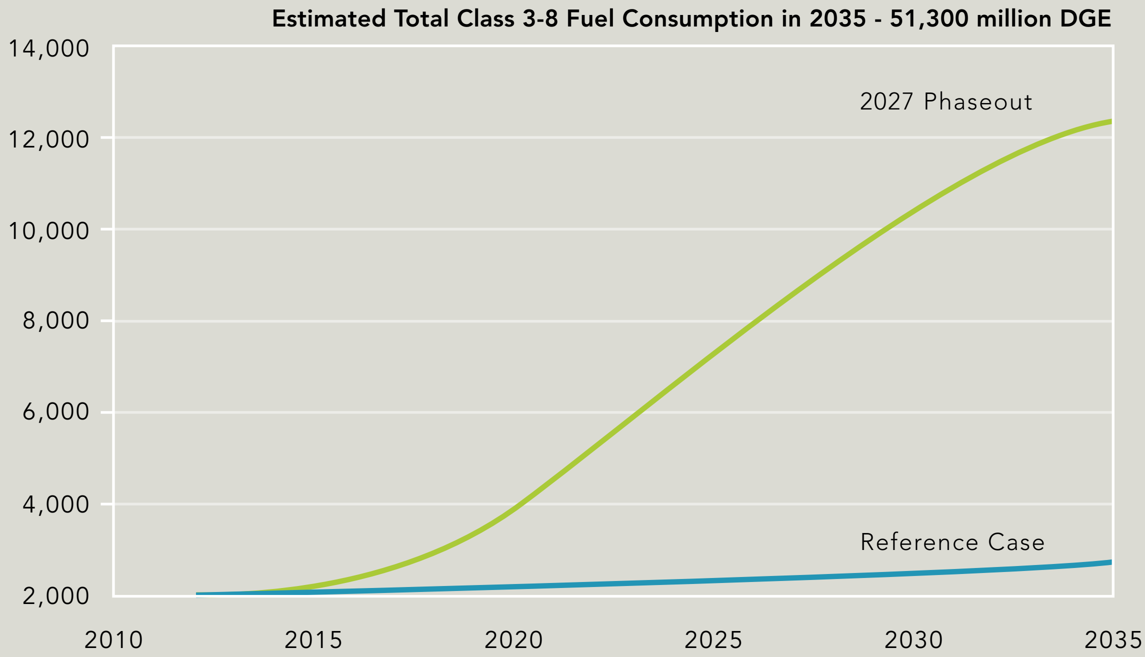
Figure 3.1.3-1

The 2027 Phaseout Case projects heavy-duty NGV sales and fuel consumption assuming that government incentives for vehicles, infrastructure, and fuel are in place until 2027. In contrast, the Reference Case assumes no incentives.

NGV Sales
(1000s)



NGV Fuel Consumption
(million DGE)



3.1.4 Fuel Prices

The fuel prices assumed in this scenario analysis use projections from EIA's 2010 Annual Energy Outlook "Reference Fuel Case."

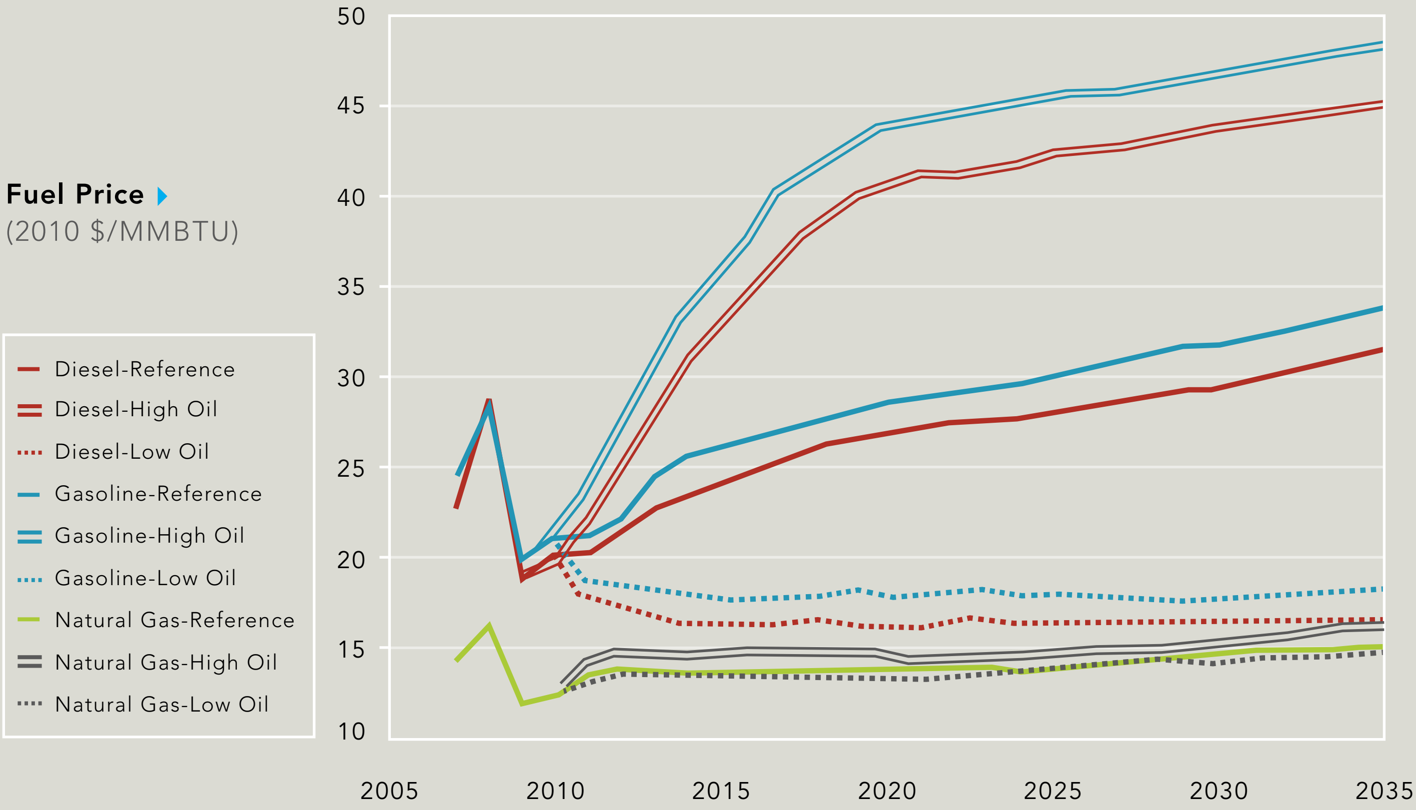
As discussed in other reports of the overall TIAX assessment, market viability of NGVs depends most significantly on the existence of a sufficiently large fuel cost differential between natural gas and conventional fuels. Figure 3.2-1 shows EIA's projections for diesel, gasoline, and natural gas transportation fuel prices in 2010 dollars for the "Reference Fuel Case." To illustrate the wide range of potential fuel cost differentials for natural gas relative to conventional fuels, Figure 3.2-1 also shows EIA projections for two other cases: "High Oil Case" and "Low Oil Case." According to these projections, gasoline and diesel prices may vary significantly while natural gas prices remain relatively constant. As a result, the relative fuel cost savings to NGV purchasers may also vary significantly. For example, if future fuel prices were to track with the High Oil Case, then infrastructure developers may see much higher ROIs as fuel sales margins increase for natural gas.

This analysis uses the fuel prices projected in the Reference Fuel Case. For CNG, the price projections for uncompressed pipeline fuel delivered to stations is determined by multiplying the EIA-projected wellhead prices by the current ratio of delivered price to wellhead price.[10] For LNG, citygate prices are used as surrogates for the prices of natural gas delivered to liquefaction facilities. These prices are determined by multiplying the EIA-projected wellhead prices by the current ratio of citygate price to wellhead price. These ratios are applied because EIA does not project prices for natural gas delivered uncompressed to stations or to liquefaction facilities and only provides general use categories: residential, commercial, industrial, electrical power and transportation (pump price).

10 As presented in the CNG Infrastructure report of the overall TIAX assessment.

Figure 3.1.4-1

This analysis assumes natural gas, gasoline, and diesel prices according to EIA projections in the Reference Fuel Case. If fuel prices follow the High Oil Case or Low Oil Case, the fuel cost differentials for natural gas may be significantly different and affect the business case for NGV market stakeholders.



3.1.5 Station and Infrastructure Costs

Station and infrastructure cost assumptions are based on station sizes and costs identified in the CNG Infrastructure and LNG Infrastructure reports of the overall TIAX assessment.

In addition to fuel costs, the market viability of NGVs also depends heavily on fueling infrastructure costs. While fuel costs provide compelling motivations for end user to adopt NGVs, fuel cost savings cannot be realized unless infrastructure is in place to enable the use of natural gas. As such, the cost considerations for infrastructure developers are an important factor in the success of the NGV market.

The CNG scenarios use two types of stations, public access and private access, and assume the specific station types, capacities, and costs listed in Table 3.3-1. These values are consistent with and detailed further in the CNG Infrastructure report of the overall TIAX assessment. Public CNG stations are assumed to be the same between the light- and heavy-duty vehicle scenarios, except that heavy-duty stations have higher utilization than light-duty stations due to higher annual fuel consumption per vehicle and the clustering of stations for heavy-duty use. The throughput of the light-duty and heavy-duty public stations is less than average gasoline stations (3,700 gasoline gallons equivalent, or GGE, per day)[11] and the smallest diesel trucks stops (4,700 diesel gallons equivalent, or DGE, per day[12]). The small size of the assumed natural gas fueling stations suggests an option of "add-on" CNG stations to existing stations, along with construction of standalone CNG stations. Assuming the most viable business case, the build out of CNG stations over time is modeled to meet the fueling demands of the growing vehicle population.

The LNG scenario uses a base station, additional station storage, liquefaction facility, and LNG distribution tanker trucks of the capacities and costs shown in Table 3.3-2. These values are consistent with and detailed further in the LNG Infrastructure report of the overall TIAX assessment. The throughput of the LNG stations roughly equal to that of small diesel trucks stop. As with CNG infrastructure, this assessment assumes that stations and liquefaction plants are built and tanker trucks are purchased as required by vehicle demand. For public refueling, stations will be built as needed until there are enough stations for every 250 miles of interstate, which corresponds approximately to the expected range of LNG vehicles.[13] As a point of reference, there are 46,726 total miles of interstate highway in the U.S.,[14] so 187 LNG stations distributed every 250 miles would be sufficient to cover this distance. For Canada, which has fewer miles of highway, the number of LNG stations needed is even smaller. This assessment also assumes that once all the required stations are constructed, additional storage tanks will be installed at existing stations to meet further demand.

11 Based on U.S. Census Bureau 2007 Economic Census for number of stations and EIA Annual Energy Outlook for total throughput.
12 TIAX LLC. "Executive Summary for: SCR-Urea Implementation Strategies Update Final Report." Prepared for Engine Manufacturers Association. June 2006.
13 Hartley, P. "Sterling LNG Trucks Go into Service." Fleet Equipment, February 1, 2009.
14 U.S. Department of Transportation Federal Highway Administration. http://www.fhwa.dot.gov/programadmin/interstate.cfm. Accessed December 2010.

Table 3.1.5-1

CNG infrastructure with these assumed capacities and costs is modeled to grow continuously to meet the projected vehicle fuel demand.

CNG Infrastructure Assumptions	Light-Duty Public Station*	Heavy-Duty Public Station*	Heavy-Duty Private Station*
Capacity (gallons/day)	6,900 GGE (600 scfm)	6,300 DGE (600 scfm)	3,150 DGE (300 scfm)
Utilization Factor	0.25	0.45	0.45
Throughput (per day)	1,730 GGE	2,840 DGE	1,418 DGE
Number of Vehicles Supported**	1,800 - 2,300	103 - 432	52 - 216
Cost	$1,000,000	$1,000,000	$675,000

*Assumes that public stations use cascade type storage and private stations use buffer type storage
**Assumes: 275 GGE per year per light-duty bi-fuel vehicle and 345 GGE per year per light-duty dedicated vehicle; 2,400 – 10,000 DGE per day per heavy-duty vehicle

Table 3.1.5-2

LNG infrastructure with these assumed capacities and costs is modeled to grow to meet the projected vehicle fuel demand through the establishment of base stations at every 250 miles of interstate highway then through installation of additional storage capacity at these stations.

LNG Infrastructure Assumptions	LNG Base Station	Additional Station Storage	Liquefaction Facility	LNG Tanker Trucks
Capacity (LNG gal/day)	15,000	15,000	100,000	10,000
Utilization (LNG gal/day)	10,000	15,000	100,000	10,000
Number of Vehicles Supported*	104	158	1,040	104
Throughput (DGE/day)	5,800	8,800	58,000	5,800
Cost	$770,000	$572,000	$31,800,000	$345,000

*Assumes 18750 DGE per year per heavy-duty vehicle (equivalent to 32,000 LNG gallons per year per vehicle)

4 Light-Duty Scenarios

4.1 Scenario Projections

The projections in the light-duty scenarios are dominated by bi-fuel NGVs and require the need for nearly 13,000 CNG stations by 2035.

The projections of the light-duty vehicle scenarios are dominated by bi-fuel passenger car sales and consumption, which are modeled to achieve higher and faster market penetration than dedicated passenger cars and bi-fuel light trucks, as discussed in Section 3.1.2. Figure 4.1-1 shows that by 2035, the light-duty NGV fleet is projected to consume over 6.6 billion GGE of natural gas per year, which is 4 percent of the total transportation fuel consumption by light-duty vehicles estimated by EIA.[15] By 2035, NGV purchases are projected to reach 7.5 percent of all light-duty vehicle sales. Peak sales of NGVs are projected to be 1.5 million vehicles per year, and the ability of vehicle manufacturers to meet this demand is discussed in Section 6.

As shown in Figure 4.1-1, to meet the fueling demands of this projected light-duty NGV fleet, nearly 13,000 stations are constructed by 2035, which is approximately 10 percent of the 118,756 gasoline stations currently in the U.S.[16] The number of stations is not higher due to the relatively small number of dedicated NGVs that are reliant on natural gas stations and cannot use existing gasoline stations. The maximum number of stations that must be built to support the projected vehicle population is projected to be 1,400 stations per year, and the ability of infrastructure equipment suppliers and engineering and construction companies to meet this demand is also discussed in Section 6.

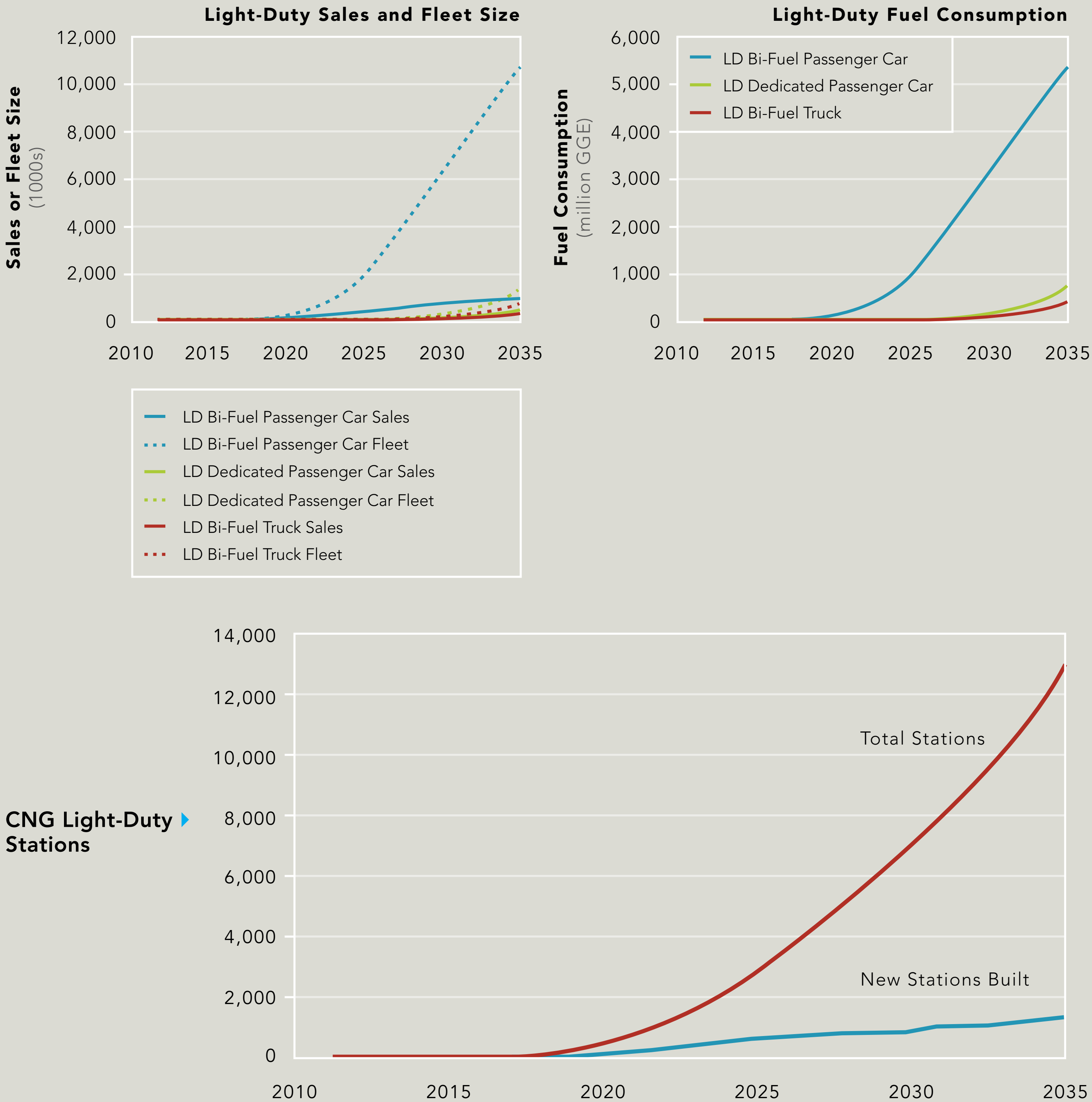
For the light-duty scenarios, it is critical that the build out of CNG stations match the fueling demands of the growing vehicle population. If the necessary infrastructure is not available at the right time for light-duty NGVs, market penetration and consumption of CNG by light-duty NGVs may be significantly reduced. In particular, the limited number of CNG stations may push bi-fuel vehicles to refuel more often with gasoline and drive down the adoption rate for light-duty NGVs as stations are not readily convenient for consumers. These scenarios analyzed here assume that home refueling is not used, but may assist in overcoming the limited number of stations in the near-term.

It is important to note the synergism between the stations projected for light-duty vehicles here and those for heavy-duty CNG vehicles in the following section. Light- and heavy-duty NGVs may see some overlap in the public stations at which they can refuel, and the establishment of infrastructure to serve one vehicle sector may benefit the other.

15 U.S. EIA. "Annual Energy Outlook." 2010.
16 U.S. Census Bureau. "Economic Census." 2007

Figure 4.1-1

Bi-fuel NGVs dominate the projections in the light-duty scenarios, and light-duty vehicles combined suggest the need for a total of nearly 13,000 CNG stations by 2035.



Investing in natural gas for the light-duty transportation sector offers ROIs that may range from 1 to 13 percent, depending on whether ongoing fuel incentives are available.

The light-duty scenario projections suggest the number of stations that may be needed to sustain a light-duty NGV fleet. The economic viability of these stations determines if there is a business case for targeting and investing in natural gas for light-duty vehicles. Using the ROI as defined in Section 3.1.1, Table 4.2-1 shows the station ROIs calculated for four different incentive cases: no incentives, incentives for station capital only, incentives for fuel only, and incentives for both station capital and fuel. These incentives correspond to those currently available in the U.S. and/or proposed by the NAT GAS Act.

With no incentives or incentives on station capital only, there is a low ROI of 1 to 2 percent for light-duty CNG infrastructure. The low ROI is due to the low utilization of each station established to serve light-duty NGVs. With fuel incentives, the ROI increase to 11 to 13 percent. These ROIs suggest that natural gas infrastructure investments targeted toward light-duty vehicles may not offer a compelling business case without fuel incentives granted for the lifetime of the stations.

Figure 4.2-1 shows the small margin that is shared between transportation fuel providers and gas producers based on the difference between fuel price at the pump and their capital and operating costs. It is assumed that the distribution companies have an acceptable margin built into their prices to the rest of the supply chain. The shared margin may increase in later years as station capital costs are been completely amortized but are bounded by the cost of the gas itself and the retail price of fuel. As shown by the ROIs in Table 4.2-1, these margins will be small without significant fuel incentives and may offer an unattractive business case to stakeholders. The incentives, benefits, and costs to the stakeholders are discussed in the next section.

Table 4.2-1

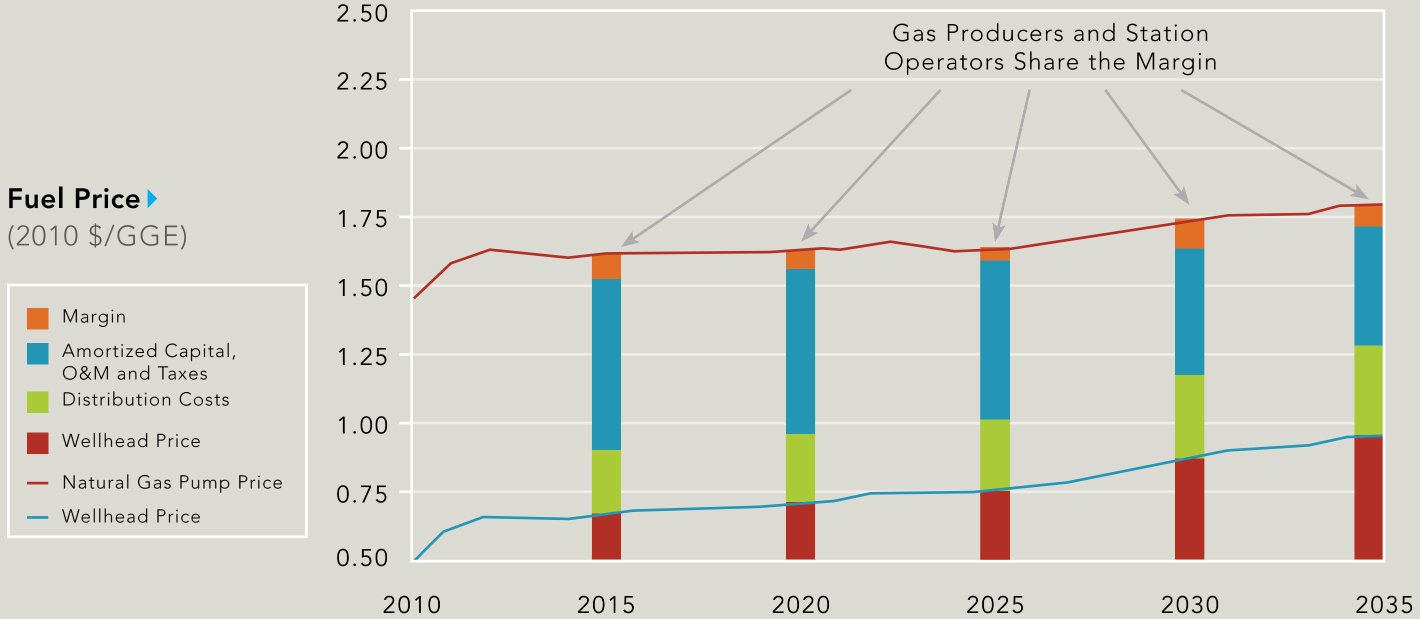
The ROIs for infrastructure investments targeting light-duty NGVs suggest a compelling business case only if fuel incentives are available for the lifetime of the stations.

	No Incentive	Station Capital Incentive Only ($100,000 per New Station)	Fuel Incentive Only ($0.50 per GGE)	Both Incentives
Infrastructure ROI*	1%	2%	11%	13%

*Assumes 20 year station lifetime; 2% inflation and 8% real discount rate

Figure 4.2-1

The infrastructure ROI is represented by fuel price margins that are shared between gas producers and station operators and may be relatively small without fuel incentives.



4.3 Market Analysis

Natural gas in the light-duty vehicle sector, without increases in fuel prices over EIA projections, may not offer an acceptable business case for end users and infrastructure developers.

In addition to the ROI for infrastructure developers, the economic justification for natural gas in light-duty vehicles depends on the investments and gains of all stakeholders and whether there may be opportunities for stakeholders receiving disproportionate gains to distribute these gains to the other stakeholders, enabling them to enter this market. As presented in Section 2, end user investments are incremental NGV costs, and their gains are lifecycle fuel savings. Infrastructure developer investments are capital investments for infrastructure, and their gains are the ROIs calculated in the previous section. Government investments are vehicle, fuel, and/or station incentives, and their gains are societal benefits.[17]

Using the projections of light-duty fuel consumption and station growth, two cases are examined to illustrate the extremes of stakeholder cash flows in achieving the projected market penetration levels. In one extreme, the government provides no incentives for the NGV market, and investments come solely from end users and infrastructure developers. In the other extreme, the government provides both station capital and fuel incentives as described in the previous section, as well as full incentives needed to cover incremental vehicle costs. While these extremes do not necessarily correspond to the incentives assumed in projecting vehicle and station growth, they are useful in providing bounds on stakeholder cash flows and highlight opportunities to distribute potential gains among stakeholders.

Table 4.3-1 shows the cash flows of two cases on a per station basis. In the non-incentivized case, society receives significant benefits with no investments, and end users receive significant fuel cost savings relative to their incremental cost investments, distributed across the entire fleet of light-duty NGVs. The infrastructure developers have a smaller total investment than end users and achieve a 1 percent ROI. In this case, government takes on no burden in developing in the NGV market, and the burden is carried primarily by infrastructure developers, who receive the smallest gains for their investments.

In the incentived case, the government has investment costs greater than the societal benefits that are achieved. End users make no investment into incremental vehicle costs and receive the same fuel cost savings as in the non-incentivized case. The infrastructure developers invest less than in the non-incentivized case but receive a significantly higher 13 percent ROI. In this case, end users take on no burden in developing in the NGV market, and the burden is carried primarily by the government, which receives a negative return on its investment.

The calculations presented in Table 4.3-1 indicate that the business case of light-duty end users may be compelling both with and without incentives. Though it is possible to shift some of the cash flow burden to end users to enable more acceptable business cases for infrastructure developers and government, despite already favorable economics, end users may be reluctant to adopt NGVs without external encouragement, and government incentives are likely still necessary to some extent to increase market penetration beyond current levels. Furthermore, if dedicated NGVs are adopted instead of bi-fuel NGVs, the total investment by end users in the non-incentivized case increases to $19.9 million, more than their total fuel savings and more than double the corresponding societal benefits offered by dedicated light-duty NGVs.

For infrastructure developers, the business case depends on whether government incentives are available. If the government can offer stable fuel incentives for the lifetime of the stations that are up to the value of societal benefits gained (minus any incentives for end users), the business cases for both infrastructure and government stakeholders may be positive. However, if government incentives are insufficient, there may not be a business case for infrastructure developers to enter the light-duty NGV market. If infrastructure developers require ROIs closer to those in the incentivized case than those in the non-incentivized case, government will likely need to provide incentives that cost significantly more than the societal benefits that would be achieved.

17 The societal benefits of NGVs are calculated in the Comparative Analysis report of the overall TIAX assessment.

Table 4.3-1

With no incentives, the financial burden of developing the light-duty NGV market is carried primarily by infrastructure developers. With full incentives, the burden is carried primarily by the government. Depending on the gains required by stakeholders for their investments, the needed incentives may exceed the societal benefits achieved.

No Incentives (per station in 2010$)

Stakeholders		Investment	Gain
Government/Society	Vehicles	$0	$7,800,000
	Stations*	$0	
Infrastructure Developer		$840,000	1% ROI
End User**		$6,800,000	$7,100,000

Full Incentives (per station 2010$)

Stakeholders		Investment	Gain
Government/Society	Vehicles	$6,800,00	$7,800,000
	Stations*	$2,600,00	
Infrastructure Developer		$750,000	13% ROI
End User**		$0	$7,100,000

*Station incentives include fuel incentives ($0.50/GGE) and capital incentives ($100,000/station).
**Considers only first owner lifetime of 14 years. In year 15, a new set of vehicles is purchased.
***2% inflation rate and 8% real discount rate

5 Heavy-Duty Scenarios

5.1 Scenario Projections

The projections in the heavy-duty scenarios suggest significant market penetration can be achieved by natural gas in heavy-duty vehicle sales and fuel consumption.

Figure 5.1-1 shows that by 2035, in the business-as-usual Reference Case, heavy-duty NGVs may be less than 2 percent of the total heavy-duty fleet and less than 1 percent of total fuel consumption by heavy-duty vehicles.[18] However, in the 2027 Phaseout Case, heavy-duty NGVs are projected to make up over 20 percent of the total heavy-duty fleet and 15 percent of total fuel consumption by heavy-duty vehicles.

For CNG, the Reference Case projects that fewer than 800 stations will be built across the U.S., while in the 2027 Phaseout Case, over 12,000 stations (5,000 of which are public stations) may be built. These stations will be in addition to the existing 1,091 CNG station in the U.S.[19] As mentioned previously, there are potential synergies between stations designed to serve light- and heavy-duty CNG vehicles, and the establishment of infrastructure to serve one vehicle sector may benefit the other.

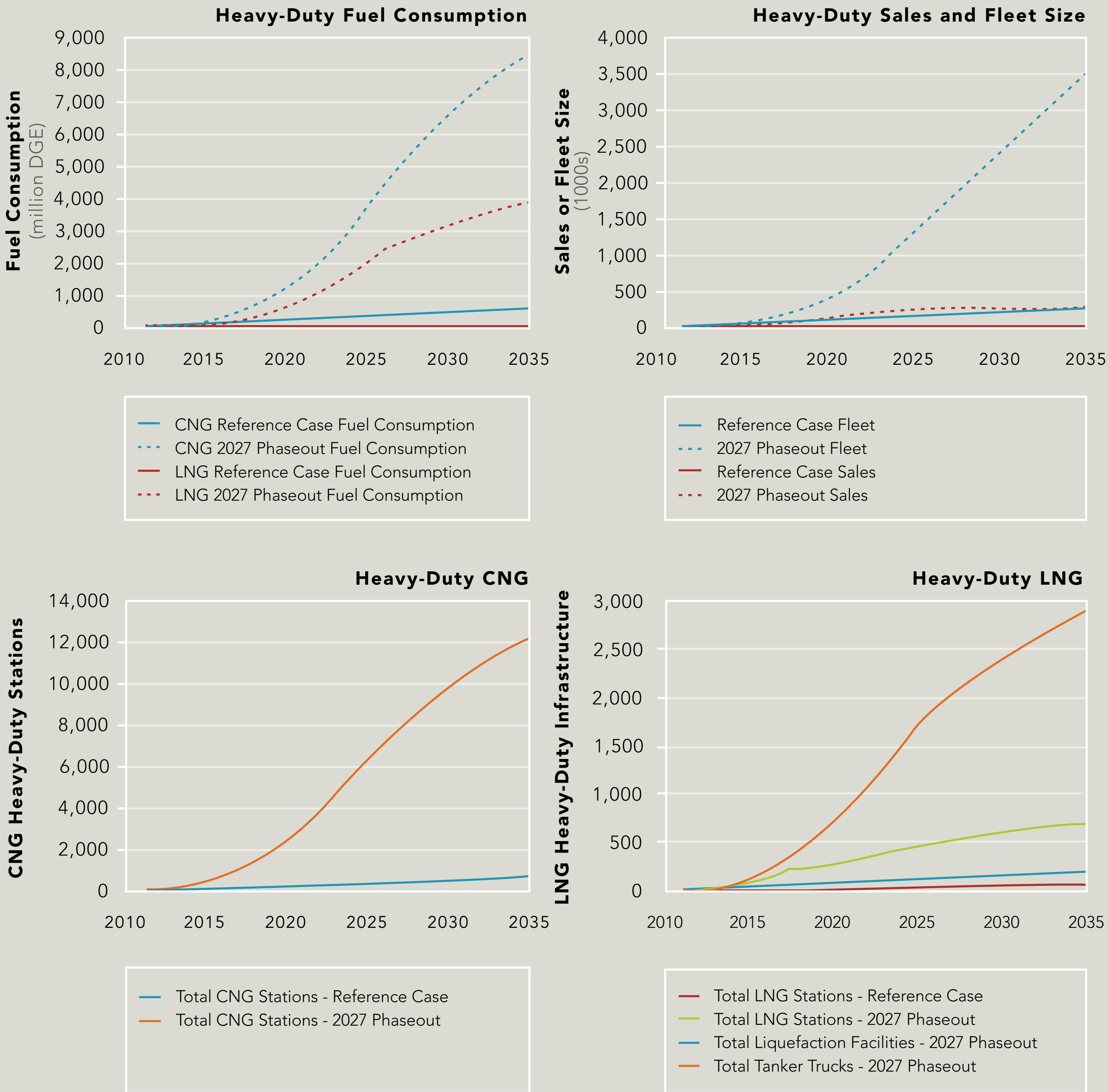
For LNG, the Reference Case projects that 61 stations built across the U.S., while in the 2027 Phaseout Case, over 700 stations may be built. These stations will be in addition to the existing 58 LNG stations in the U.S.[20] 187 of these stations are public access, and the remaining private stations represent just under 2 percent of the non truck-stop diesel stations in the U.S.[21] In the 2027 Phaseout Case, the number of public LNG stations reach the maximum of 187 (as defined previously in Section 3.3), and with installation of an additional 90,000 gallons of LNG storage capacity at each of these stations, the throughput of public LNG stations is estimated to be 72,000 gallons of LNG (42,000 DGE) per station per day. This throughput is comparable to some of the highest throughput diesel truck stops, which dispense between 33,000 and 43,000 DGE per day.[22]

To meet the fueling needs of heavy-duty NGVs (as well as any light-duty NGVs that may potentially use the same infrastructure), it is possible to construct LCNG stations that dispense both CNG and LNG. The public stations are projected to make up approximately 45 percent of all heavy-duty CNG stations, which may dramatically increase the distribution of publicly available LNG stations and possibly sustain larger LNG fleets in broader markets.

18 Estimated fleet of 15 million vehicles and fuel consumption of 51.5 billion DGE from EIA 2010 Annual Energy Outlook.
19 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
20 Ibid.
21 TIAX LLC. "Executive Summary for: SCR-Urea Implementation Strategies Update Final Report." Prepared for Engine Manufacturers Association. June 2006.
22 Ibid.

Figure 5.1-1

Given the incentives assumed in the 2027 Phaseout Case, natural gas is projected to achieve significant vehicles sales and fuel consumption in the heavy-duty sector.



5.2 Economic Results

Infrastructure to support heavy-duty NGVs may be a compelling business case for both CNG and LNG regardless of incentives, offerings ROIs ranging from 8 to 31 percent.

The 2027 Phaseout Case shows significant market penetration of heavy-duty NGVs fueled by CNG and LNG. Estimating the economic viability of the CNG and LNG scenarios is necessary to determine if there is a business case for investing in natural gas for heavy-duty NGVs. The economic viability is determined by calculating the ROI per station as defined in Section 3.1.1. For LNG infrastructure, liquefaction facility and tanker truck capital investments are included.

Table 5.2-1 shows the station ROIs calculated for four different incentive cases: no incentives, incentives for station capital only, incentives for fuel only, and incentives for both station capital and fuel, again corresponding to those currently available in the U.S. and/or proposed by the NAT GAS Act. Even in the absence of incentives, there may be acceptable ROIs for both CNG and LNG infrastructure developers, with higher ROIs for CNG than LNG. Station incentives do little to improve the ROIs, while fuel incentives have a significant impact.

Figure 5.2-1 shows the margins that are shared between transportation fuel providers and gas producers for CNG and LNG stations. As with light-duty infrastructure, it is assumed that the gas distribution companies have an acceptable margin built into their prices to the rest of the supply chain. Again, the shared margin may increase in later years as station capital costs are been completely amortized but are bounded by the cost of the gas itself and the retail price of fuel. For LNG, the margins are additionally shared with liquefaction plant operators and LNG tanker truck operators. The shared nature of these margins suggest that all stakeholders in the fuel supply chain need to work together to make long-term commitments that prevent gouging so each can achieve acceptable ROIs. The margins for LNG are initially smaller than those for CNG as the capital being amortized but are larger after the capital is paid off. This is due to the lower operating and distribution costs of LNG. After the capital is paid off, there may be opportunities for larger profit margins for LNG than CNG.

Based on the ROIs in Table 5.2-1, the heavy-duty NGV scenarios for both CNG and LNG are compelling business cases for infrastructure developers regardless of incentives. The investments and gains by stakeholders are discussed in the next section.

Table 5.2-1

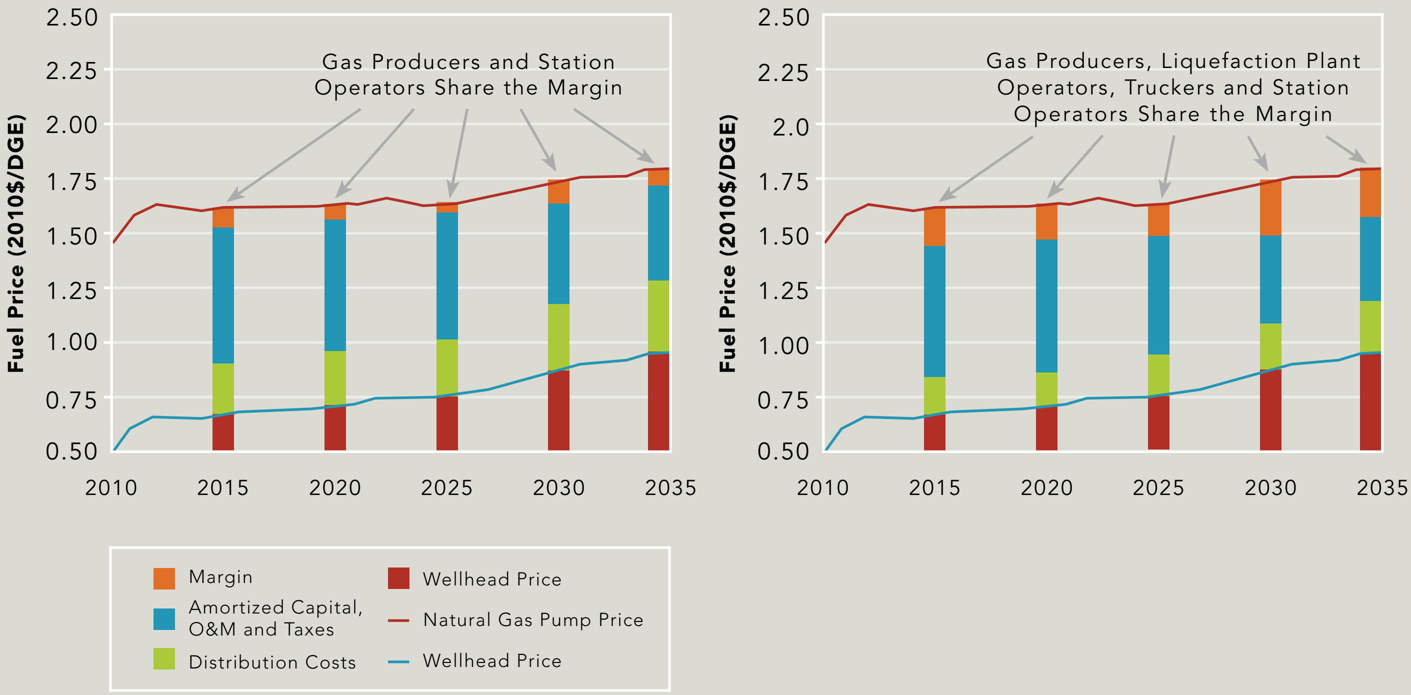
The ROIs for infrastructure investments targeting heavy-duty NGVs suggest a compelling business case regardless of whether incentives are available.

	No Incentive	Station Capital Incentive Only ($100,000 per New Station)	Fuel incentive only ($0.57 per DGE CNG* and $0.50 per Gallon LNG)	Both incentives
CNG Infrastructure ROI**	10%	12%	27%	31%
LNG Infrastructure ROI**	8%	9%	22%	23%

*Equivalent to $0.50 per GGE
**Assumes 20 year station lifetime; 2% inflation and 8% real discount rate

Figure 5.2-1

The infrastructure ROI is represented by fuel price margins that are shared between gas producers and station operators and may result in substantial profits from high fuel use heavy-duty fleets. For LNG, margins are also shared with liquefaction plant and tanker truck operators.



Government incentives for vehicles may encourage end users to buy heavy-duty NGVs, but even without incentives, the business case offered by natural gas may be compelling for all stakeholders.

In addition to the ROI for infrastructure developers, the economic justification for natural gas in heavy-duty vehicles depends on the investments and gains of all stakeholders and whether there may be opportunities for stakeholders receiving disproportionate gains to distribute these gains to the other stakeholders, enabling them to enter this market.

Investments and gains for the stakeholders are calculated on a per station basis. For LNG, capital investments for liquefaction facilities and tanker trucks are included in the analysis. As with light-duty infrastructure, two cases are examined to illustrate the extremes of stakeholder cash flows in achieving the projected market penetration levels. In one extreme, the government provides no incentives for the NGV market, and investments come solely from end users and infrastructure developers. In the other extreme, the government provides both station capital and fuel incentives, as well as full incentives needed to cover incremental vehicle costs. While these extremes do not necessarily correspond to the incentives assumed in projecting vehicle and station growth, they are useful in providing bounds on stakeholder cash flows and highlight opportunities to distribute potential gains among stakeholders.

Table 5.3-1 shows the cash flows of the incentivized and non-incentivized cases for CNG and LNG. In the non-incentivized cases, the government receives significant benefits with no investments. CNG end users may receive marginal fuel cost savings while LNG end users receive significant fuel costs savings due to their high fuel consumption per vehicle. CNG infrastructure developers invest significantly less capital than LNG infrastructure developers and receive a larger ROI, while LNG offers twice the societal benefits of CNG, again due to high fuel consumption by the types of vehicles that use LNG.

In the fully incentivized CNG case, the government's investments are greater than the societal benefits achieved. CNG end users, while making no incremental cost investments, receive the same fuel cost savings as the non-incentivized case. Compared to the non-incentivized case, CNG infrastructure developers invest less in the incentivized case and receive triple the ROI. In the fully incentivized LNG case, the government's investments are 1.3 times higher than the societal benefits achieved. LNG end users, with no incremental vehicle costs, receive extremely high fuel savings. Compared to the non-incentivized case, LNG infrastructure developers invest less in the incentivized case and receive nearly triple the ROI.

The calculations presented in Table 5.3-1 suggest that even without government incentives, infrastructure developers may have a compelling business case. Temporary incentives may be beneficial to these stakeholders to encourage initial investments into natural gas as a transportation fuel, but with an already acceptable ROI, incentives for end users are may be important for attracting and achieving significant market share, especially for CNG vehicles.

Table 5.3-1

The business case for end users and infrastructure developers may be compelling for natural gas targeted toward heavy-duty vehicles, even in the absence of incentives.

CNG No Incentives (per station in 2010$)

Stakeholders		Investment	Gain
Government	Vehicles	$0	$9,100,000 to $11,800,000[a]
	Stations	$0	
Infrastructure Developer		$840,000	10% ROI
End Users[b]		$10,800,000 to $13,100,000[a]	$11,700,000

CNG Full Incentives (per station 2010$)

Stakeholders		Investment	Gain
Government	Vehicles	$10,800,000 to $13,100,000[c]	$9,100,000 to $11,800,000[a]
	Station	$4,600,000[d]	
Infrastructure Developer		$750,000	31% ROI
End Users[b]		$0	$11,700,000

LNG No Incentives (per station in 2010$)

Stakeholders		Investment	Gain
Government	Vehicles	$0	$25,700,000[a]
	Stations	$0	
Infrastructure Developer		$3,500,000	8% ROI
End Users[b]		$17,100,000[a]	$39,400,000

LNG Full Incentives (per station 2010$)

Stakeholders		Investment	Gain
Government	Vehicles	$17,100,000[c]	$25,700,000[a]
	Stations	$16,600,000[d]	
Infrastructure Developer		$3,400,000	23% ROI
End Users[b]		$0	$39,400,000

a Incremental vehicle costs and societal benefits vary depending on vehicle type as calculated in the Comparative Analysis report of the overall TIAX assessment.
b Conservatively considers only first owner lifetime of vehicles; 2% inflation and 8% real discount rate.
c Vehicle incentives range from $17,000 to $60,000 per vehicle depending on vehicle type.
d Station incentives include fuel incentives (CNG - $0.57/DGE and $0.50/LNG gallon) and capital incentives ($100,000/station).

6 Industry-Level Actions

6.1 Bottlenecks

Projections of vehicle and station growth highlight the need to foresee and address potential industry bottlenecks in vehicle manufacturing and station construction capacity.

The end user, infrastructure developer, and government stakeholders analyzed thus far are major players in driving the expansion of the NGV market. The fourth category of stakeholders, vehicle and equipment suppliers, will also affect the growth of this market because they enable its growth. For the market penetration of natural gas to be successful and potentially achieve the fuel cost savings, ROIs, and societal benefits projected in the previous sections, the market needs to have sufficient capacity to offer the needed vehicles and infrastructure equipment.

Figure 6.1-1 shows the current production capacity of stations and tanks and the peak annual demand identified in the above scenarios. Currently, there may only be enough capacity to build 150 CNG stations per year,[23] and the projected growth of the NGV market may require over 12,000 CNG stations each for light and heavy-duty NGVs, with a peak of 2,000 stations per year. Tank manufacturers are currently producing fewer than 20,000 CNG tanks per year,[24] while projections suggest that 200,000 and over 1 million tanks may be required in the heavy- and light-duty scenarios, respectively. LNG tank manufacturers are producing fewer than 2,000 tanks per year, while peak demand may be over 25,000 per year. While most of these facilities are currently underutilized and can meet near-term demand, there needs to be significant investment into expanding tank and station equipment capacity in order to realize these projections.

Vehicle and equipment suppliers have certain production and throughput thresholds to reduce per unit manufacturing costs and achieve economies of scale before they are willing to invest in providing their products. Figure 6.1-1 also compares the current capacity vs. projected demand for light- and heavy-duty vehicle engines. During the NGV build-up period, one or more of the following must happen for successful NGV penetration in order to justify the initially higher per unit manufacturing costs for vehicle and equipment suppliers:

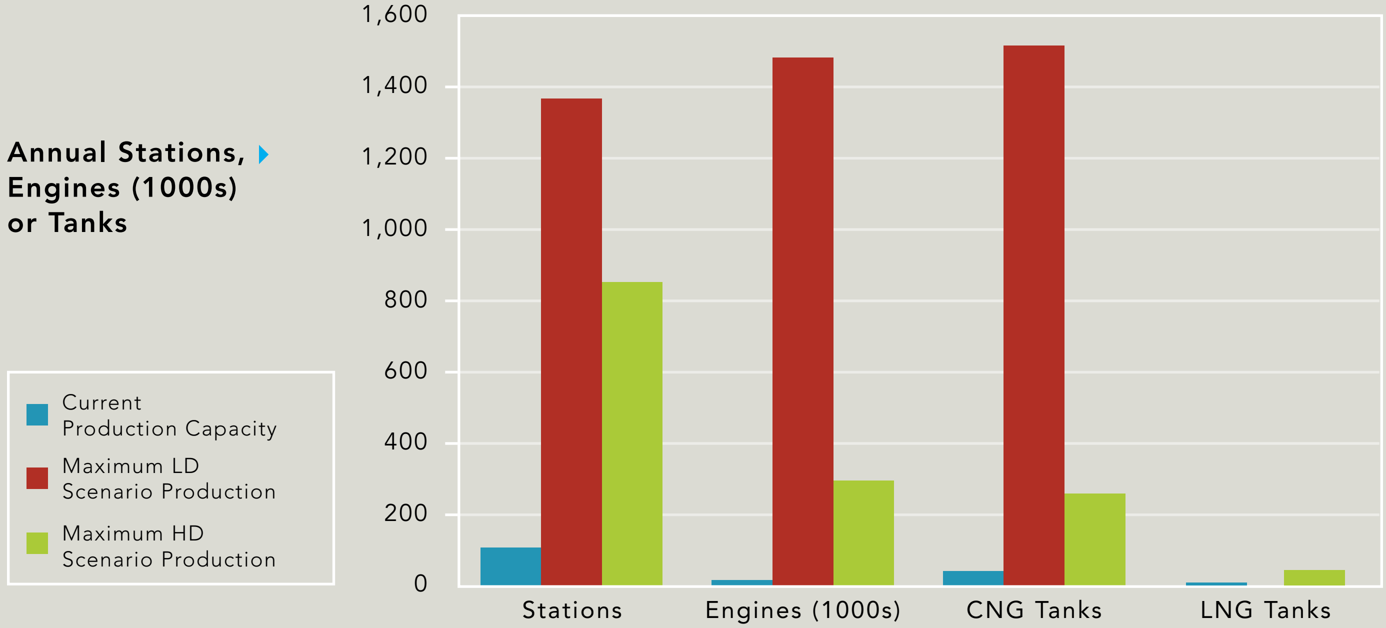
- Vehicle and equipment suppliers accept a reduced margin or loss
- End users pay a larger incremental cost
- Government incentivizes production facility capital costs or the increased incremental cost of the vehicles and equipment
- Vehicle and equipment suppliers form collaboratives to pool resources and lower per unit manufacturing costs

A final potential bottleneck for NGV market growth is the limited number and selection of vehicle options. There is currently only one original equipment manufacturer (OEM) of light-duty NGVs and a small handful of heavy-duty OEMs. The numbers of OEMs and vehicle options will need to increase to attract end users and achieve projected natural gas adoption.

23 Based on station equipment, engineering, and construction stakeholder inputs as described in the CNG Infrastructure report of the overall TIAX assessment.
24 Based on tank manufacturer inputs as described in the Market Segmentation report of the overall TIAX assessment

Figure 6.1-1

Current limitations in production capacity need to be foreseen and addressed in order to expand the NGV market.[25]



25 Based on input from manufacturers, equipment suppliers, and engineering and construction companies as described in the *Market Segmentation, Light- and Medium-Duty Vehicle Ownership and Production, Heavy-Duty Vehicle Ownership and Production, CNG Infrastructure,* and *LNG Infrastructure* reports of the overall TIAX assessment.

6.2 Opportunities

Heavy-duty CNG and LNG vehicles offer compelling business cases for infrastructure developers, as well as end users and government. There may also be a secondary market opportunity in natural gas for light-duty vehicles when they can leverage the infrastructure built for heavy-duty NGVs.

Based on the above scenarios and the calculated ROIs, there is a positive business case for natural gas as a transportation fuel for infrastructure developers in the heavy-duty sector. Figure 6.2-1 shows that based on the scenarios in this report, the heavy-duty market has twice the fuel consumption and five times the potential ROI of the light-duty market when no station or fuel incentives are available. Incentives for alternative fuel stations and fuel in the U.S. have historically been fickle, and it may be a challenging business proposition to rely completely on them for future investments. In addition, the lower ROIs for light-duty scenarios compared to heavy-duty scenarios seen in Figure 6.2-1 reflect the significantly higher investments required for vehicle and equipment infrastructure in the light-duty scenarios.

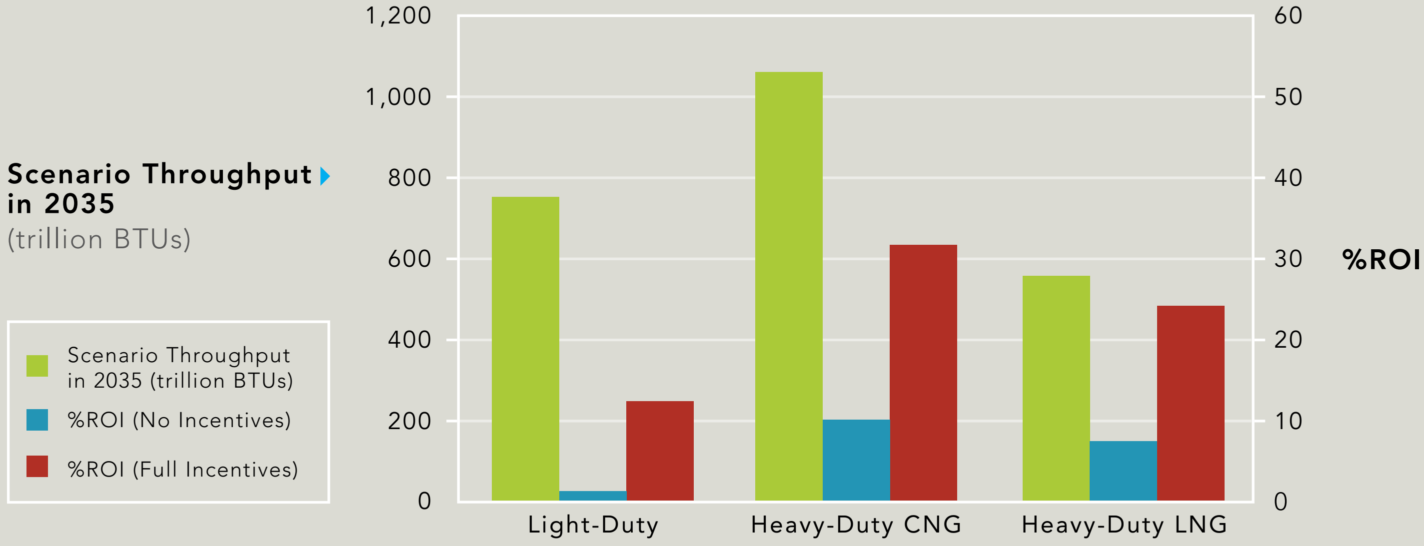
In the heavy-duty sector, incremental costs are lower and fuel savings are greater for LNG end users than CNG end users. This difference is attributed to LNG vehicles, which include line-haul Class 8 tractors, having higher annual fuel consumption than CNG vehicles, which include shorter range vehicles such as package delivery trucks. As discussed previously, heavy-duty CNG infrastructure initially has a higher ROI than LNG infrastructure, but after the capital is paid off, LNG infrastructure has higher margins due to lower operating and fuel distribution costs than CNG.

There is a possible future market opportunity for light-duty vehicles where they can leverage the build-up of CNG stations by the heavy-duty sector. When there is higher fueling capacity, total station availability, and station density, there may be an opportunity to grow the light-duty NGV market without requiring as much infrastructure investment as is currently needed. Under current business cases, it is not likely that light-duty sector will reach the market penetration levels projected in the light-duty scenarios.

For the near-term market penetration of NGVs, there must be adequate infrastructure to sustain both CNG and LNG fleets and sufficient government incentives for the incremental costs of the vehicles to entice end users to switch to natural gas. Even when economics may be favorable for end users, the uncertainties and risks associated with adopting a new technology may cause end users to be hesitant to purchase NGVs. In the beginning, it is likely that the government incentives will exceed the societal benefits since economies of scale have not yet been attained. As the market develops and NGVs become more prevalent, the proven performance of natural gas in transportation will enable the NGV market to be self-sustaining.

Figure 6.2-1

Heavy-duty NGVs offer a compelling business case for infrastructure developers, with and without incentives, and may be considered the primary target of NGV stakeholders to expand the use of natural gas in transportation.



U.S. and Canadian Natural Gas Vehicle Market Analysis:

Comparative Analysis

Final Report

Legal Disclaimer

Table of Contents

Abbreviations
Conversion Factors
Preface
Executive Summary

Chapter 1

Introduction

Chapter 2

2 Transportation Sector Today
2.1 Conventional Fuel Use in Transportation
2.2 Societal Costs of Conventional Fuel Use
2.2.1 Energy Security Premium
2.2.2 Air Pollution Costs
2.2.3 Greenhouse Gas Costs

Chapter 3

3 Societal Costs of Transportation
3.1 Scope
3.1.1 Assessment Basis
3.1.2 Major Assumptions
3.2 Light-Duty Passenger Car
3.3 Medium-Duty Class 2b Van
3.4 Heavy-Duty Class 4 Package Delivery Van
3.5 Heavy-Duty Class 6 Beverage Truck
3.6 Heavy-Duty Class 7 Transit Bus
3.7 Heavy-Duty Class 8 Refuse Hauler
3.8 Heavy-Duty Class 8 Tractor
3.9 Relative Societal Benefits of Alternatives

Chapter 4

4 Alternatives to Conventional Transportation Fuels
4.1 Baseline Technologies
4.2 Light-Duty Passenger Car
4.2.1 Compressed Natural Gas
4.2.2 Hydrogen Fuel Cell
4.2.3 Electric
4.2.4 Ethanol Flex-Fuel
4.2.5 Implementation Considerations
4.2.5.1 Consumer Perceptions
4.2.5.2 Infrastructure
4.3 Medium-Duty Class 2b Van
4.3.1 Compressed Natural Gas
4.3.2 Diesel
4.3.3 Biodiesel
4.3.4 Electricity
4.3.5 Implementation Considerations
4.4 Heavy-Duty Class 4 Package Delivery Van
4.4.1 Compressed Natural Gas
4.4.2 Biodiesel
4.4.3 Electricity
4.4.4 Implementation Considerations
4.5 Heavy-Duty Class 6 Beverage Truck
4.5.1 Compressed Natural Gas
4.5.2 Biodiesel
4.5.3 Electricity
4.5.4 Implementation Considerations
4.6 Heavy-Duty Class 7 Transit Bus
4.6.1 Compressed Natural Gas
4.6.2 Biodiesel
4.6.3 Electricity
4.6.4 Implementation Considerations
4.7 Heavy-Duty Class 8 Refuse Hauler
4.7.1 Compressed Natural Gas
4.7.2 Biodiesel
4.7.3 Implementation Considerations
4.8 Heavy-Duty Class 8 Tractor
4.8.1 Liquefied Natural Gas
4.8.2 Biodiesel
4.8.3 Implementation Considerations
4.9 Dependence on Other Foreign Materials

Chapter 5

Justification for Incentives

Abbreviations

AFV	Alternative fuel vehicle
AGA	American Gas Association
ANGA	America's Natural Gas Alliance
B20	Blend of 20% biodiesel, 80% diesel
BEV	Battery electric vehicle
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CEC	California Energy Commission
CNG	Compressed natural gas
CO	Carbon monoxide
DOE	Department of Energy
DGE	Diesel gallon equivalent (=131.7 cubic feet of natural gas)
E10	Blend of 10% ethanol with 90% gasoline
E15	Blend of 15% ethanol with 85% gasoline
E85	Blend of 85% ethanol with 15% gasoline
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EV	Electric vehicle
FCV	Fuel cell vehicle
FFV	Flex-fuel vehicle
FTA	Federal Transit Administration
GGE	Gasoline gallon equivalent (=115.6 cubic feet of natural gas)
GHG	Greenhouse gas
HEV	Hybrid electric vehicle
lb	Pound
LFG	Landfill gas
LNG	Liquefied natural gas (1 gallon LNG = 0.58 DGE)
mi	Mile
MY	Model year
NGV	Natural gas vehicle
NHTSA	National Highway Traffic Safety Administration
NOx	Oxides of nitrogen
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
RFS	Renewable Fuel Standard
VOC	Volatile organic compound

Conversion Factors

Energy Efficiency Ratio	Light-Duty	Medium-Duty	Heavy-Duty				
	Passenger Car	Class 2b Van	Class 4 Package Delivery Van	Class 6 Beverage Truck	Class 7 Transit Bus	Class 8 Refuse Hauler	Class 8 Tractor
Relative to:	*Gasoline*	*Gasoline*	*Diesel*	*Diesel*	*Diesel*	*Diesel*	*Diesel*
BEV	2.53[b]	3.00[c]	3.00[c]	3.00[c]	3.00[c]		
B20		1.15[e]	1.00[c]				1.00[c]
B20-HEV			1.33[c]	1.33[c]	1.43[e]	1.33[c]	
CNG	1.03[c]	1.00[c]	0.94[c]	0.94[c]	0.94[c]	0.94[c]	
Diesel		1.15[e]					
Diesel-HEV			1.3[c]	1.33[c]	1.43[e]	1.33[c]	
FCV	2.30[c]						
FFV	1.03[c]						
LNG							0.95[c]
PHEV	1.53[d]						

Lower heating value energy content[a]

Diesel	129,488 BTU/gal
Ethanol	110,126 BTU/gal
Gasoline	113,602 BTU/gal
LNG	74,720 BTU/gal
Natural gas	983 BTU/cubic foot (=131.4 BTU/gal of volume)

a Argonne National Laboratory, "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
b Based on fuel economy of Nissan Leaf from Nissan, " Nissan LEAF Electric Car," http://www.nissanusa.com/leaf-electric-car/news/environment#/leaf-electric-car/news/environment, accessed December 2010
c California Energy Commission, "Assembly Bill 1007 State Alternative Fuels Plan," 2007
d Based on fuel economy of Chevrolet Volt from Chevrolet, "Chevrolet Volt Fuel Economy Label Explained," http://www.chevroletvoltage.com/images/stories/EPA_Label_FINAL.pdf, accessed December 2010
e TIAX LLC, "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," prepared for National Academy of Sciences, 2009

Preface

Identifying the most productive and effective means to increase the use of natural gas vehicles

With the primary objective of identifying the most productive and effective means to increase the use of natural gas vehicles (NGVs) in the U.S. and Canada, the TIAX team has conducted a thorough and independent assessment of the NGV market. To highlight the major opportunities to spur the market's development and expansion, this assessment examines the key technical, economic, regulatory, social, and political drivers and challenges that shape this market. TIAX has partnered with The CARLAB, Clean Fuels Consulting, the Clean Vehicle Education Foundation, Jack Faucett Associates, the Natural Gas Vehicle Institute, and St. Croix Research to provide perspective and insights into the development of the future NGV market.

TIAX's overall approach relies on six key stages

- Segmentation of the vehicle market
- Identification of market decision drivers
- Assessment of market development actions
- Analysis of competing technologies
- Analysis of market scenarios
- Integration of overall market development opportunities

The market perspectives, for which decision drivers and opportunities have been identified and assessed are: light-, medium-, and heavy-duty vehicle ownership; light-, medium-, and heavy-duty vehicle manufacturing; compressed and liquefied natural gas infrastructure; and government.

Drawing on the respective expertise of each team member, TIAX presents an integrated assesment of the U.S. and Canadian NGV market in a collection of eight reports. Each report is capable of standing alone while integrating the data, ideas, and themes of the other seven reports. The collection of reports in this TIAX analysis of the NGV market is funded by America's Natural Gas Alliance (ANGA) and further supported by participating members of the American Gas Association (AGA).

Executive Summary

Our transportation system must increase its use of domestic energy sources

Over the last century, transportation fuel emerged as one of the most important sources of energy in the world. Its high energy density, abundance, relatively low cost, and ease of distribution has allowed it to become an ideal transportation fuel. For these reasons, transportation fuel is familiar and ubiquitous fuel, and its production and distribution infrastructure is now well-established and extensive. In 2010, the U.S. consumed a total of 4.7 billion barrels of transportation fuel in the transportation sector and imported 4.2 billion barrels of foreign crude. This heavy reliance on imports, coupled with increasing global demand for oil, will push the price of oil upward and make North American dependence from geopolitically unstable regions of the world an increasing vulnerability.

In addition to the direct monetary costs, North American dependence carries with it societal costs in the form of high energy security premiums and environmental costs. These costs, resulting from the economic effects of commodity prices in the long-run, U.S. import costs, short-run disruption premium, effects on output of the overall economy, and the overall societal impacts, are borne by society as a whole. In order to compare societal costs to the direct costs of conventional fuel, this assessment quantifies these impacts in terms of energy security, air pollutants, and greenhouse gas emissions. Additionally, reductions to the societal costs of conventional fuel achieved by using various alternative technologies are considered to be societal benefits.

Using indirect cost monetization factors derived by U.S government agencies, the societal benefits of the alternatives to current transportation fuel are assessed against gasoline, diesel, and hybrid diesel baselines for light-duty passenger cars, medium-duty Class 2b vans, and heavy-duty package delivery vans, transit buses, refuse haulers, and Class 8 tractors (Table ES-1). These societal benefits are compared to the incentives needed to allow the economics of the alternative technologies to be equal to those of the baselines. These direct costs are calculated in terms of total lifetime fuel and vehicle costs. As Table ES-1 shows, the comparison of societal benefits with the cost needed to make them economically viable indicates that not all required incentives are justified by their societal benefits. For passenger cars, incentives may be fully justified by societal benefits for dedicated and bi-fuel CNG vehicles, hydrogen vehicles, battery electric vehicles (BEVs), and ethanol vehicles. For medium-duty vans, incentives may be fully justified for CNG and electric vehicles only. For package delivery vans, beverage trucks, and refuse haulers, incentives may be fully justified for all of the alternative fuel vehicles. For transit buses, electricity and biodiesel vehicles may be fully justified. For Class 8 tractors, incentives may be justified for LNG vehicles only. In each case, the incentive may be best applied to different combinations of vehicles, fuel, and home, public, or fleet fueling infrastructure.

The comparison of alternatives to conventional fuel is also affected by three other factors. First, continued dependence on potentially supply-constrained foreign materials, including conventional fuel, rare-earth minerals, lithium, and platinum-group metals, may be a concern. Second, consumer perceptions of and interest in the various alternatives to conventional fuel will drive their adoption, and efforts to increase consumer awareness of the direct and societal costs of their options will affect their decisions. Finally, the availability of alternative fuel infrastructure will influence consumer acceptance of the fuels, and expanded infrastructure to meet consumer needs, whether public, fleet, or home fueling, will determine the attractiveness of the various alternatives.

Table ES-1

Each alternative to current transportation fuel offers different societal benefits and economics over its conventional baseline that can be quantified by direct, energy security, and environmental costs. The benefits may justify incentives for making alternatives economically attractive.

Vehicle Segment (Baseline)	Alternative Fuel	Incremental Vehicle and Lifetime Fuel (Costs) or Saving ($ per Vehicle)[a]	Societal Benefit ($ per Vehicle)[b]	For the Given Assumptions, if Expected Societal Benefit ≥ Incremental Cost, Where May Incentive Be Needed?
Light-duty Passenger Car *(gasoline, MY2016)*	CNG (dedicated)[c]	(1,500) to 3,000	3,100	Vehicle Infrastructure (public, home)
	CNG (bi-fuel)[c]	2,500 to 7,000	2,600	
	Hydrogen[d]	(1,000) to 1,500	2,900	Vehicle Infrastructure (public)
	Electricity (BEV)[e]	(3,000) to (5,000)	3,400 to 4,500	Vehicle Infrastructure (public, home)
	Electricity (PHEV)[e]	(10,500) to (15,000)	1,500 to 2,200	
	E85[f]	500	2,100 to 3,400	Fuel Infrastructure (public)
Medium-duty Class 2b Van *(gasoline, MY2010)*	CNG[c]	(500) to 13,000	7,800	Vehicle Infrastructure (public, fleet)
	Diesel[g]	(3,500) to (5,500)	1,400	
	B20[h]	(5,500) to (7,500)	2,500	
	Electricity[e]	(1,800) to 4,100	16,000 to 17,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 4 Package Delivery Van *(diesel-HEV, MY2010)*	CNG[c]	(1,400) to 25,000	12,000	Infrastructure (fleet)
	B20 (HEV)[h]	(2,700)	2,300	Infrastructure (upstream)
	Electricity[e]	31,000 to 37,000	30,000 to 33,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 6 Beverage Truck *(diesel-HEV, MY2010)*	CNG[c]	(35,000) to 31,000	19,000	Vehicle Infrastructure (public, fleet)
	B20 (HEV)[h]	(4,400)	3,400	Infrastructure (upstream)
	Electricity[e]	58,000 to 78,000	43,000 to 45,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 7 Transit Bus *(diesel-HEV, MY2010)*	CNG[c]	(127,000) to 46,000	44,000	
	B20 (HEV)[h]	(5,000)	7,600	Infrastructure (upstream)
	Electricity[e]	88,000 to 126,000	90,000 to 93,000	Vehicle Infrastructure (fleet)
Heavy-duty Class 8 Refuse Hauler *(diesel-HEV, MY2010)*	CNG[c]	(47,000) to 38,000	24,000	Infrastructure (fleet)
	B20 (HEV)[h]	(5,700)	3,900	Infrastructure (upstream)
Heavy-duty Class 8 Tractor *(diesel, MY2010)*	LNG[c]	(23,000) to 58,000	27,000 to 36,000	Vehicle Infrastructure (public, fleet)
	B20[h]	(5,600) to (7,400)	3,600 to 5,100	

a As compared to baseline vehicle
b As quantified by energy security premiums and environmental costs in Section 2.2
c Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from pipeline gas
d Assuming vehicle price at 85,000 vehicles/yr (not yet commercialized), DOE $3/GGE fuel price target (not yet available at scale), fuel from natural gas reforming
e Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from U.S. and California grid mixes
f Assuming zero incremental cost for FFV, EIA fuel price projections, fuel from corn and cellulosic biomass
g Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from crude oil
h Assuming zero incremental cost for biodiesel vehicle, EIA fuel price projections, fuel from soybean oil

1 Introduction

Limited global supply and growing global demand will push conventional fuel prices higher and higher, and our current transportation portfolio is accompanied by costs to society. Accordingly, considerations of alternative fuels should be assessed by the distinct direct and indirect benefits they individually offer.

As demand increases for current transportation fuels, prices are expected to increase as well. On top of these direct costs, societal costs are borne by society as a whole. These costs take many forms, including economy-wide effects, energy security premiums, and effects on the environment.

Given that current transportation fuel has associated direct and societal costs, a fair comparison of alternatives to conventional fuel considers these costs. Each alternative transportation technology offers different direct and indirect cost benefits over the status quo. In order to bridge the gap between the decision making consumer, who generally sees only the direct costs, and government, which is concerned with the societal costs, the costs and benefits of the alternatives should be weighed against each other so that government incentives to the consumer can be justified by the specific societal benefits gained. Stated differently, alternative technologies that to date have been grouped together in the same category and assumed to be equal should instead be assessed individually by the benefits they each offer.

This report focuses on comparing the direct and societal costs of transportation fuel use and quantifies the societal benefits achieved by displacing current transportation fuel with alternatives. Following an overview of the transportation sector today and its direct costs in Section 2, the societal costs of fuel use in seven vehicle segments (Table 1-1) are examined in Section 3. In Section 4, alternatives to conventional fuel in these vehicle segments are assessed in terms of their economics relative to conventional fuel baselines. For each alternative in each segment, the incentives needed to make the alternative economically attractive are compared to the societal benefits gained by using that alternative. Finally, Section 5 summarizes the benefits of alternatives and discusses potential implications for these alternatives affected by future energy prices and greenhouse gas (GHG) legislation. For natural gas vehicles (NGVs) specifically, the justified incentives for the various vehicle segments are analyzed in the context of proposed U.S. policies.

Table 1-1

Alternative fuels in seven representative vehicle segments are analyzed in this report.

Vehicle Segment	Gross Vehicle Weight Rating	Examples
Light-Duty Passenger Car	≤ 6,000 lbs	Compact Car
Medium-Duty Class 2b Van	6,000 to 10,000 lbs	Commercial Van
Heavy-Duty Class 4 Package Delivery Van	14,001 to 16,000 lbs	Uniform Delivery Van
Heavy-Duty Class 6 Beverage Truck	19,501 to 26,000 lbs	Water Delivery Truck
Heavy-Duty Class 7 Transit Bus	26,001 to 33,000 lbs	Transit Bus
Heavy-Duty Class 8 Refuse Hauler	≥ 33,001 lbs	Refuse Hauler
Heavy-Duty Class 8 Tractor	≥ 33,001 lbs	Goods Movement Truck

2 Transportation Sector Today

2.1 Conventional Fuel Use in Transportation

The current advantages of conventional fuel have led to ever increasing global demand, which will exert upward pressure on prices and increase direct costs to consumers.

Over the last century, transportation fuel emerged as one of the most important sources of energy in the world. Its high energy density, abundance, relatively low cost, and ease of distribution has allowed it to become an ideal transportation fuel. For these reasons, transportation fuel has been proven as a familiar and ubiquitous fuel, and its production and distribution infrastructure is now well-established and extensive.

The U.S. currently depends heavily on petroleum as its conventional fuel source, consuming a total of 4.7 billion barrels in 2010 in the transportation sector.[1] When compared to the 4.2 billion barrels of crude oil that were imported in 2010, much from geopolitically unstable regions of the world, it becomes apparent that the U.S. will be greatly affected by the rest of the world's energy consumption. Though the U.S. and other countries in the Organization for Economic Co-operation and Development have been reducing their demand for transportation fuel, overall global demand is expected to grow, particularly in developing countries. As global demand increases, the price of transportation fuel will be pushed upward (Figure 2.1-1) by basic principles of supply and demand, making North American dependence on transportation fuel an increasing vulnerability.

Multiplied by the increasing quantity of transportation fuel imported (Figure 2.1-2), the U.S. import bill for transportation fuel is currently nearing $350 billion per year. From the consumer perspective, this cost is reflected in the price per gallon at the retail pump. For commercial and fleet vehicle operators whose total cost of doing business is significantly influenced by small changes in fuel price, both the volatility of and increase in transportation fuel prices can have a large negative impact. For private vehicle users, fuel price to date has generally represented a small fraction of total lifetime vehicle costs, and thus consumer vehicle use has been relatively insensitive to fuel price. However, prices shocks, such as those seen in 1973 and 2008, have resulted in even this segment of the market reacting by reducing vehicle use and seeking alternatives.

As the direct costs of transportation continue to increase, alternatives will be essential to maintain economic competitiveness across the entire economy. Alternatives such as natural gas will see their relative direct economic benefits grow as prices increase and diverge from natural gas prices as expected.[2] If these alternatives can offer abundant domestic fuel resources, proven technology, and consumer acceptance, decisive actions to move these alternatives into the mainstream marketplace will enable the North American economy to hedge against widespread economic impacts of dependence.

1 U.S. Energy Information Administration. "Annual Energy Review." October 19, 2011.
2 U.S. Energy Information Administration. "Annual Energy Outlook 2012." June 2012.

Figure 2.1-1

Conventional fuel prices are expected to rise significantly in the next 25 years, increasing from $93 per barrel today to $145 per barrel by 2035, and most of this fuel will likely come from foreign sources.[3]

Conventional Fuel Price
(2010$/barrel)

Note: Prices are given as annual averages and do not reflect their volatility of conventional fuel prices

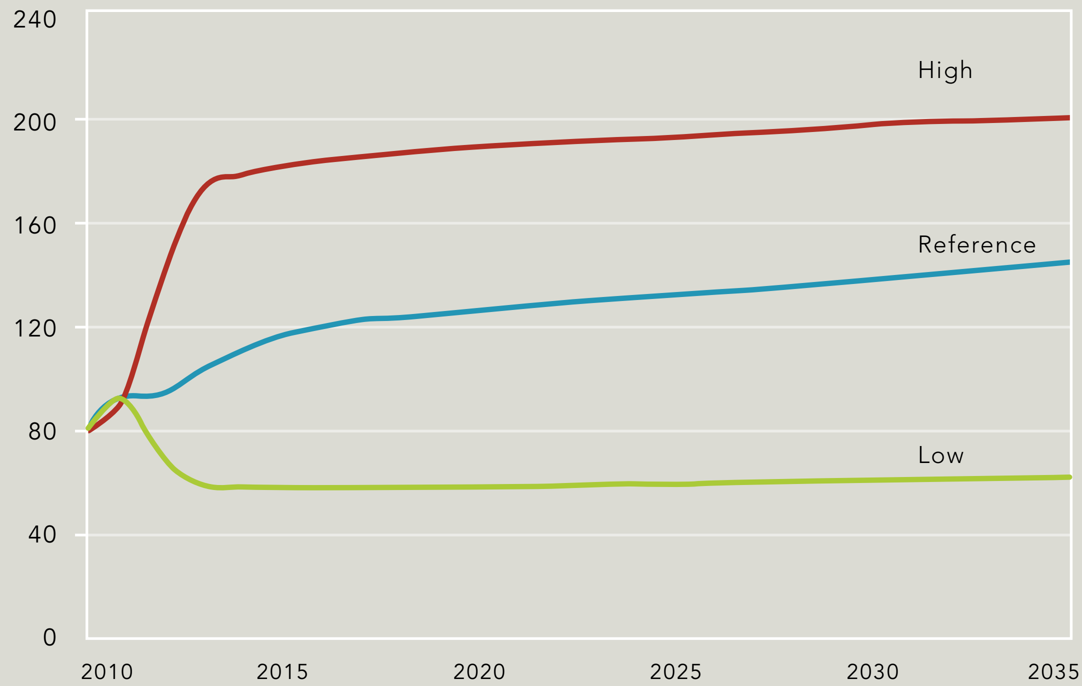
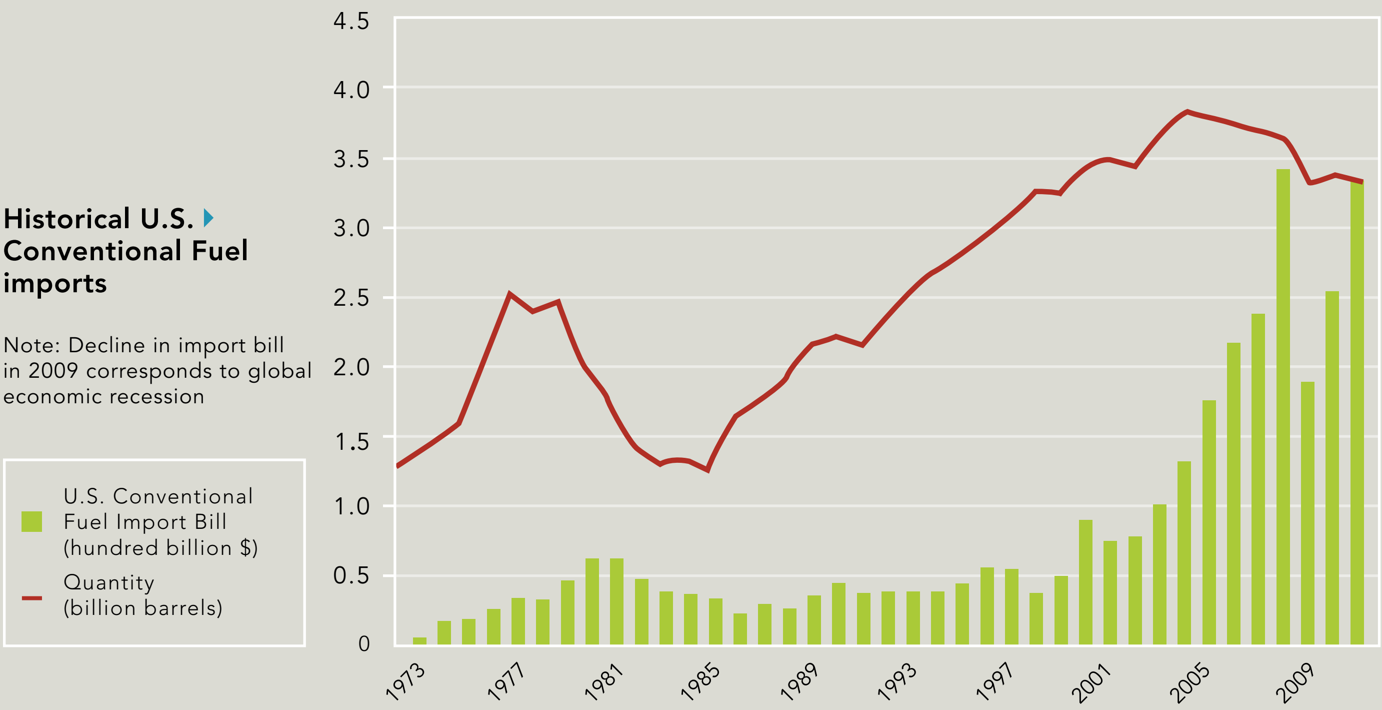


Figure 2.1-2

Transportation today relies almost entirely on conventional fuels, and the U.S. pays hundreds of billions of dollars each year for imported fuel.[4]

Historical U.S. Conventional Fuel imports

Note: Decline in import bill in 2009 corresponds to global economic recession



3 U.S. Energy Information Administration. "Annual Energy Outlook 2012." June 2012.
4 U.S. Census Bureau Foreign Trade Division. "U.S. Imports of Crude Oil." http://www.census.gov/foreign-trade/statistics/historical/petr.pdf. Accessed August 20, 2012.

2 Transportation Sector Today

2.2 Societal Costs of Conventional Fuel Use

2.2.1 Energy Security Premium

North American dependence on foreign sources of energy, particularly in the transportation sector, carries with it societal costs in the form of high energy security premiums.

In addition to the direct cost of current transportation fuel, defined by the actual dollars paid for the commodity, North American dependence on foreign sources of energy also results in societal costs. These costs are not negotiated in the form of currency but are instead paid by society as a whole. Societal costs use include: unhealthful emissions, military tensions, economic strain, and environmental degradation. One of the most significant societal costs is the energy security premium.

Energy security can be defined as protecting the economy against circumstances that result in significant increases and volatility in energy costs, which affects all sectors of the economy. Discussions of energy security typically involve the economic costs of dependence on oil imports. Much concern arises because North America relies on imported oil from potentially unstable sources. In addition, oil exporters can raise the price of oil by exerting essentially monopoly power through the Organization of Petroleum Exporting Countries. These factors contribute to the vulnerability of the North American economy to sporadic supply shocks and price spikes. The reduction of consumption through increased use of natural gas will reduce oil imports, which will reduce the financial and strategic risks associated with potential supply disruptions and price spikes. This abatement of financial and strategic risks is a measure of improved energy security and a logical course of action for the U.S. and Canada.

The need for greater energy security through decreased reliance on foreign sources of energy has been widely acknowledged. The Obama administration has declared that this reliance threatens national security, the environment, and the economy (Table 2.2.1-1).[5] The Center for a New American Security has echoed these sentiments, urging U.S. independence from transportation fuel within thirty years.[6] Former President Bush called for technology to move beyond imported oil in his 2006 State of the Union address,[7] and former Vice President Al Gore highlighted the role of natural gas as the most viable substitute for diesel in heavy-duty vehicles.[8] To understand the effects of dependence and to determine the energy security benefits associated with various vehicle GHG and fuel economy regulations, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) developed monetized estimates of energy security premiums.[9] These estimates are quantified by the economic effects of oil prices in the long-run, U.S. import costs, short-run disruption premium, and effects on output of the overall economy and are calculated to be $0.46 per gallon of current transportation fuel.

5 The White House. “Energy & Environment.” http://www.whitehouse.gov/issues/energy-and-environment. Accessed November 2010.

6 Parthemore, C., J. Nagl. “Fueling the Future Force: Preparing the Department of Defense for a Post-Petroleum Era.” Center for a New American Security. September 2010.

7 Bush, G.W., State of the Union address, 2006.

8 Gore, A., National Clean Energy Roundtable, Washington, D.C., February 23, 2009.

9 U.S. EPA and NHTSA. “Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis.” EPA-420-R-10-009. April 2010.

Figure 2.2.1-1

The economic and environmental risks posed by dependence on foreign sources of energy from geopolitically unstable regions of the world have been widely acknowledged.

"Our dependence on foreign oil threatens our national security, our environment, and our economy. We must make the investments in clean energy sources that will put Americans back in control of our energy future, create millions of new jobs, and lay the foundation for long-term economic security."

–The Obama administration[10]

"Given projected supply and demand, we cannot assume that oil will remain affordable or that supplies will be available to the U.S. reliably three decades hence. Ensuring that the Department of Defense can operate on non-petroleum fuels thirty years from today is a conservative hedge against prevailing economic, political and environmental trends, conditions and constraints."

–Center for a New American Security [11]

"Keeping America competitive requires affordable energy. And here we have a serious problem: America is addicted to oil, which is often imported from unstable parts of the world. […] By applying the talent and technology of America, this country can dramatically improve our environment, move beyond a petroleum-based economy and make our dependence on Middle Eastern oil a thing of the past."

–George W. Bush[12]

"Electrifying the auto fleet, using natural gas for the 18-wheelers and the heavy vehicles as a transition – then we can get off of all those imported liquid fuels that come from foreign oil and foreign products and solve the security and economic problem and put people to work in the process."

–Al Gore[13]

Table 2.2.1-1

Energy security premiums resulting from dependence on sources of energy from geopolitically unstable regions of the world are quantified by major effects on the economy due to volatility and high costs.

Energy Security Premium = $0.462 per gallon transportation fuel (2010 U.S. dollars)[14]
Decreased economic output Loss of national gross product Economic strain and volatility Supply shocks and price spikes Supply disruption Import costs

10 The White House. "Energy & Environment." http://www.whitehouse.gov/issues/energy-and-environment. Accessed November 2010.
11 Parthemore, C., J. Nagl. "Fueling the Future Force: Preparing the Department of Defense for a Post-Petroleum Era." Center for a New American Security. September 2010.
12 Bush, G.W., State of the Union address, 2006.
13 Gore, A., National Clean Energy Roundtable, Washington, D.C., February 23, 2009.
14 U.S. EPA and NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009. April 2010.

2.2 Societal Costs of Conventional Fuel Use
2.2.2 Air Pollution Costs

In addition to high energy security premiums, North American dependence on foreign sources of energy from geopolitically unstable regions of the world is accompanied by indirect air pollution costs that are borne by society as a whole.

A full fuel cycle analysis (Figure 2.2.2-1) provides a more complete picture of the true impacts of transportation energy use and considers not only the impacts of the vehicles, but also the impacts associated with production and distribution of the fuel, known as "upstream" impacts.

Though not currently accounted for in retail prices, every transportation fuel carries a societal cost that reflects the costs of impacts on society as a whole (Table 2.2.2-1). These costs are different for each fuel, and by increasing use of domestic alternatives, these societal costs can be reduced. These quantifications are estimated by considering increased risks and tangible outcomes of these risks. The major air pollutants include oxides of nitrogen (NOx), particulate matter (PM2.5), carbon monoxide (CO), and volatile organic compounds (VOCs). These compounds can be found in the exhaust gas resulting from combustion of fuel in vehicles and each carries its own impact to society. The monetized values calculated by EPA, NHTSA, and CEC for these pollutants are listed in Table 2.2.2-1.[15,16,17]

15 U.S. EPA and NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009. April 2010.

16 TIAX communication with Neal Fann, EPA Office of Air Quality Planning & Standards, August/September 2010.

17 CEC. "Reducing California's Petroleum Dependence, Appendix A: Benefits of Reducing Demand for Gasoline and Diesel (Task 1)." P600-03-005A1. September 2003.

Figure 2.2.2-1

A full fuel cycle analysis incorporates impacts from all phases of fuel extraction, production, distribution, and end use.

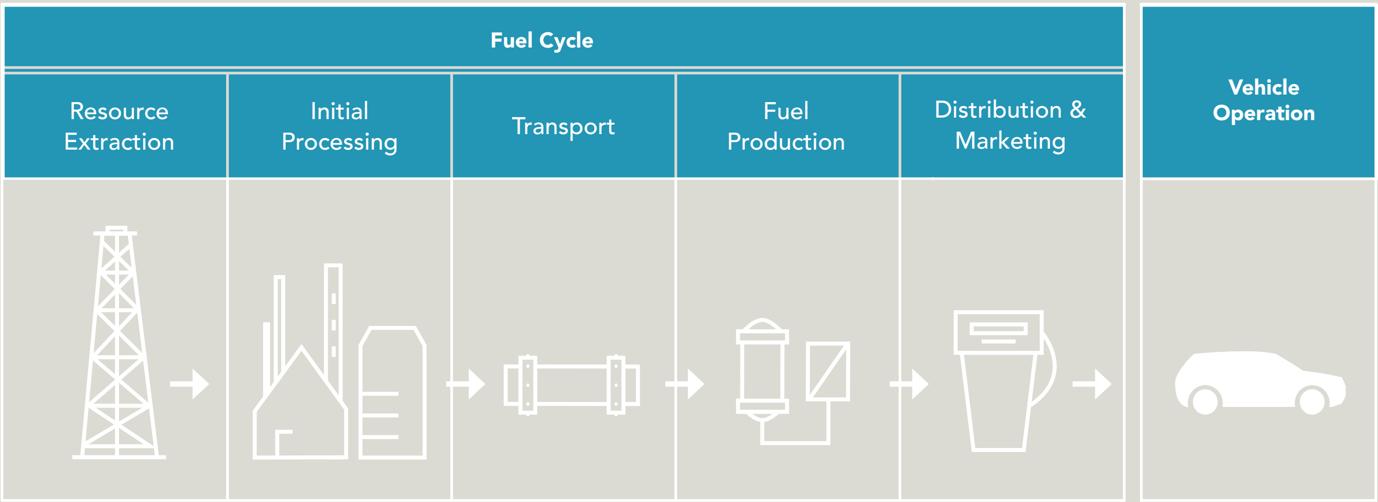


Table 2.2.2-1

Indirect air pollution costs are quantified by major effects on society.

Air Pollution Costs[18,19,20,21] =	**$9,072**	per ton NO_X
	$270	per ton CO
	$7,401	per ton VOC
	$283,274	per ton $PM_{2.5}$

18 Costs for NOx and VOCs include both direct emissions of these pollutants and their indirect emissions (as precursors to PM); all costs are given in 2010 U.S. dollars.
19 U.S. EPA and NHTSA. “Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis.” EPA-420-R-10-009. April 2010.
20 TIAX communication with N. Fann, EPA Office of Air Quality Planning & Standards, August/September 2010.
21 CEC. “Reducing California’s Petroleum Dependence, Appendix A: Benefits of Reducing Demand for Gasoline and Diesel (Task 1).” P600-03-005A1. September 2003.

2.2 Societal Costs of Conventional Fuel Use

2.2.3 Greenhouse Gas Costs

GHG emissions are another cost to society resulting from conventional fuel use.

In addition to energy security and pollution costs, the third indirect cost of fuel use results from GHG emissions. Examples of GHGs include carbon dioxide, methane, and nitrous oxide.

The U.S. government, including the Department of Energy, Department of Transportation, and the EPA, has established a monetary value for the social cost of carbon, as shown in Table 2.2.3-1.[22,23] This value reflects the costs to society as a whole from increased release of GHGs. Together, these risks describe the social cost of carbon.

Table 2.2.3-1

Indirect GHG costs are quantified by the U.S. government, including the Department of Energy, Department of Transportation and the EPA.

GHG Costs[24,25] = $23.13 per ton GHG

22 U.S. Government. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis, Under Executive Order 12866." Interagency Working Group. February 2010.
23 U.S. EPA and NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009. April 2010.
24 U.S. Government. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis, Under Executive Order 12866." Interagency Working Group. February 2010.
25 U.S. EPA and NHTSA. "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." EPA-420-R-10-009. April 2010.

3 Societal Costs of Transportation

3.1 Scope

3.1.1 Assessment Basis

The societal costs of transportation, in terms of energy security, air pollutants, and GHGs, can be quantified by the value of benefits gained by using various alternatives to current transportation fuel.

This section quantifies the societal costs of transportation in terms of energy security, air pollutants, and GHGs. For this analysis, vehicles considered include on-road vehicles but exclude planes, trains, ships, and off-road vehicles; however, the same methodology can also be applied to these. Because societal costs of transportation depend on fuel, annual mileage, fuel economy, and use characteristics, the costs in this section are presented for seven vehicle segments:

1) passenger cars, 2) medium-duty vans, 3) heavy-duty package delivery vans, 4) heavy-duty beverage trucks, 5) heavy-duty transit buses, 6) heavy-duty refuse haulers, and 7) heavy-duty Class 8 tractors.[26] All passenger cars are assumed to meet model year (MY) 2016 vehicle standards, and all other vehicles are assumed to meet MY2010 vehicle standards. The vehicle tailpipe emissions used to calculate societal costs are based on the emissions standards in place for these years.

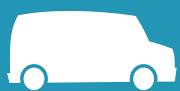
The fuels considered include gasoline blended with 10 percent ethanol, diesel, compressed natural gas (CNG), liquefied natural gas (LNG), 85 percent blends of ethanol in gasoline (E85), hydrogen, electricity, and 20 percent blends of biodiesel in diesel (B20). This assessment examines each vehicle segment in terms of its available fuels (Table 3.1.1-1). For the passenger car, the vehicles that operate on E85 and hydrogen are flex-fuel vehicles (FFVs) and fuel cell vehicles (FCVs), respectively. Two types of CNG passenger cars are considered: dedicated, which operate entirely on natural gas, and bi-fuel, which operate on either natural gas or gasoline. All other NGVs are assumed to be dedicated NGVs. For the purposes of this assessment, CNG is assumed to be used in all NGVs except Class 8 tractors; further discussion about the applicability of CNG vs. LNG can be found in the Heavy-Duty Vehicle Ownership and Production report of the overall TIAX assessment.

Two types of electric passenger cars are considered: battery electric vehicles (BEVs), which operate entirely on electricity, and plug-in hybrid electric vehicles (PHEVs), which operate on electricity and gasoline. For other vehicle segments, electric vehicles are assumed to be BEVs. For the package delivery van, transit bus, and refuse hauler, the baseline vehicles are assumed to be diesel hybrid electric vehicles (HEVs), which offer higher fuel economy than diesel vehicles of the past. Though hybridization is not necessary in the near term to meet fuel economy and air pollutant emissions standards, fleets will be looking toward HEVs for other reasons, including corporate sustainability initiatives, public image, and potential GHG emissions regulations. For vehicle segments that use HEVs as baselines, any vehicle operating on biodiesel is also assumed to be an HEV, since the vehicle technologies are identical. NGVs can also be HEVs, but hybridized NGVs will entail higher vehicle costs, and manufacturers are not expecting to be offering such vehicles,[27] thus all NGVs in this assessment are assumed to not be HEVs.

26 Details regarding the duty cycles of each of these vehicle segments can be found in the *Market Segmentation* report of the overall TIAX assessment.
27 See the *Heavy-Duty Vehicle Ownership and Production* report in overall TIAX assessment for OEM perspectives on the expected availability of hybrid NGVs.

Table 3.1.1-1

The following baselines and alternatives to conventional fuel are considered for each of the light-, medium-, and heavy-duty vehicle segments.

Vehicle Segment		Baseline	Alternative Considered
	Light-Duty Passenger Car	Gasoline, MY2016	CNG (dedicated and bi-fuel) E85 (FFV) Electricity (BEV and PHEV) Hydrogen (FCV)*
	Medium-Duty Class 2b Van	Gasoline, MY2010	CNG B20 Diesel Electricity
	Heavy-Duty Class 4 Package Delivery Van	Diesel-HEV, MY2010	B20-HEV CNG Electricity
	Heavy-Duty Class 6 Beverage Truck	Diesel-HEV, MY2010	B20-HEV CNG Electricity
	Heavy-Duty Class 7 Transit Bus	Diesel-HEV, MY2010	B20-HEV CNG Electricity
	Heavy-Duty Class 8 Refuse Hauler	Diesel-HEV, MY2010	B20-HEV CNG
	Heavy-Duty Class 8 Tractor	Diesel, MY2010	B20 LNG

*Not yet commercialized

3 Societal Costs of Transportation

3.1 Scope

3.1.2 Major Assumptions

Specific fuel pathways and prices and vehicle technologies and costs are assumed for this assessment, and calculated societal benefits and economics are highly dependent on these assumptions.

This assessment makes assumptions about the fuel pathways and vehicles for the alternative technologies (Figure 3.1.2-1 and Table 3.1.2-1) that significantly impact the calculated societal benefits and economics. The benefits and economics presented here are intended to illustrate examples of various fuels and technologies rather than provide definitive quantifications of their merits. All comparisons are based on a set of "snapshot" assumptions of the various technologies and fuels and should not be considered judgments about their relatively desirability.

Notably, use of fuel feedstocks different from those assumed here will change the calculated societal benefits. Advances in vehicle technology and increased production volumes will change the calculated direct costs, as will higher-than-expected transportation fuel prices. Use of nuclear feedstocks instead of natural gas feedstocks to produce hydrogen and annual production volumes of hundreds of thousands of FCVs, for example, may dramatically increase its relative societal benefits and decrease its direct costs.

Though important, the societal costs of military activity, water use, motor vehicle accidents, traffic congestion, market rebound effects, highway noise, refueling time, and vehicle safety are difficult to quantify for each of the fuels and vehicle segments and are thus not considered in this analysis.

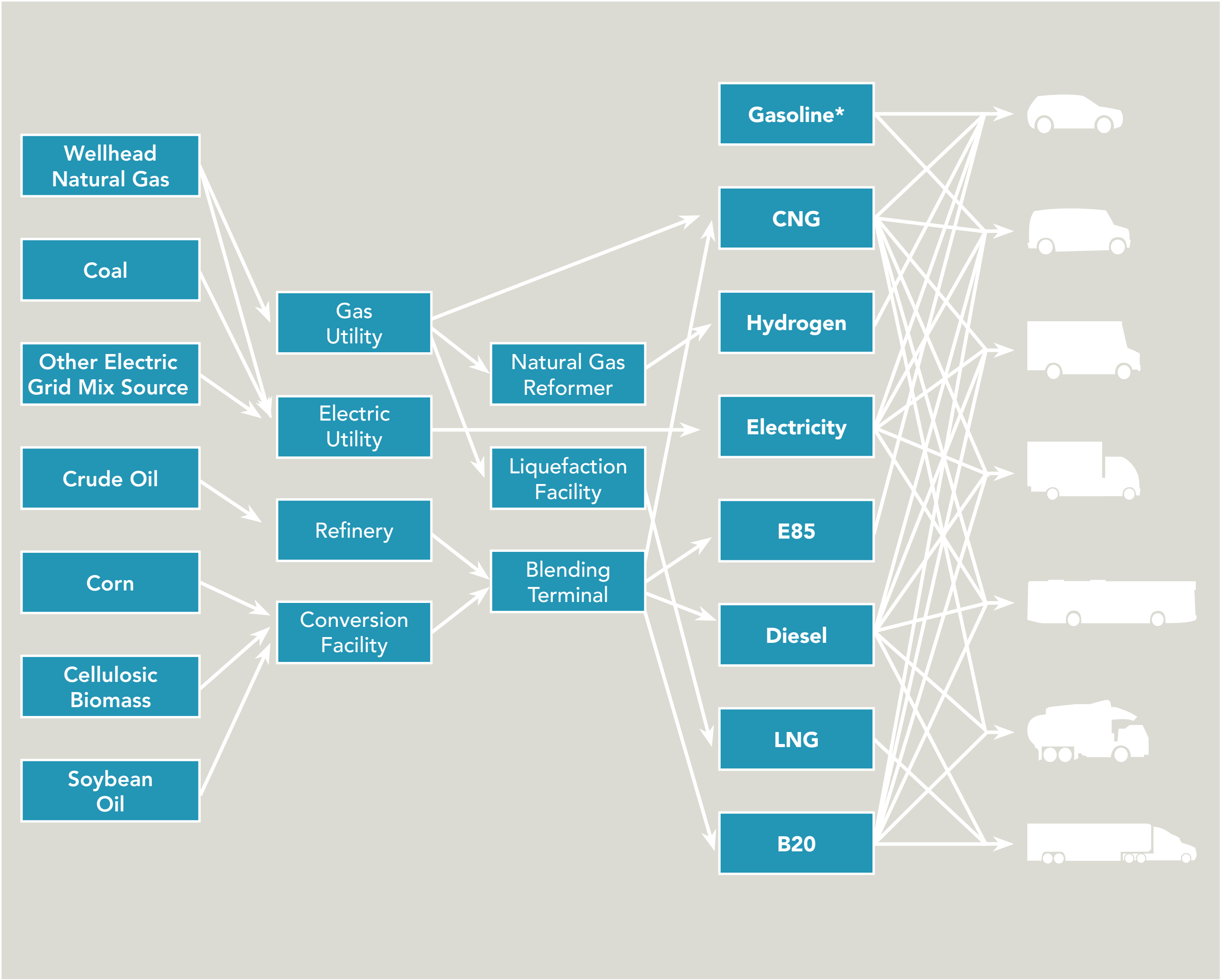
For purposes of simplicity, the direct costs calculated in this assessment examine vehicle purchase prices and lifetime fuel costs. Other cost factors, such as maintenance costs and resale values, are not included and are assumed to be comparable. Direct costs are based on simple economics, without including amortized costs associated with the cost of money. For example, capital costs for infrastructure do not account for loans and interest payments needed to finance the building of the infrastructure, which can be significant over many years. In addition, it should be noted that despite the economics calculated here, consumers may be risk and/or loss adverse and will generally discount future savings because whether fuel savings will actually be realized is an unknown.[28] In this case, up front savings (e.g., through vehicle incentives) may be more important for overall economics than future savings (e.g., through favorable fuel cost differentials).

In addition to converting fuel costs to the same energy equivalent basis, efficiency adjustment factors are applied to calculate fuel cost differentials, taking into account the vehicles' efficiency in using the fuel. These efficiency adjustment factors, listed in the Conversion Factors section, are values used by the California Energy Commission (CEC) in its 2007 alternative fuels assessment to support California Assembly Bill 1007.

28 Green, D. "Why the Market for New Passenger Cars Generally Undervalues Fuel Economy." Discussion paper at Joint Transport Research Centre Round Table, Paris, France, February 18-19, 2010.

Figure 3.1.2-1

Specific fuel pathways are used to calculate societal benefits and economics; other pathways will offer different quantifications.



*Gasoline is assumed to be E10 (blend of 90% gasoline and 10% ethanol

Table 3.1.2-1

This assessment makes specific assumptions about fuel pathways and prices and vehicle technologies and costs.[29]

Alternative Technology		Assessment Assumptions
Fuel	Biodiesel	From soybean oil, EIA fuel price projections
	CNG	From pipeline gas, EIA fuel price projections
	Diesel	From crude oil, EIA fuel price projections
	Electricity	From average U.S. and California grid mixes, EIA fuel price projections for transportation electricity
	Ethanol	From corn and cellulosic biomass, EIA fuel price projections
	Gasoline	From crude oil, 10% ethanol, EIA fuel price projections
	Hydrogen	From natural gas reforming, DOE $3/GGE fuel price target tracked to EIA natural gas price projections (not yet available at scale)
	LNG	From pipeline gas, current price tracked to EIA natural gas price projections
Vehicle	BEV	Price at current production volumes
	Biodiesel vehicle	Zero incremental cost relative to diesel vehicle
	Diesel-HEV	Price at current production volumes
	Diesel vehicle	Price at current production volumes
	FCV	Price at EPA/NHTSA/CARB-estimated 85,000 vehicles/year (not yet commercialized)
	FFV	Zero incremental cost relative to gasoline vehicle
	Gasoline vehicle	Price at current production volumes
	NGV	Price at current production volumes
	PHEV	Price at current production volumes

29 Fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c. Fuel and vehicle costs are detailed in Section 4.

3.2 Light-Duty Passenger Car

The societal cost of gasoline use in a passenger car is estimated at $5,100 per vehicle over its lifetime. In comparison, the societal costs of alternatives to gasoline range from $580 to $3,500 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline gasoline passenger car in Figure 3.2-1. The societal costs of gasoline use in passenger cars total $5,100 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed by GHG emissions. PM2.5 also contributes significantly to the societal costs of gasoline.

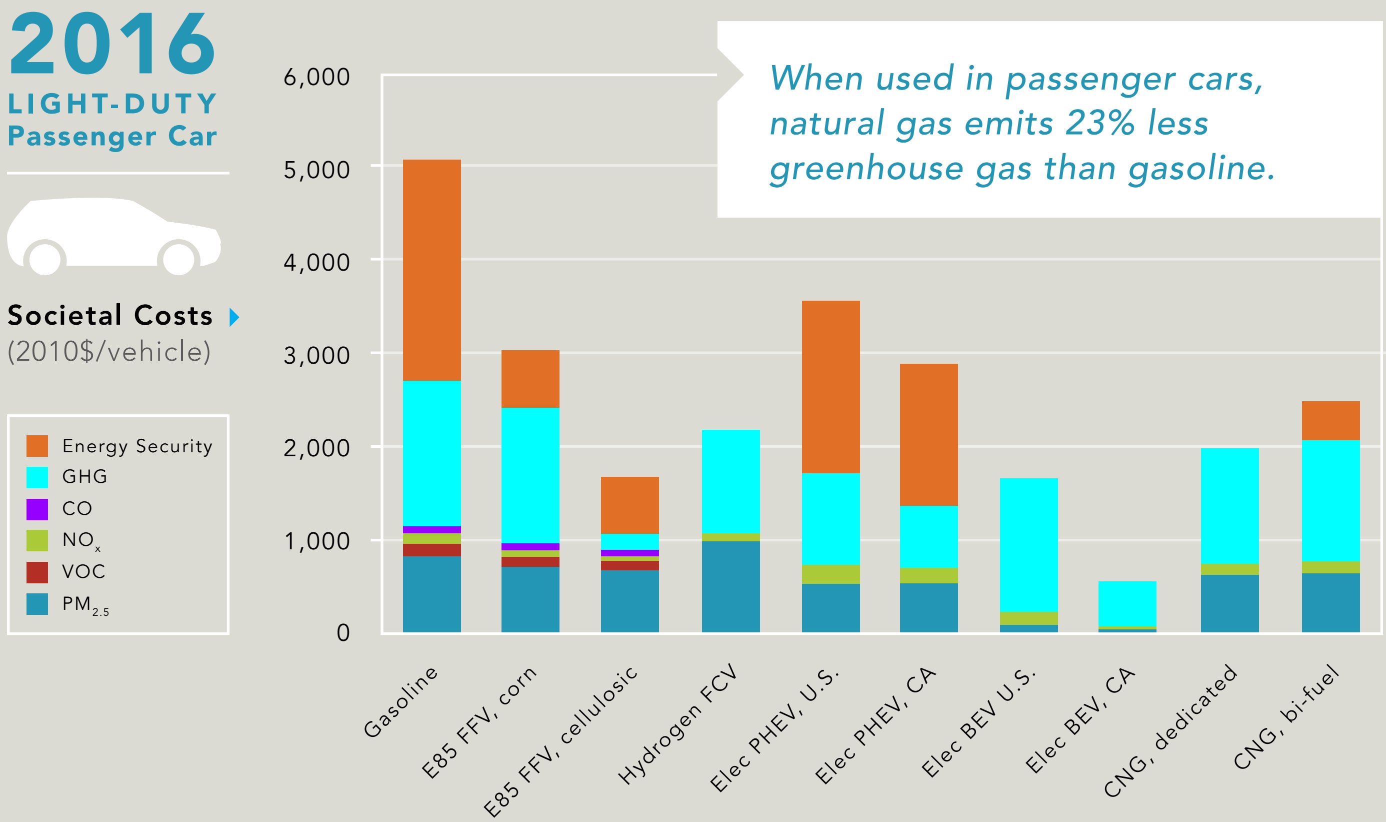
In comparison, the societal costs of E85 use in FFVs range from $1,700 to $3,000 per vehicle, depending on whether the ethanol is derived from cellulosic materials or from corn, respectively. The societal costs of hydrogen use in FCVs are estimated at $2,200 per vehicle, assuming natural gas is used to produce the fuel. The societal costs of electricity use in passenger vehicles depend on whether the vehicle is fully electric, as with a BEV, or partially electric, as with a PHEV,[30] and the GHG intensity of the grid mix used to generate the electricity. To provide a range for the costs of electricity, using the U.S. average grid mix,[31] the societal costs for BEVs and PHEVs are $1,700 and $3,500 per vehicle, respectively. In contrast, using the California average grid mix,[32] the societal costs for BEVs and PHEVs are $580 and $2,900 per vehicle, respectively. The societal costs of CNG use in passenger cars depend on whether the vehicle is a dedicated NGV or a bi-fuel NGV[33] and range from $2,000 to $2,500 per vehicle for dedicated and bi-fuel NGVs, respectively.

Similar to the societal costs of gasoline, the costs attributed to GHG emissions make up the largest fraction of costs for alternatives. For FFVs, PHEVs, and bi-fuel NGVs, energy security premiums are associated with the gasoline used in conjunction with the alternative fuels, although these premiums are smaller over the lifetime of the vehicles than for gasoline vehicles because less gasoline is used. For E85, hydrogen, and CNG, PM2.5 emitted during production of the fuels also contributes to total societal costs. The costs of CO, NOx, and VOC emissions from passenger cars are relatively insignificant across all fuels.

30 Based on EPA fuel economy ratings for the Chevrolet Volt (93 mi/GGE in all electric mode, 37 mi/GGE in all gasoline mode).
31 From Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c, the average U.S. grid mix is 50.4 percent coal, 20.0 percent nuclear power, 18.3 percent natural gas, 1.1 percent residual oil, 0.7 percent biomass, and 9.5 percent other energy sources.
32 From Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c, the average California grid mix is 36.6 percent natural gas, 20.5 percent nuclear power, 13.3 percent coal, 1.3 percent biomass, and 28.3 percent other energy sources.
33 Bi-fuel NGV assumed to operate 80 percent on CNG and 20 percent on gasoline.

Figure 3.2-1

The societal costs of gasoline use in passenger cars are estimated at $5,100 per vehicle over its lifetime. In contrast, the societal costs of alternatives to gasoline range from $580 to $3,500 per vehicle.



Assumptions:	
Annual mileage	13,900 mi
Vehicle lifetime	14 years
Fuel economy	
Gasoline	39.1 mi/gal
E85 FFV	40.3 mi/GGE
Hydrogen FCV	90.0 mi/GGE
PHEV	60 mi/GGE
BEV	99 mi/GGE
CNG, dedicated	40.3 mi/GGE
CNG, bi-fuel	40.3 mi/GGE
Tailpipe emissions standard	2016

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) Gasoline from crude oil, hydrogen from natural gas reforming, electricity from U.S. and California grid mixes, CNG from pipeline natural gas; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
3) Annual mileage and vehicle lifetime derived from U.S. Department of Energy "Transportation Energy Data Book," Edition 29, 2010
4) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.3 Medium-Duty Class 2b Van

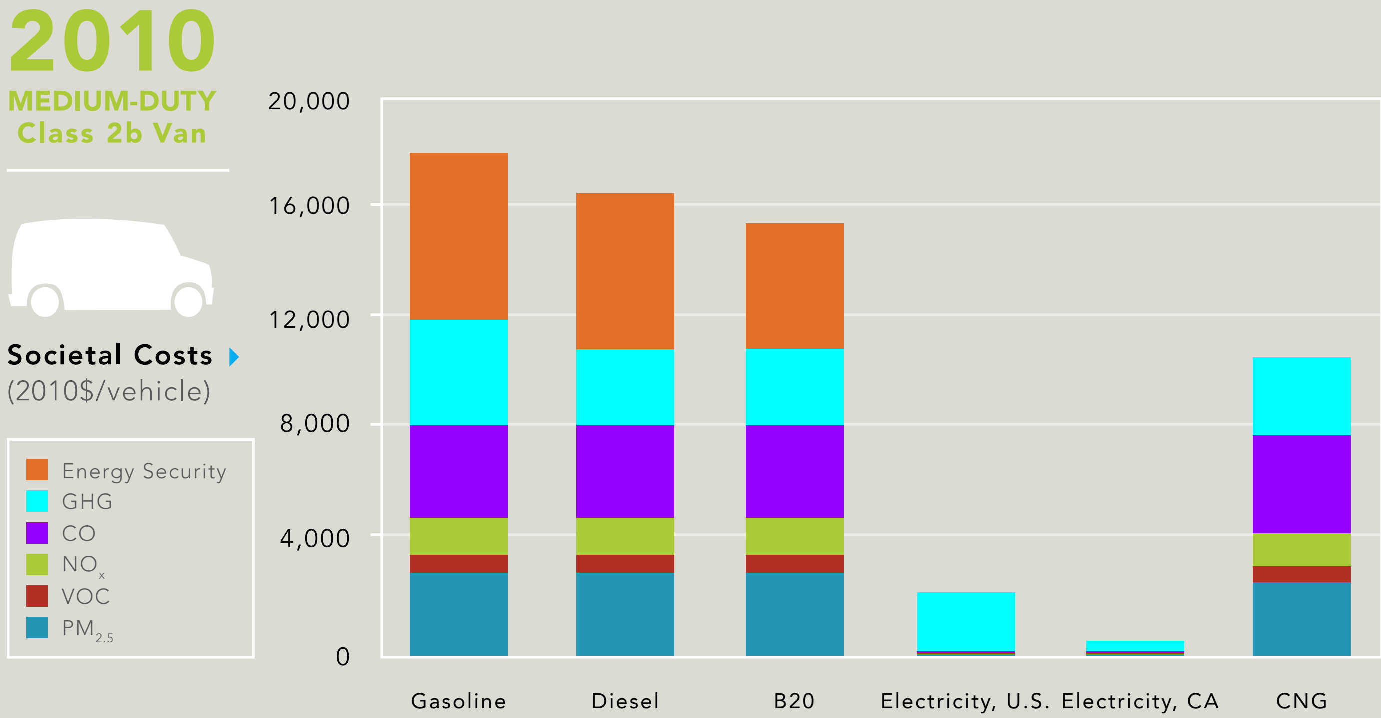
The societal costs of gasoline use in medium-duty vans are estimated at $18,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to gasoline range from $700 to $17,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline gasoline Class 2b van in Figure 3.3-1. The societal costs of gasoline use in vans total $18,000 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed GHG, CO, and PM2.5 emissions. In comparison, the societal costs of diesel use in Class 2b vans are $17,000 per vehicle, resulting from higher fuel economy for diesel systems compared to gasoline systems. The societal costs of B20 use in the same diesel system are estimated at $16,000 per vehicle, and the societal costs of CNG use are estimated at $10,000 per vehicle. For electricity, the societal costs are estimated at $700 to $2,100 per vehicle, depending on whether the California or U.S. average grid mix is used.

Similar to the societal costs of gasoline, the costs attributed to GHG, CO, and PM2.5 emissions make up the largest fractions of costs for diesel, B20 and CNG. Societal costs for electricity are dominated by GHGs alone. For diesel and B20 vehicles, energy security premiums are associated with the diesel used. The costs of NOx and VOC emissions are small but significant across all fuels and are roughly equal since the vehicles meet the same 2010 tailpipe emissions standards.

Figure 3.3-1

The societal costs of gasoline use in Class 2b vans are estimated at $18,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to gasoline range from $700 to $17,000 per vehicle.



Assumptions:	
Annual mileage	13,750 mi
Vehicle lifetime	15 years
Fuel economy	
Gasoline	14.0 mi/gal
Diesel	16.1 mi/GGE
Biodiesel	16.1 mi/GGE
CNG	14.0 mi/GGE
Electricity	42.1 mi/GGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) Gasoline from crude oil, diesel from crude oil, biodiesel from soybean oil, CNG from pipeline natural gas, electricity from U.S. and California grid mixes; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
3) Annual mileage is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
4) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
5) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.4 Heavy-Duty Class 4 Package Delivery Van

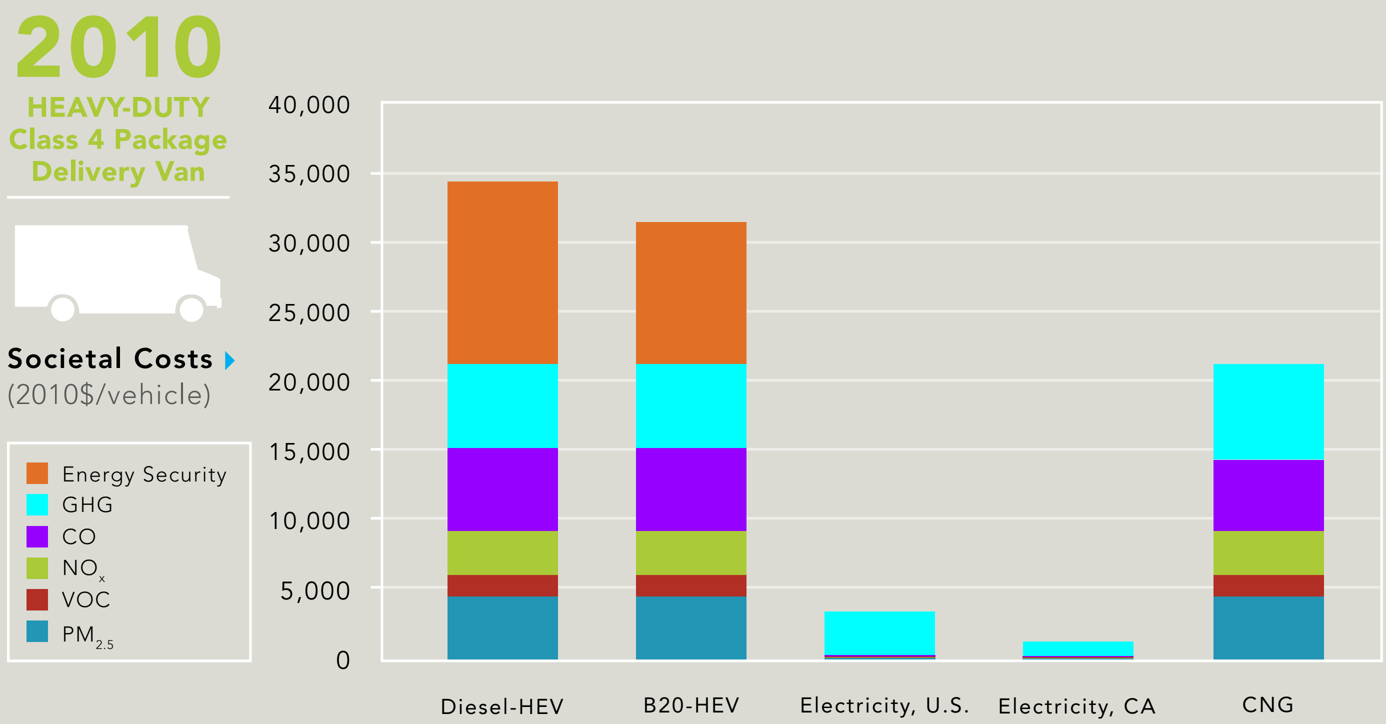
The societal costs of diesel use in hybrid package delivery vans are estimated at $34,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to diesel range from $1,400 to $32,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline gasoline Class 2b van in Figure 3.3-1. The societal costs of gasoline use in vans total $18,000 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed GHG, CO, and PM2.5 emissions. In comparison, the societal costs of diesel use in Class 2b vans are $17,000 per vehicle, resulting from higher fuel economy for diesel systems compared to gasoline systems. The societal costs of B20 use in the same diesel system are estimated at $16,000 per vehicle, and the societal costs of CNG use are estimated at $10,000 per vehicle. For electricity, the societal costs are estimated at $700 to $2,100 per vehicle, depending on whether the California or U.S. average grid mix is used.

Similar to the societal costs of gasoline, the costs attributed to GHG, CO, and PM2.5 emissions make up the largest fractions of costs for diesel, B20 and CNG. Societal costs for electricity are dominated by GHGs alone. For diesel and B20 vehicles, energy security premiums are associated with the diesel used. The costs of NOx and VOC emissions are small but significant across all fuels and are roughly equal since the vehicles meet the same 2010 tailpipe emissions standards.

Figure 3.4-1

The societal costs of diesel use in package delivery vans are estimated at $34,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to diesel range from $1,400 to $32,000 per vehicle.



Assumptions:	
Annual mileage	20,000 mi
Vehicle lifetime	20 years
Fuel economy	
Diesel-HEV	15.0 mi/gal
B20-HEV	15.0 mi/DGE
CNG	10.5 mi/DGE
Electricity	33.7 mi/DGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) CNG vehicle is not an HEV
3) Diesel from crude oil, biodiesel from soybean oil, CNG from pipeline natural gas, electricity from U.S. and California grid mixes; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
4) Annual mileage is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
5) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.5 Heavy-Duty Class 6 Beverage Truck

The societal costs of diesel use in hybrid beverage trucks are estimated at $47,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to diesel range from $1,400 to $43,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline diesel HEV beverage truck in Figure 3.5-1. The societal costs of diesel use in beverage trucks total $47,000 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed by GHG, CO, and PM2.5 emissions. In comparison, the societal costs of B20 use in the same diesel HEVs are estimated at $43,000 per vehicle, and the societal costs of CNG use are estimated at $28,000 per vehicle. For electricity, the societal costs ranges from $1,400 to $4,100 per vehicle, depending on whether the California or U.S. average grid mix is used.

Similar to the societal costs of diesel, the costs attributed to GHG, CO, and PM2.5 emissions make up the largest fractions of costs for B20 and CNG. Societal costs for electricity are dominated by GHGs alone. For B20 vehicles, an energy security premium is associated with the diesel blended into the fuel, although this premium is slightly smaller over the lifetime of the vehicles than for full diesel vehicles because 20 percent less diesel is used. The costs of NOx and VOC emissions are small but significant across all fuels and are roughly comparable, which is expected since all vehicles must meet the same 2010 tailpipe emissions standards.

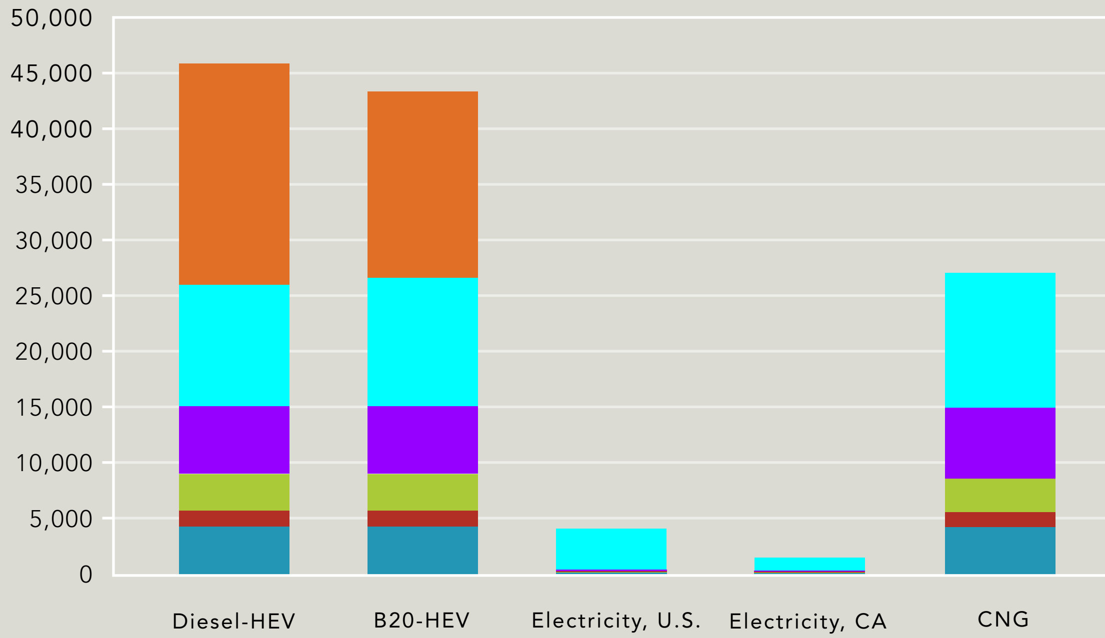
Figure 3.5-1

The societal costs of diesel use in beverage trucks are estimated at $47,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to diesel range from $1,400 to $43,000 per vehicle.

2010

HEAVY-DUTY
Class 6
Beverage Truck

Societal costs
(2010$/vehicle)



Assumptions:	
Annual mileage	27,500 mi
Vehicle lifetime	15 years
Fuel economy	
Diesel-HEV	9.3 mi/gal
B20-HEV	9.3 mi/DGE
CNG	6.6 mi/DGE
Electricity	21.0 mi/DGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) CNG vehicle is not an HEV
3) Diesel from crude oil, biodiesel from soybean oil, CNG from pipeline natural gas, electricity from U.S. and California grid mixes; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
4) Annual mileage is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
5) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.6 Heavy-Duty Class 7 Transit Bus

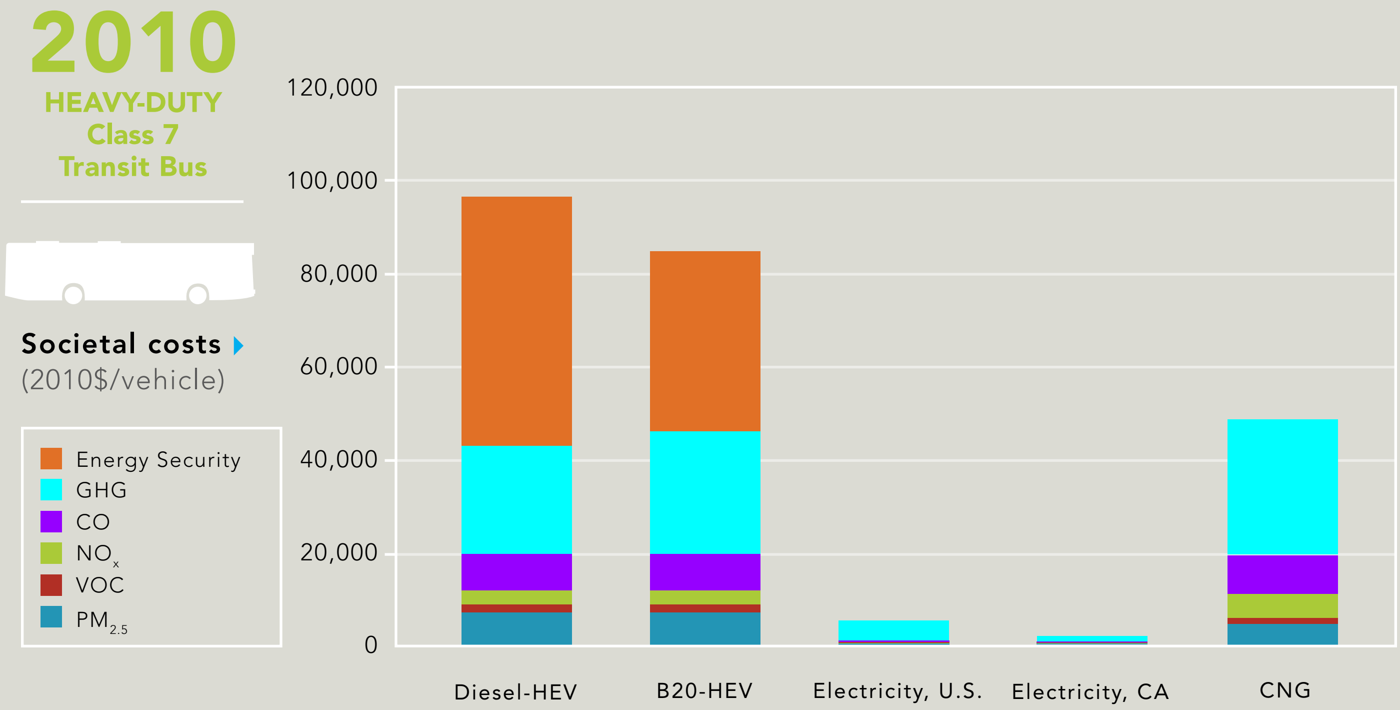
The societal costs of diesel use in transit buses are estimated at $95,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to diesel range from $1,800 to $88,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline diesel HEV transit bus in Figure 3.6-1. The societal costs of diesel use in transit buses total $95,000 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed by GHG emissions. Air pollutants (CO, VOCs, NOx, and PM2.5) also contribute in part to the societal costs of diesel. In comparison, the societal costs of B20 use in the same diesel HEVs are estimated at $88,000, and the societal costs of CNG use are estimated at $52,000 per vehicle. For electricity, the societal costs ranges from $1,800 to $5,200 per vehicle, depending on whether the California or U.S. average grid mix is used.

Similar to the societal costs of diesel, the costs attributed to GHG emissions make up a large fraction of costs for B20 and CNG. Societal costs of electricity are dominated by GHGs alone. For B20 vehicles, an energy security premium is associated with the diesel blended into the fuel, although this premium is slightly smaller over the lifetime of the vehicles than for full diesel vehicles because 20 percent less diesel is used. The costs of CO, VOC, NOx, and PM2.5 emissions are small but significant for both B20 and CNG and are similar for all buses, since they all meet the same 2010 tailpipe emissions standard.

Figure 3.6-1

The societal costs of diesel use in transit buses are estimated at $95,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to diesel range from $1,800 to $88,000 per vehicle.



Assumptions:	
Annual mileage	44,000 mi
Vehicle lifetime	12 years
Fuel economy	
Diesel-HEV	4.9 mi/gal
B20-HEV	4.9 mi/DGE
CNG	3.2 mi/DGE
Electricity	10.3 mi/DGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) NGV is not an HEV
3) Diesel from crude oil, biodiesel from soybean oil, CNG from pipeline natural gas, electricity from U.S. and California grid mixes; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
4) Annual mileage is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
5) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.7 Heavy-Duty Class 8 Refuse Hauler

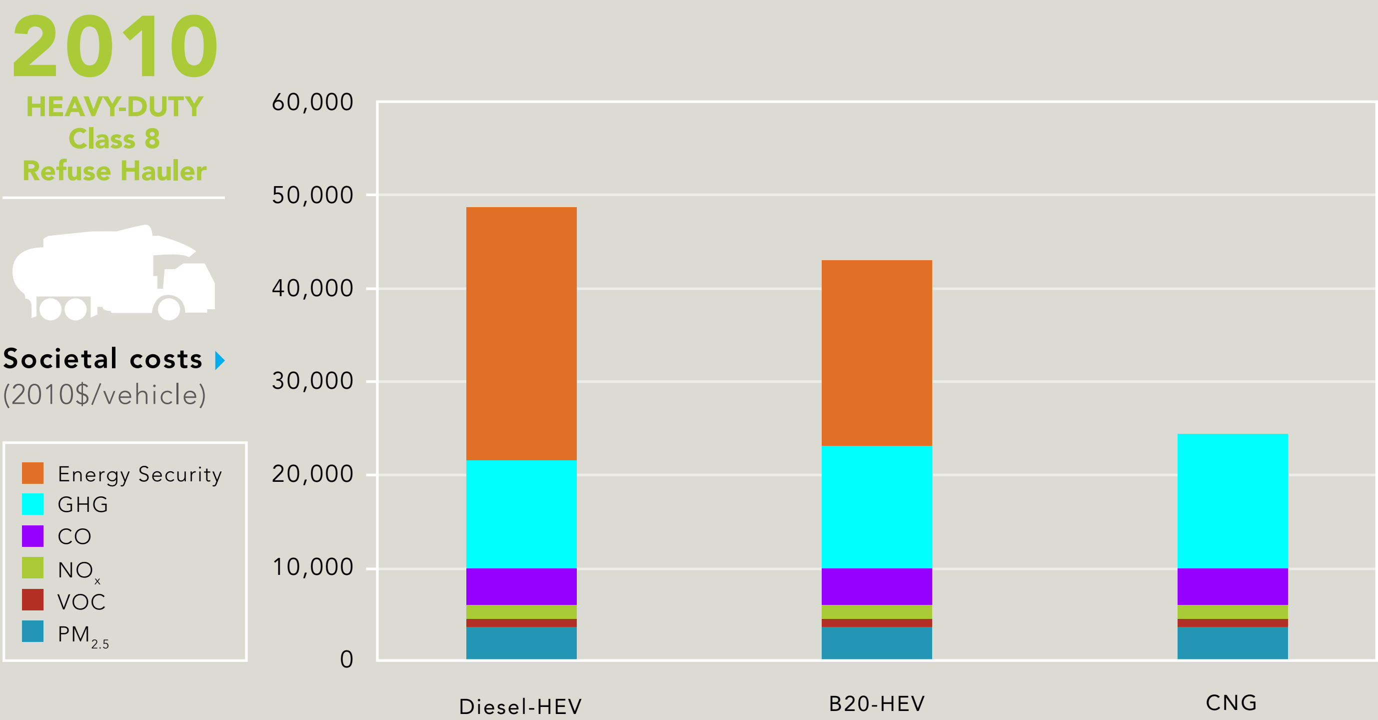
The societal costs of diesel use in refuse haulers are estimated at $49,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to diesel range from $25,000 to $45,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline diesel HEV refuse hauler in Figure 3.7-1. The societal costs of diesel use in refuse haulers total $49,000 per vehicle over its lifetime. The greatest portion of these costs is attributed to the energy security premium, followed by GHG emissions. Air pollutants (CO, VOCs, NOx, and PM2.5) also contribute in part to the societal costs of diesel. In comparison, the societal costs of B20 use in biodiesel HEVs are estimated at $45,000. The societal costs of CNG use are estimated at $25,000 per vehicle.

Similar to the societal costs of diesel, the costs attributed to GHG emissions make up a large fraction of costs for B20 and CNG. For B20 vehicles, an energy security premium is associated with the diesel blended into the fuel, although this premium is slightly smaller over the lifetime of the vehicles than for full diesel vehicles because 20 percent less diesel is used. Similar to those for diesel, the costs of CO, VOC, NOx, and PM2.5 emissions are small but significant for B20 and CNG.

Figure 3.7-1

The societal costs of diesel use in refuse haulers are estimated at $49,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to diesel range from $25,000 to $45,000 per vehicle.



Assumptions:	
Annual mileage	25,000 mi
Vehicle lifetime	10 years
Fuel economy	
Diesel-HEV	4.4 mi/gal
B20-HEV	4.4 mi/DGE
CNG	3.1 mi/DGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) NGV is not an HEV
3) Diesel from crude oil, biodiesel from soybean oil, CNG from pipeline natural gas; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
4) Annual mileage is derived from TIAX LLC "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," prepared for National Academy of Sciences, 2009
5) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.8 Heavy-Duty Class 8 Tractor

The societal costs of diesel use in Class 8 tractors range from $48,000 to $70,000 per vehicle over its lifetime. In comparison, the societal costs of alternatives to diesel range from $21,000 to $65,000 per vehicle.

The monetized costs of each alternative vehicle are compared to the baseline diesel Class 8 tractor in Figures 3.8-1 and 3.8-2. Because Class 8 tractors can be operated for applications ranging from short distance port drayage to regional grocery distribution to cross-country goods movement, these comparisons are bounded by tractors in a local-haul duty cycle (less than 200 miles per day) and a line-haul duty cycle (over 300 miles per day). The societal costs of tractors in various applications are expected to fall within these bounds.

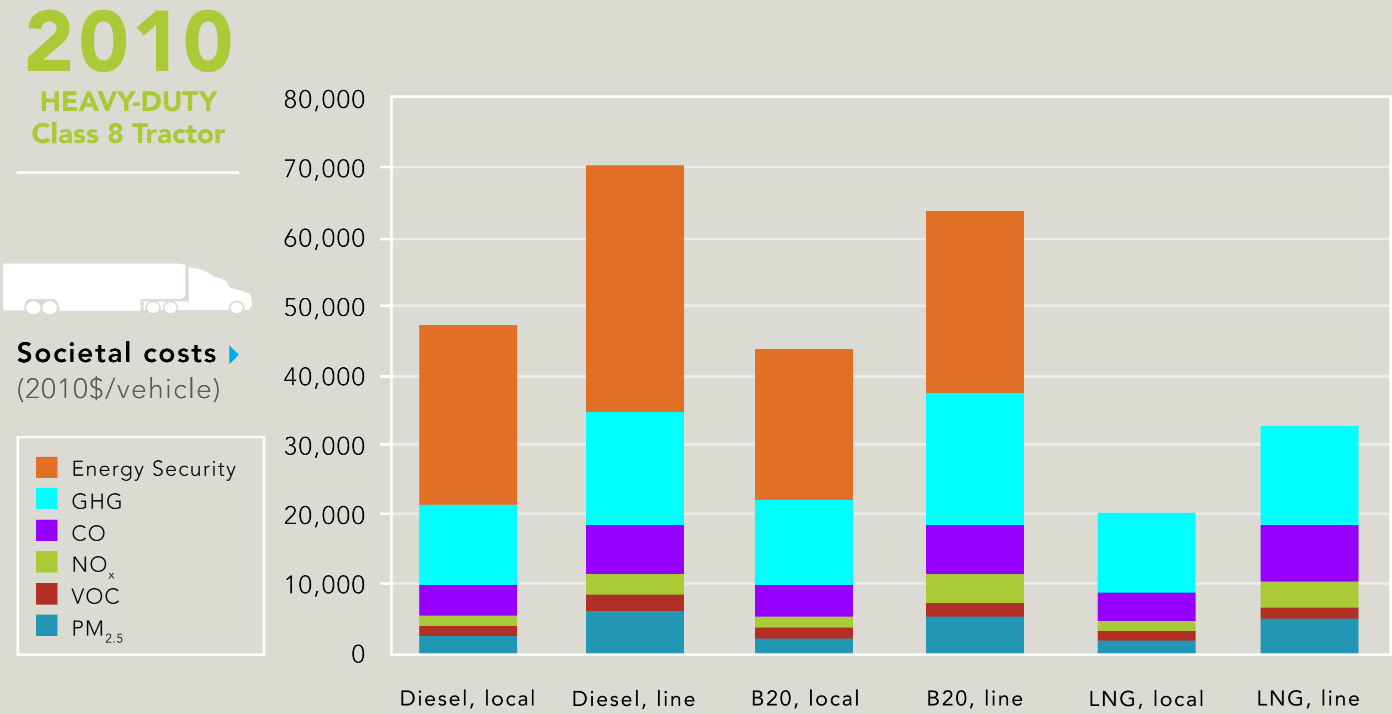
The societal costs of diesel use in Class 8 tractors range from $48,000 to $70,000 per vehicle over its lifetime, based on local- and line-haul applications, respectively. The greatest portion of these costs is attributed to the energy security premium, followed by GHG emissions. Air pollutants, particularly CO and PM2.5, also contribute to the societal costs of diesel. In comparison, the societal costs of B20 use range from $44,000 to $65,000 per vehicle, and the societal costs of LNG use range from $21,000 to $34,000 per vehicle, again depending on duty cycle.

Similar to the societal costs of diesel, the costs attributed to GHG emissions make up a large fraction of costs for B20 and LNG, and air pollutants, particularly CO and PM2.5, also contribute to their societal costs. For B20 vehicles, an energy security premium is associated with the diesel blended into the fuel, although this premium is slightly smaller over the lifetime of the vehicles than for full diesel vehicles because 20 percent less diesel is used.

Similar to the societal costs of diesel, the costs attributed to GHG emissions make up a large fraction of costs for B20 and CNG. Societal costs of electricity are dominated by GHGs alone. For B20 vehicles, an energy security premium is associated with the diesel blended into the fuel, although this premium is slightly smaller over the lifetime of the vehicles than for full diesel vehicles because 20 percent less diesel is used. The costs of CO, VOC, NOx, and PM2.5 emissions are small but significant for both B20 and CNG and are similar for all buses, since they all meet the same 2010 tailpipe emissions standard.

Figure 3.8-1

The societal costs of diesel use in Class 8 tractors range from $48,000 to $70,000 per vehicle over its lifetime. In contrast, the societal costs of alternatives to diesel range from $21,000 to $65,000 per vehicle across local- and line-haul applications.



Assumptions:	
Annual mileage, local	40,000 mi
Annual mileage, line	120,000 mi
Vehicle lifetime, local	6 years
Vehicle lifetime, line	4 years
Fuel economy, local	
Diesel	4.3 mi/gal
B20	4.3 mi/DGE
LNG	4.1 mi/DGE
Fuel economy, line	
Diesel	6.5 mi/gal
B20	6.5 mi/DGE
LNG	6.2 mi/DGE
Tailpipe emissions standard	2010

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) Diesel from crude oil, biodiesel from soybean oil, LNG from pipeline natural gas; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
4) Annual mileage is derived from TIAX LLC "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," prepared for National Academy of Sciences, 2009
5) Vehicle lifetime is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

3.9 Relative Societal Benefits of Alternatives

The lower societal costs of natural gas, hydrogen, electricity, ethanol, and biodiesel compared to conventional fuel baselines translate into quantifiable societal benefits.

Based on the societal costs of transportation fuel use in the seven vehicle segments, the differences between the costs of conventional fuels and their alternatives represent the quantified societal benefits of using alternatives. These benefits are summarized in Table 3.9-1.

For passenger cars, the societal benefits of alternative technologies range from $1,500 to $4,500 per vehicle. For Class 2b vans, the benefits range from $1,400 to $17,000 per vehicle. For Class 4 package delivery vans, the benefits range from $2,300 to $33,000 per vehicle. For Class 6 beverage trucks, the benefits range from $3,400 to $45,000 per vehicle. For Class 7 transit buses, the benefits range from $7,600 to $93,000 per vehicle. For Class 8 refuse haulers, the benefits range from $3,900 to $24,000 per vehicle. For Class 8 tractors, the benefits range from $3,600 to $36,000 per vehicle, depending on the vehicles' duty cycles.

It is important to note that all societal benefits have been calculated for the first owner vehicle lifetime as specified in the assumptions corresponding to each vehicle segment. The benefits that would be achieved in vehicle use by subsequent owners are not included but may be substantial, especially for vehicles such as Class 8 tractors that see multiple owners for use over as many as 1 million miles. The next section puts the first-owner benefits in context with the economics, or direct costs, of these alternatives.

Table 3.9-1

Each alternative to conventional fuel offers different societal benefits over its conventional fuel baseline that can be quantified, in part, by these reductions in energy security premiums and environmental costs.

Alternative Fuel	Societal Benefits over Conventional Fuel ($)						
	Light-Duty Passenger Car	**Medium-Duty Class 2b Van**	**Heavy-Duty Class 4 Package Delivery Van**	**Heavy-Duty Class 6 Beverage Truck**	**Heavy-Duty Class 7 Transit Bus**	**Heavy-Duty Class 8 Refuse Hauler**	**Heavy-Duty Class 8 Tractor**
Baseline:	*Gasoline*	*Gasoline*	*Diesel-HEV*	*Diesel-HEV*	*Diesel-HEV*	*Diesel-HEV*	*Diesel*
CNG dedicated	3,100	7,800	12,000	19,000	44,000	24,000	
CNG bi-fuel	2,600						
LNG							27,000 - 36,000[a]
Hydrogen	2,900						
Electric PHEV	1,500 - 2,200[b]						
Electric BEV	3,400 - 4,500[b]	16,000 - 17,000[b]	30,000 - 33,000[b]	43,000 - 45,000[b]	90,000 - 93,000[b]		
E85	2,100 - 3,400[c]						
Diesel		1,400					
Biodiesel		2,500					3,600 - 5,100[a]
B20-HEV			2,300	3,400	7,600	3,900	

Details and sources used to calculate these values can be found in Sections 3.1 through 3.8.

a Range corresponds to local- and line-haul applications
b Range corresponds to electricity from U.S. and California grid mixes
c Range corresponds to ethanol from corn and cellulosic biomass

4 Alternatives to Conventional Transportation Fuels

4.1 Baseline Technologies

Alternative fuels will likely retain their societal benefits over transportation fuel, even with improvements to baseline technologies to meet increasingly stringent emissions and fuel economy standards.

In order to compare alternative fuels, baselines for comparison must be established. The baseline for light-duty passenger cars and medium-duty vans is assumed to be gasoline. Gasoline is currently the dominant fuel for light-duty vehicles, and though diesel was previously the dominant fuel for medium-duty vehicles due to its favorable economics and efficiency, more stringent emissions and fuel economy standards have increased the cost and complexity of diesel systems, making gasoline a conceivable alternative. As discussed earlier, the baseline for package delivery vans, transit buses, and refuse haulers is assumed to be hybridized diesel, using energy storage to boost fuel economy but not requiring any fuel other than diesel. The baseline for Class 8 tractors is assumed to be diesel, their dominant fuel today.

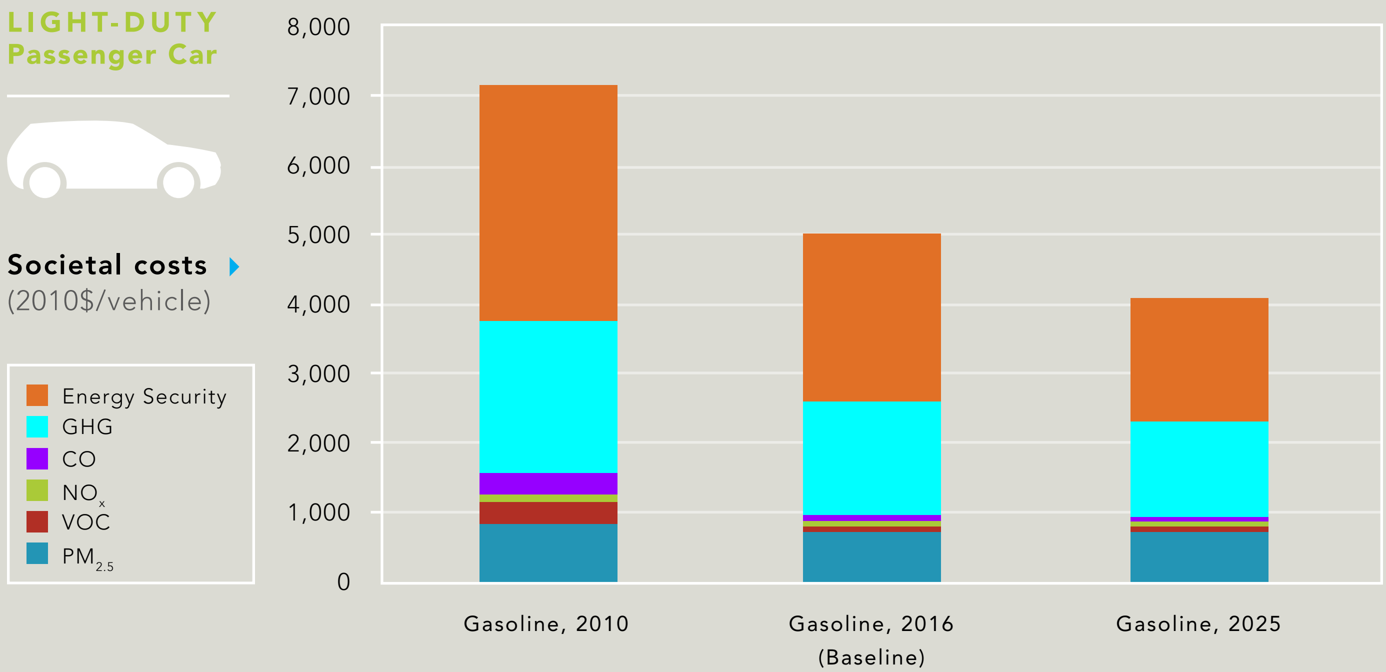
In general, the higher vehicle costs for advanced gasoline and diesel technologies necessary to meet future standards, GHG emissions standards in particular, will make alternatives relatively more favorable. From an societal costs perspective, more stringent emissions and fuel economy standards will lower the societal costs of conventional fuels, thus reducing the relative benefits of its alternatives. However, even with improvements in gasoline and diesel technology, the relative benefits of the alternative fuels are still expected to be largely retained.

Figure 4.1-1 shows examples of how societal costs for light- and heavy-duty vehicles change with improvements in conventional fuel technologies to meet future standards. For the gasoline passenger car, fuel economy improvements between 2010 and 2016, from 27.5 to 39.1 miles per gallon, decrease the societal costs of gasoline by $2,200 per vehicle. After 2016, to meet 2025 standards equivalent to fuel economy of 51.1 miles per gallon, the reduction in societal costs of gasoline is smaller at $850 per vehicle. For diesel line-haul tractors, technology improvements between 2010 and 2017 are expected to change societal costs by $3,300 per vehicle. These reductions in societal costs are significantly smaller than the benefits offered by most of the alternative fuels as presented earlier in Table 3.8-1, and furthermore, improvements in baseline technologies may transfer to alternative technologies and allow all benefits to scale accordingly. Therefore, improvements in baseline technologies will generally not eliminate the societal benefits of the alternatives.

The following sections compare the direct costs of alternative technologies to their conventional fuel baselines and relate these costs to their societal benefits. The direct costs are presented in terms of vehicle and lifetime fuel costs, the two primary components distinguishing alternative technologies from baseline technologies. A complete lifecycle cost of assessment of each vehicle technology would also include additional costs, such as maintenance and insurance, but for the purposes of this assessment, these additional costs are assumed to be equal across all fuels for a given vehicle segment and thus not used for comparison.

Figure 4.1-1

As gasoline and diesel technologies improve, the reductions in societal costs are significantly smaller than the societal benefits offered by alternatives such as CNG and LNG.



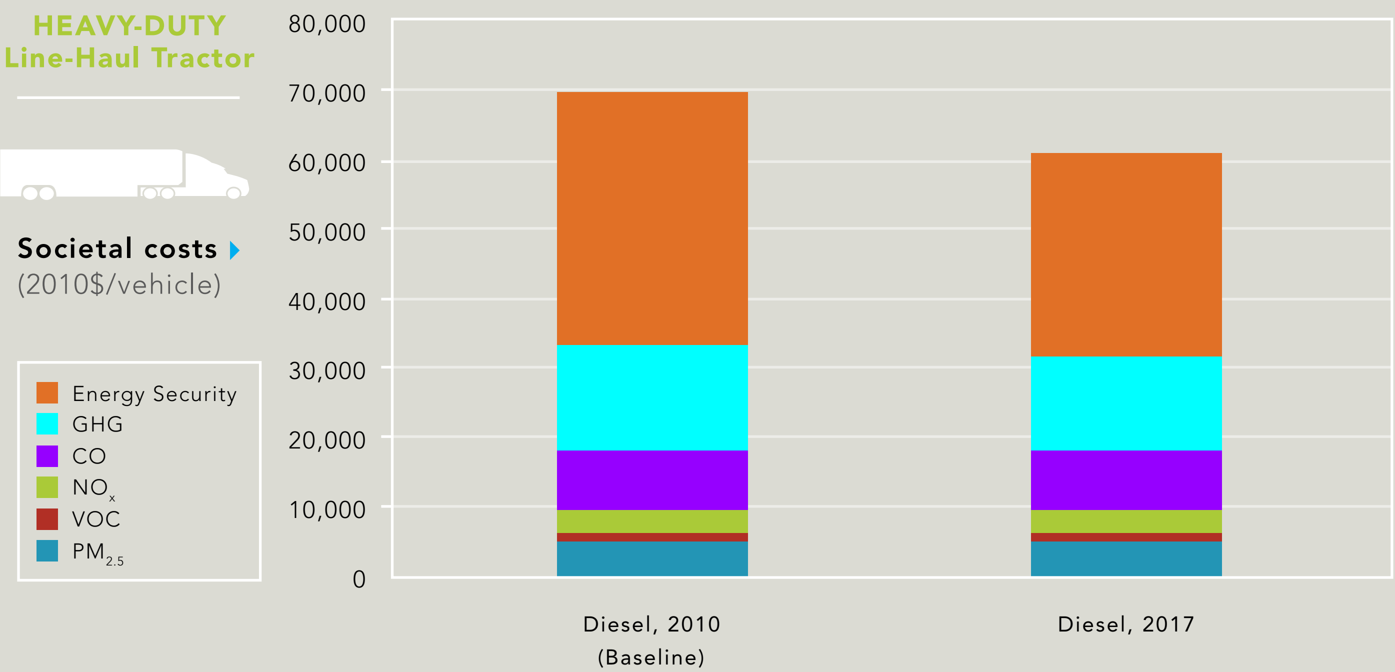
Assumptions:	
Annual mileage	13,900 mi
Vehicle lifetime	14 years
Fuel economy	
Gasoline, 2010	27.5 mi/gal
Gasoline, 2016	39.1 mi/gal
Gasoline, 2025	51.1 mi/gal

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) Gasoline and diesel from crude oil; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
3) Annual mileage and vehicle lifetime for light-duty passenger car derived from U.S. Department of Energy "Transportation Energy Data Book," Edition 29, 2010
4) Annual mileage for line-haul tractor is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
5) Vehicle lifetime for line-haul tractor is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

Figure 4.1-2

As gasoline and diesel technologies improve, the reductions in societal costs are significantly smaller than the societal benefits offered by alternatives such as CNG and LNG.



Assumptions:	
Annual mileage	120,000 mi
Vehicle lifetime	4 years
Fuel economy	
Diesel, 2010	6.4 mi/gal
Diesel, 2016	6.8 mi/gal

Notes:

1) Societal costs do not include premiums associated with dependence on foreign non-petroleum materials or societal costs other than those listed in the legend
2) Gasoline and diesel from crude oil; fuel pathways are derived from Argonne National Laboratory "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation," version 1.8c
3) Annual mileage and vehicle lifetime for light-duty passenger car derived from U.S. Department of Energy "Transportation Energy Data Book," Edition 29, 2010
4) Annual mileage for line-haul tractor is derived from U.S. Census Bureau "Vehicle Inventory and Use Survey," 2002
5) Vehicle lifetime for line-haul tractor is estimated in TIAX LLC "Market Segmentation," prepared for ANGA, December 2010
6) Fuel economy values are calculated based on the energy efficiency ratios found in the Conversion Factors section

4.2 Light-Duty Passenger Car

4.2.1 Compressed Natural Gas

The societal benefits achieved by switching from gasoline to CNG in passenger cars may exceed the incentives needed to make CNG economically attractive.

Based on U.S. Energy Information Administration (EIA) projections of gasoline and CNG prices, the fuel cost savings offered by CNG over the next 25 years are expected to be between $1.00 and $2.00 per gasoline gallon equivalent (GGE). The divergence of prices seen in Figure 4.2.1-1 can be attributed to increasing gasoline prices, driven by increasing global oil demand and decreasing global supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the passenger car and fuel over its lifetime is presented in Figure 4.2.1-2. The economics for both dedicated and bi-fuel CNG vehicles are shown. Within the expected fuel cost differential range (highlighted in white), dedicated CNG passenger cars will have lifetime costs ranging from $1,500 per vehicle more to $3,000 per vehicle less than gasoline cars; bi-fuel CNG cars will have lifetime costs $2,500 to $7,000 per vehicle less than gasoline cars. Bi-fuel vehicles will be less expensive than gasoline vehicles across the entire expected fuel cost differential range, and dedicated vehicles will be less expensive than gasoline vehicles for differentials greater than $1.40 per GGE. For differentials less than $1.40 per GGE, incentives may be needed to encourage dedicated CNG vehicle purchase. As established in Section 3.2, the societal benefits of dedicated and bi-fuel CNG vehicles are $3,100 and $2,600 per vehicle, respectively. Hence, the incentive needed to make CNG passenger cars economically attractive compared to gasoline passenger cars is less than the societal benefits that would be achieved by switching to CNG. As discussed in the Light-and Medium-Duty Vehicle Ownership and Production report of the overall TIAX assessment, because NGVs are a mature and proven technology that can offer the range demanded by private vehicle consumers, the support to make these vehicles economically attractive may be sufficient to enable the adoption of NGVs in the passenger car segment. In parallel or alternatively, incentive support may also be applied to establishing CNG infrastructure, ensuring convenience for NGV owners.

An important additional factor is the cost to the owner when the NGV is fueled at home using a home refueling appliance. The Light-and Medium-Duty Vehicle Ownership and Production and CNG Infrastructure reports of the overall TIAX assessment estimate that the purchase and installation of this appliance may cost between $2,000 and $5,000 per unit. The actual fueling of the vehicle requires electricity to operate the appliance, which may be approximately $0.10 to $0.50 per refueling.[34] Over the lifetime of the vehicle, the cost of home refueling may range from $2,500 to $7,700 per vehicle. If the refueling appliance is used for longer than the lifetime of a single vehicle, however, the cost of the appliance may be distributed over multiple vehicles. Furthermore, home refueling may offer significantly lower prices for the natural gas itself than retail stations because station capital and operating costs are not added to the price of the fuel.

34 Estimated from power consumption specifications by BRC FuelMaker, assuming electricity price of $0.10/kWh and 360 refueling events per year. BRC Fuel Maker, "USA Specifications," http://www.brcfuelmaker.it/ing/specificheUsa.asp, accessed November 2010.

Figure 4.2.1-1

CNG prices are expected to continue to diverge from gasoline prices over the next 25 years, giving fuel cost differentials between $1.00 and $2.00 per GGE.

Efficiency Adjusted Fuel Price
(Passenger Car)

Notes:

1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

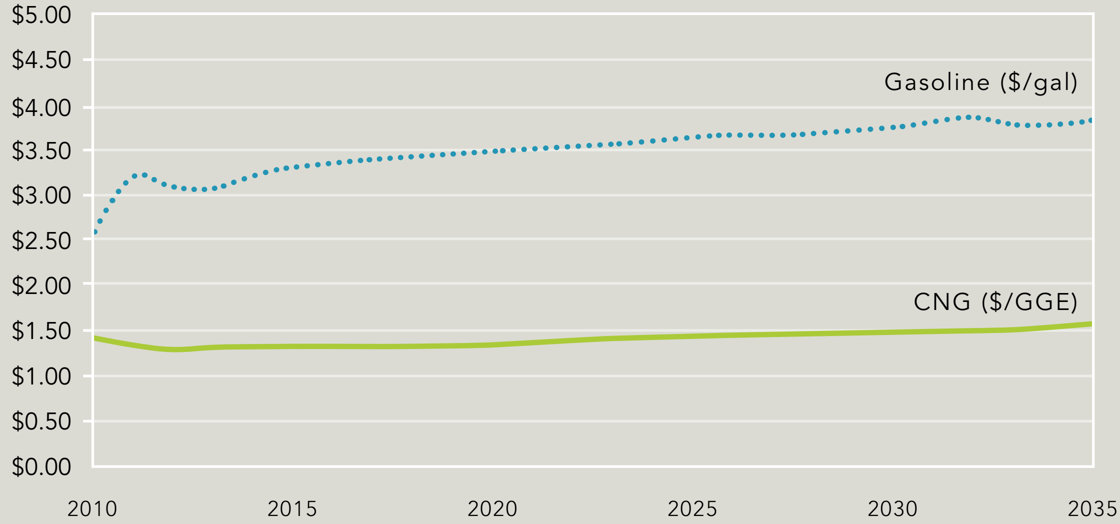
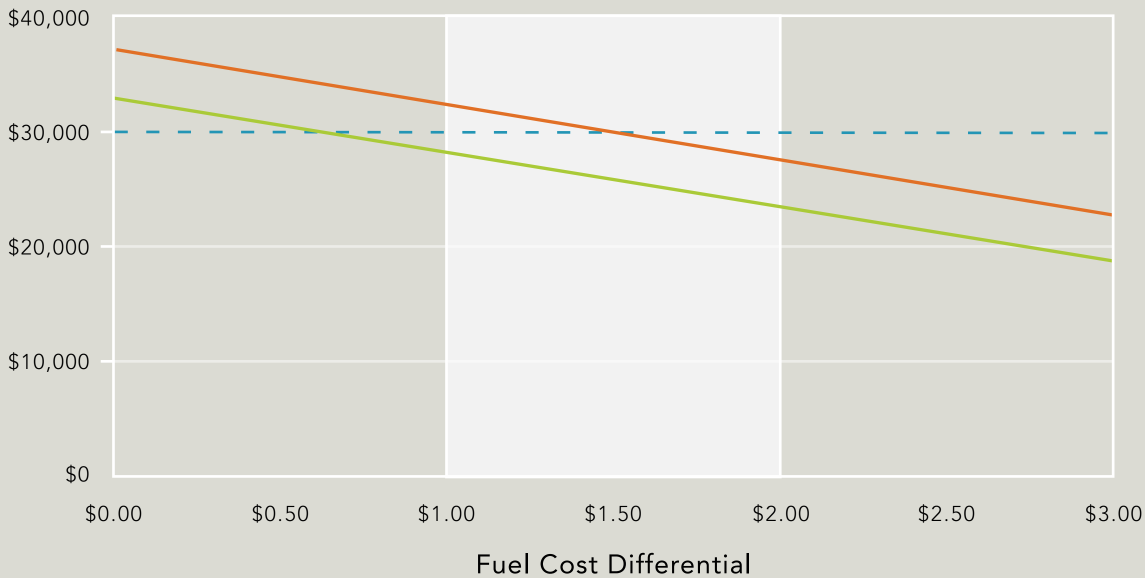


Figure 4.2.1-2

Within the expected fuel cost differential range, CNG passenger cars will have lifetime costs similar to or less than their gasoline counterparts, and justified incentives may be used to encourage vehicle purchase.

Vehicle and Lifetime Fuel Cost Comparison
(Passenger Car)



Assumptions:	
Baseline vehicle price[a]	$18,360
CNG vehicle price (dedicated)[a]	$25,295
CNG vehicle price (bi-fuel)[a]	$21,276
Annual mileage	13,900 mi
Baseline fuel economy	39.1 mi/gal
CNG fuel economy	40.3 mi/GGE
Vehicle lifetime	14 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of passenger cars, refer to Section 3.2.

[a] The CARLAB and TIAX LLC. "Light- and Medium-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.2 Light-Duty Passenger Car

4.2.2 Hydrogen Fuel Cell

The societal benefits achieved by switching from gasoline to hydrogen in passenger cars may exceed the incentives needed to make FCVs economically attractive, provided hydrogen and FCVs can be made available at the assumed prices.

Gasoline prices are based on EIA projections, and hydrogen prices are based on the U.S. Department of Energy (DOE) fuel price target of $3/GGE,[35] tracked to EIA-projected natural gas prices. Natural gas is used to project the trend for hydrogen since one of the primary methods of producing hydrogen is by reforming natural gas. From these projected prices, hydrogen is expected to cost $1.00 to $2.25 per GGE less than gasoline over the next 25 years (Figure 4.2.2 1). As gasoline prices increase due to increasing global oil demand and decreasing global oil supply, the fuel cost differential for hydrogen increases.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the passenger car and fuel over its lifetime is presented in Figure 4.2.2-2. Within the expected fuel cost differential range (highlighted in white), FCVs will have lifetime costs ranging from $1,000 per vehicle more to $1,500 per vehicle less than their gasoline counterparts. At the assumed hydrogen fuel prices and FCV production volumes, FCVs can compare favorably with gasoline vehicles, though incentives may be needed to encourage FCV purchase. As established in Section 3.2, the societal benefit of FCVs is $2,900 per vehicle. Hence, the incentive needed to make FCVs economically attractive compared to gasoline passenger cars is less than the societal benefits that would be achieved by switching to hydrogen. Consumer perception of FCVs is generally positive (discussed further in Section 4.2.4), and hydrogen may be a successful alternative to transportation fuel if the assumed fuel and vehicle prices can be attained.

35 Price projections tracked to natural gas projections (assuming natural gas reforming used to produce hydrogen) from EIA "Annual Energy Outlook 2012," June 2012.

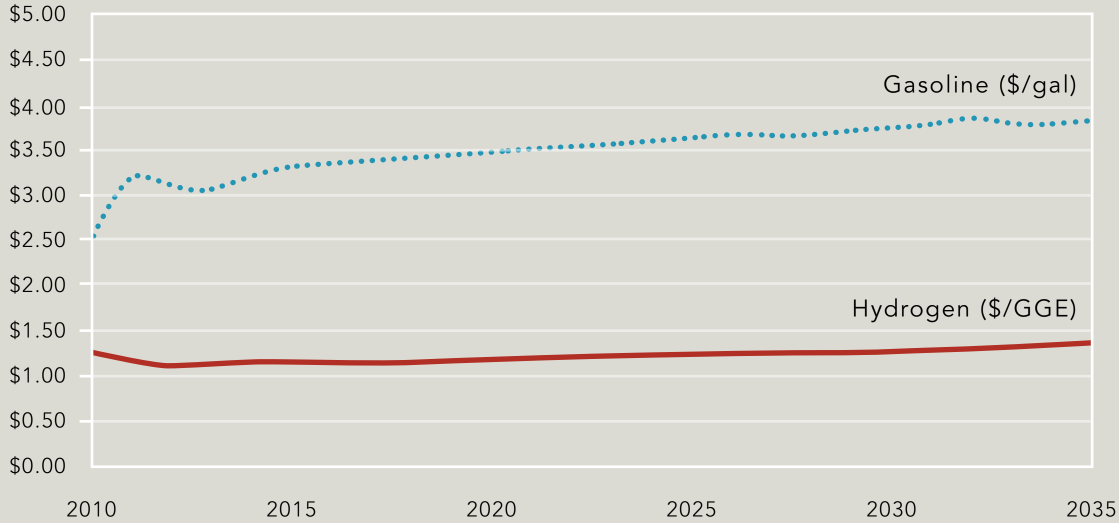
Figure 4.2.2-1

Hydrogen prices are expected to be $1.00 to $2.25 per GGE less than gasoline prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Passenger Car)

Notes:
1) Gasoline prices are derived from the reference case in U.S EIA "Annual Energy Outlook 2012," June 2012.
2) Hydrogen prices are based on DOE target of $3/GGE[36], tracked to natural gas prices from the reference case in U.S. EIA "Annual Energy Outlook2012," June 2012.
3) Fuel prices include federal and state taxes.



The incentives needed to make BEVs economically attractive compared to gasoline vehicles may be justified by their societal benefits, but the incentives needed for PHEVs may be much higher than their societal benefits.

Based on EIA projections of gasoline and transportation electricity prices, the fuel cost savings offered by electricity over the next 25 years are expected to be between $1.00 and $2.25 per GGE. The divergence of prices seen in Figure 4.2.3-1 can be attributed to increasing global demand for transportation fuel and stable domestic sources for electricity generation, including natural gas.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the passenger car and fuel over its lifetime is presented in Figure 4.2.3-2. The economics for both BEVs and PHEVs are shown. Within the expected fuel cost differential range (highlighted in white), BEVs will have lifetime costs ranging from $3,000 to $5,000 per vehicle more than their gasoline counterparts; PHEVs will have lifetime costs ranging from $10,500 to $15,000 per vehicle more than their gasoline counterparts. The higher lifetime costs for these electric vehicles (EVs) are attributable primarily to high vehicle costs (using the Chevrolet Volt and the Nissan Leaf as models).

It is important to note that these vehicles offer different driving ranges, which affect consumer purchase decisions beyond pure economics, and are therefore not directly comparable. These quantifications assume EV costs at current production volumes, and as volumes increase, these costs may change significantly.

Fuel costs are favorable for EVs, and thus any incentives granted to EVs should work primarily to encourage the initial vehicle purchase and/or establish charging infrastructure to support these vehicles. As established in Section 3.2, the societal benefits of BEVs range from $3,400 to $4,500 per vehicle, and the societal benefits of PHEVs range from $1,500 to $2,200 per vehicle. Thus, the incentives needed to make BEVs economically attractive may be justified by their societal benefits, but those needed for PHEVs may be much higher than their societal benefits. For EVs, an additional cost factor is home charging. Home chargers are estimated to cost $2,000 per charger, which will affect consumer purchase decisions and increase incentives needed to make EVs economically attractive.[37]

37 Nissan. "Nissan LEAF Electric Car." http://www.nissanusa.com/leaf-electric-car/faq/list/charging#/leaf-electric-car. Accessed November 2010.

Figure 4.2.3-1

Electricity prices are expected to be $1.00 to $2.25 per GGE less than gasoline prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Passenger Car)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012. Electricity prices are specifically for transportation.
2) Fuel prices include federal and state taxes.

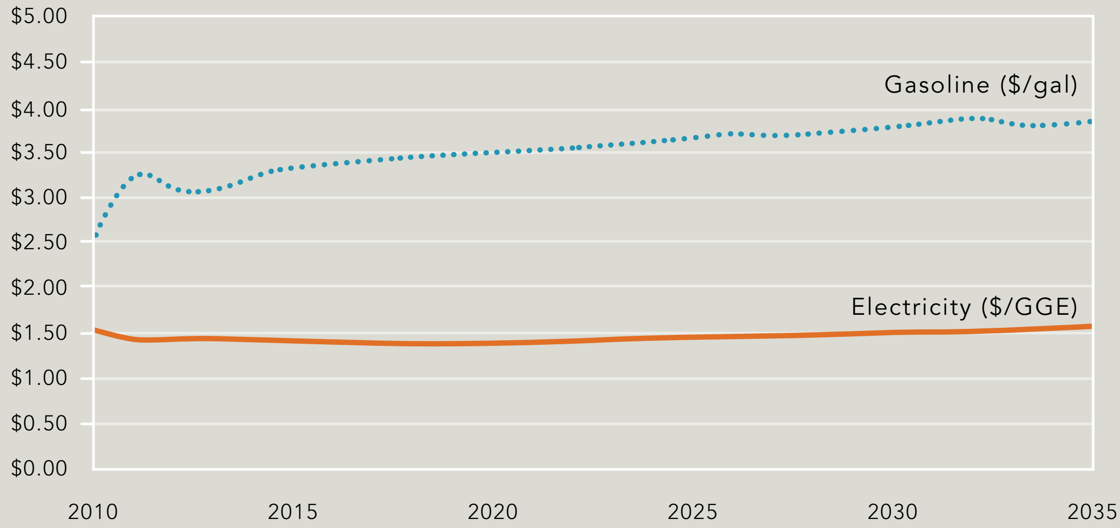
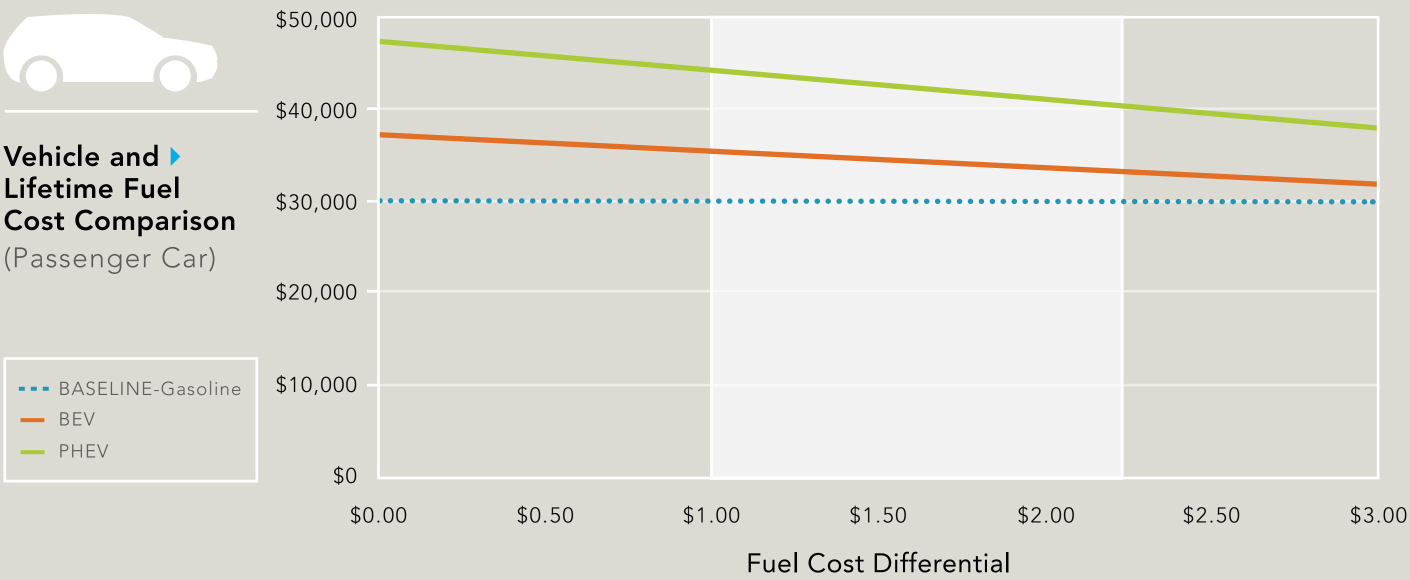


Figure 4.2.3-2

Within the expected fuel cost differential range, electric passenger cars will have lifetime costs $3,000 to $15,000 per vehicle more than their gasoline counterparts, incentives for which may or may not be justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison

(Passenger Car)



Assumptions:	
Baseline vehicle price[a]	$18,360
BEV vehicle price[b]	$32,780
PHEV vehicle price[c]	$40,280
Annual mileage	13,900 mi
Baseline fuel economy	39.1 mi/gal
BEV fuel economy	99 mi/GGE
PHEV fuel economy	60 mi/GGE
Vehicle lifetime	14 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of passenger cars, refer to Section 3.2.

[a] The CARLAB and TIAX LLC. "Light- and Medium-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.
[b] MSRP for Nissan Leaf from Nissan, "Nissan LEAF Electric Car," http://www.nissanusa.com/leaf-electric-car/faq/list/charging#/leaf-electric-car, accessed November 2010.
[c] MSRP for Chevrolet Volt from Chevrolet, "2011 Chevy Volt," http://www.chevrolet.com/volt, accessed November 2010.

4 Alternatives to Conventional Transportation Fuels

4.2 Light-Duty Passenger Car

4.2.4 Ethanol Flex-Fuel

No incentives may be needed to put E85 passenger cars on economic parity with gasoline counterparts, but incentives may be required to ensure the actual use of ethanol in FFVs.

Based on EIA projections of gasoline and E85 prices, the fuel cost savings offered by E85 over the next 25 years are expected to be on the order of $0.10 per GGE. Because E85 is primarily composed of gasoline and because ethanol prices, on an energy equivalent basis, are comparable to those of gasoline, the projected costs of the two fuels are expected to be very close (Figure 4.2.4-1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the passenger car and fuel over its lifetime is presented in Figure 4.2.4-2. Within the expected fuel cost differential range (highlighted in white), FFVs will have lifetime costs approximately $500 per vehicle less than their gasoline counterparts. As established in Section 3.2, the societal benefit of FFVs is $2,100 to $3,400 per vehicle, depending on whether the ethanol is produced from corn or cellulosic feedstocks. Because FFVs costs are identical to those of gasoline vehicles for purchasers, any incentives granted to FFVs should work primarily to encourage E85 use. FFVs produced today are not motivated by customer demand; they are primarily produced to allow vehicle manufacturers to earn Corporate Average Fuel Economy (CAFE) credits. As a result, not all vehicle purchasers are aware that their vehicles can operate on E85 and those who do may not choose to do so, especially if E85 stations are not readily available. Any incentives justified by the societal benefits of adopting E85 must ensure that ethanol is actually used in the vehicles.

Figure 4.2.4-1

E85 prices are expected to be slightly less than gasoline prices over the next 25 years.

Efficiency Adjusted Fuel Price
(Passenger Car)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

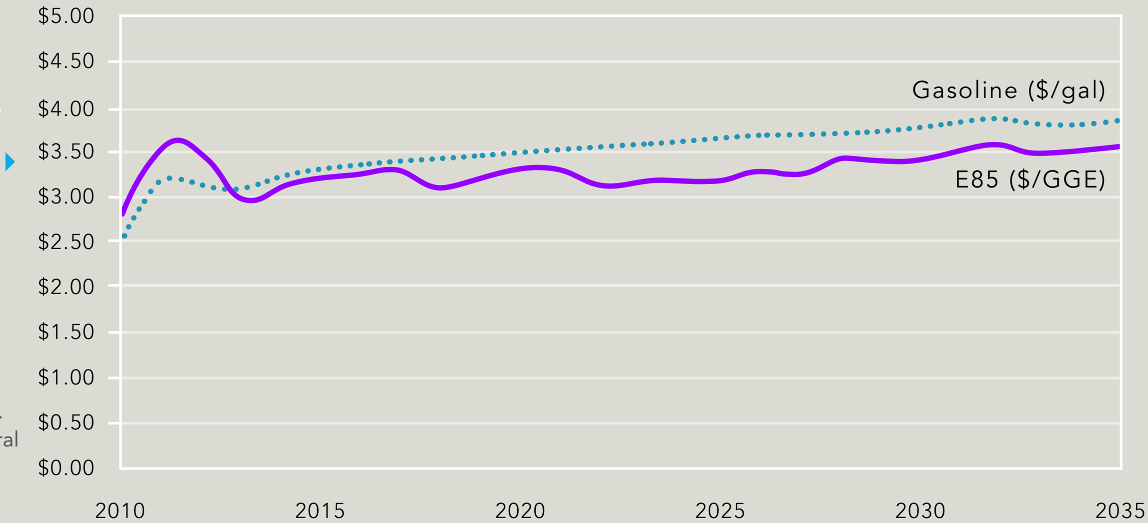
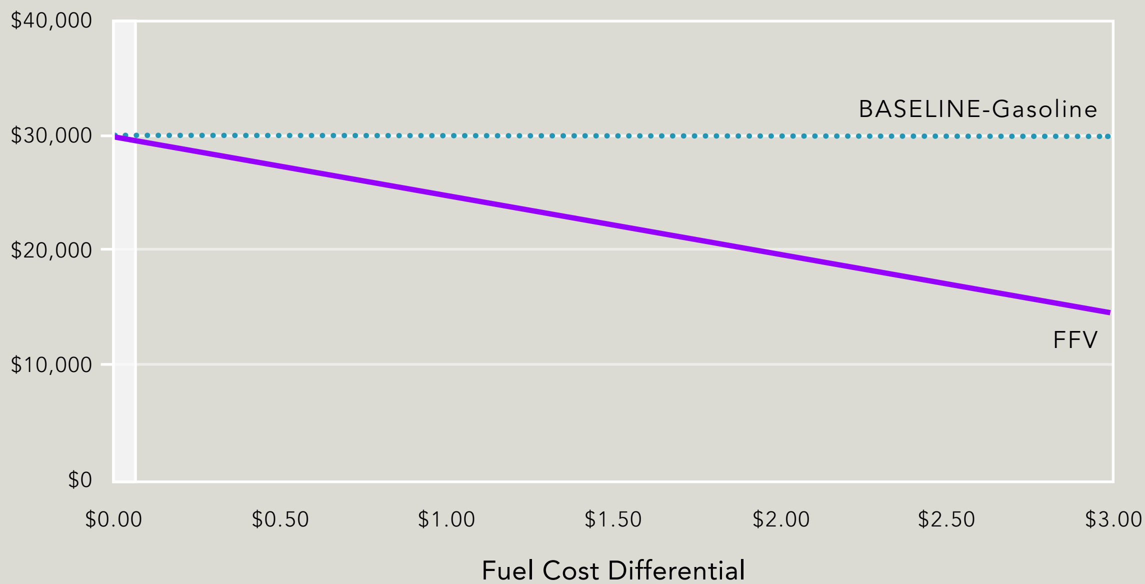


Figure 4.2.4-2

Within the expected fuel cost differential range, FFVs will have lifetime costs slightly less than their gasoline counterparts, though incentives may be needed to encourage ethanol use.

Vehicle and Lifetime Fuel Cost Comparison
(Passenger Car)



Assumptions:	
Baseline vehicle price[a]	$18,360
FFV vehicle price	$18,360
Annual mileage	13,900 mi
Baseline fuel economy	39.1 mi/gal
FFV fuel economy	40.3 mi/GGE
Vehicle lifetime	14 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of passenger cars, refer to Section 3.2.

[a] The CARLAB and TIAX LLC. "Light- and Medium-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.2 Light-Duty Passenger Car
4.2.5 Implementation Considerations
4.2.5.1 Consumer Perceptions

Consumer interest in light-duty alternative fuel vehicles (AFVs), particularly for hybrid vehicles, hydrogen FCVs, and NGVs, is growing.

Familiarity with AFV technologies among North American consumers has been growing in the last decade,[38] and the top three alternative fuel technologies in which U.S. new-vehicle shoppers are "definitely interested" are hybrid vehicles (40 percent of shoppers), hydrogen FCVs (39 percent of shoppers), and NGVs (30 percent of shoppers) (Figure 4.2.5.1-1).[39] It should be noted that hybrid vehicles are fundamentally a fuel economy improvement rather than an alternative fuel technology.

At the same time, consumer willingness to pay extra for more environmentally friendly vehicles is growing, with consumers stating on average that they are willing to spend $2,600 more for cleaner vehicles (Table 4.2.5.1-1).[40] In addition to concern about environmental impacts, purchasers of light-duty vehicles are also motivated by fuel prices. While Canadians may be more likely than Americans to be seeking to reduce their GHG emissions (28 percent of Canadian respondents vs. 23 percent of American respondents), Americans may be more likely to be seeking ways to minimize fuel costs (58 percent of Canadians vs. 64 percent of Americans).[41] For technologies not in the top three for consumer interest, consumers are less unfamiliar with or have specific concerns about the technologies. Just 16 percent of Canadians and 26 percent of Americans are familiar with E85 technology.[42] 70 percent of consumers expect an EV to travel 300 miles before they would consider purchasing one and express some anxiety about the availability and capacity of infrastructure to support EVs.[43]

In general, nearly 75 percent of mass market consumers wish there were more AFVs to choose from[44] and expect much more from government in developing or sponsoring alternative fuel technologies than is being delivered.[45] Consumers are primarily deterred from AFVs by high vehicle costs, with perceived driving range limitations being the second most claimed reason for not choosing AFVs.[46] For EVs, unknowns about the residual value of the vehicles and their batteries present uncertainty for potential customers in the vehicle purchase decision.

---

38 Synovate Motoresearch. "Study on Consumers' Attitudes Toward Advanced Propulsion and Alternative Fuels." Advanced Propulsion & Fuels Syndicated Study. December 2006/January 2007.
39 Kelley Blue Book. "All-New Eco Watch Study from Kelley Blue Book Marketing Research Tracks, Trends Shoppers' Opinions." http://mediaroom.kbb.com/all-new-eco-watch-study-kelley-blue-book-marketing-research-tracks-trends-shoppers-opinions. September 22, 2008.
40 Ibid.
41 Synovate Motoresearch. "Synovate Survey Shows Canadian New Car Buyers More Electric than American Car Buyers." http://www.synovate.com/news/article/2010/08/synovate-survey-shows-canadian-new-car-buyers-more-electric-than-american-car-buyers.html. August 17, 2010.
42 Ibid.
43 Giffi, C., R. Hill, R. Ranich. "Electric Cars: Implications for the Automotive Industry and Beyond." Deloitte Development LLC. May 13, 2010.
44 Kelley Blue Book, 2008.
45 Synovate Motoresearch, 2006/2007.
46 Convenience Store News. "Study Shows Awareness, Use of Alternative Fuel Remains Low." http://www.allbusiness.com/retail-trade/food-stores/4489359-1.html. June 6, 2006.

Figure 4.2.5.1-1

The top three alternative fuel technologies in which new car shoppers expressed greatest interest are hybrid vehicles, hydrogen FCVs, and CNG vehicles.[47]

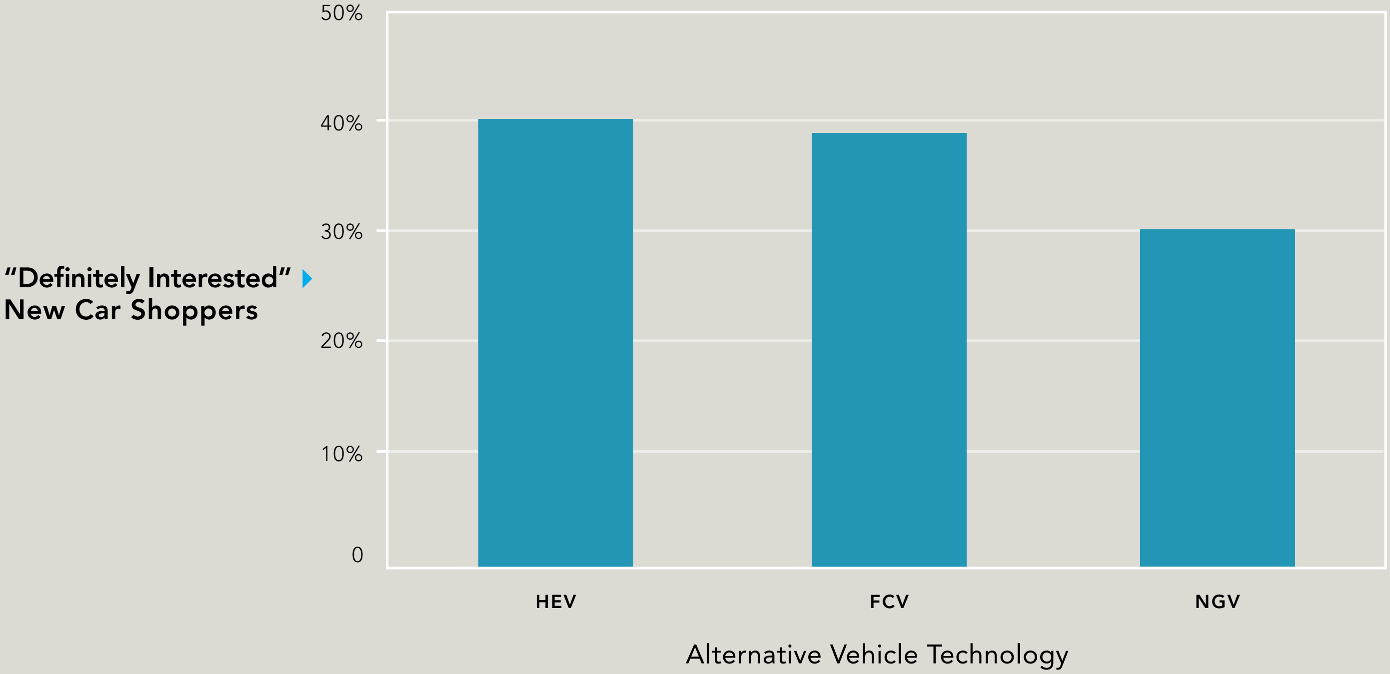


Table 4.2.5.1-1

Consumers reported willingness-to-pay for more environmentally friendly vehicles has generally been increasing,[48,49] which may be correlated with gasoline prices.

Survey Year	Median Price Consumer Willing to Pay ($)
June 2004	1,000
March 2005	1,000
December 2005	1,100
May 2006	1,000
January 2007	2,000
September 2008	2,600*

*Consumer willingness to spend reported as average price

47 Kelley Blue Book. "All-New Eco Watch Study from Kelley Blue Book Marketing Research Tracks, Trends Shoppers' Opinions." http://mediaroom.kbb.com/all-new-eco-watch-study-kelley-blue-book-marketing-research-tracks-trends-shoppers-opinions. September 22, 2008.
48 Synovate Motoresearch. "Study on Consumers' Attitudes Toward Advanced Propulsion and Alternative Fuels." Advanced Propulsion & Fuels Syndicated Study. December 2006/January 2007.
49 Kelley Blue Book, 2008.

4.2.5.2 Infrastructure

The availability of public fueling infrastructure will influence light-duty consumer acceptance of alternative fuels. CNG and electricity are unique in that home refueling is also possible.

Infrastructure to support alternative fuels is expanding in North America but currently represents a fraction of the infrastructure available for gasoline (Table 4.2.5.2-1). There are approximately 118,756 gasoline retail stations in the U.S.,[50] and alternative fuel stations combined represent 14 percent of this number.[51] E85, CNG, electricity, and hydrogen have an estimated 2,544; 1,091; 12,542; and 54 stations in the U.S., respectively.[52] Over the next decade, ethanol use will continue to increase as a result of the U.S. Renewable Fuel Standard (RFS) that mandates increasing quantities of biofuels, though ethanol will most likely first be blended into gasoline before being sold as E85. Use of CNG, hydrogen, and possibly electricity may also be positively impacted by the RFS if they incorporate biomass-based feedstocks. Meanwhile, consumer acceptance of each alternative to transportation fuel will be heavily influenced by the availability of its public stations. CNG and electricity is unique among these alternatives in that home refueling is also possible. For EVs, the grid's ability to handle simultaneous charging of many vehicles may be a concern, one that electric utilities are currently addressing.

Table 4.2.5.2-1

Infrastructure to support alternative fuels is expanding in North America.

Fuel	Number of U.S. Stations[53,54]
Gasoline	118,756
CNG	1,091
E85	2,544
Electricity	12,542
Hydrogen	54

50 U.S. Census Bureau. "Economic Census." 2007.
51 Note that the majority of these alternative fuel stations are electric chargers, and the Alternative Fuels and Advanced Vehicles Data Center counts each outlet as a station.
52 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.55 U.S. Census Bureau. "Economic Census." 2007.
53 U.S. Census Bureau. "Economic Census." 2007.
54 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.

4 Alternatives to Conventional Transportation Fuels

4.3 Medium-Duty Class 2b Van

4.3.1 Compressed Natural Gas

Little to no incentives may be needed to put medium-duty CNG vans on economic parity with gasoline counterparts, and applying the $7,800 per vehicle societal benefit of this alternative as a vehicle purchase or station establishment incentive may accelerate their adoption.

Based on EIA projections of gasoline and CNG prices, the fuel cost savings offered by CNG over the next 25 years are expected to be between $1.00 and $2.00 per GGE. Again, the divergence of prices seen in Figure 4.3.1-1 can be attributed to increasing gasoline prices, driven by increasing global oil demand and decreasing global oil supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the medium-duty van and fuel over its lifetime is presented in Figure 4.3.1-2. Within the expected fuel cost differential range (highlighted in white), CNG vans will have lifetime costs ranging from $500 per vehicle more to $13,000 per vehicle less than their gasoline counterparts. Because their lifetime costs are close to or significantly more favorable than those of gasoline vehicles, incentives for NGVs should work primarily to encourage the initial vehicle purchase, rather than help offset their direct economics for the vehicle owners, which are already favorable. In parallel or alternatively, incentives may be applied to establishing CNG infrastructure, either to support large fleets in the building of their own stations or expand the public fueling network, which may benefit more vehicles than private fleet stations. As established in Section 3.3, the societal benefit of natural gas vans is $7,800 per vehicle. As with passenger cars, because NGVs are a mature and proven technology, applying this benefit in the form of incentives for CNG may accelerate the adoption of natural gas in this vehicle segment.

Figure 4.3.1-1

CNG prices are expected to continue to diverge from gasoline prices over the next 25 years, giving fuel cost differentials between $1.00 and $2.00 per GGE.

Efficiency Adjusted Fuel Price
(Class 2b Van)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

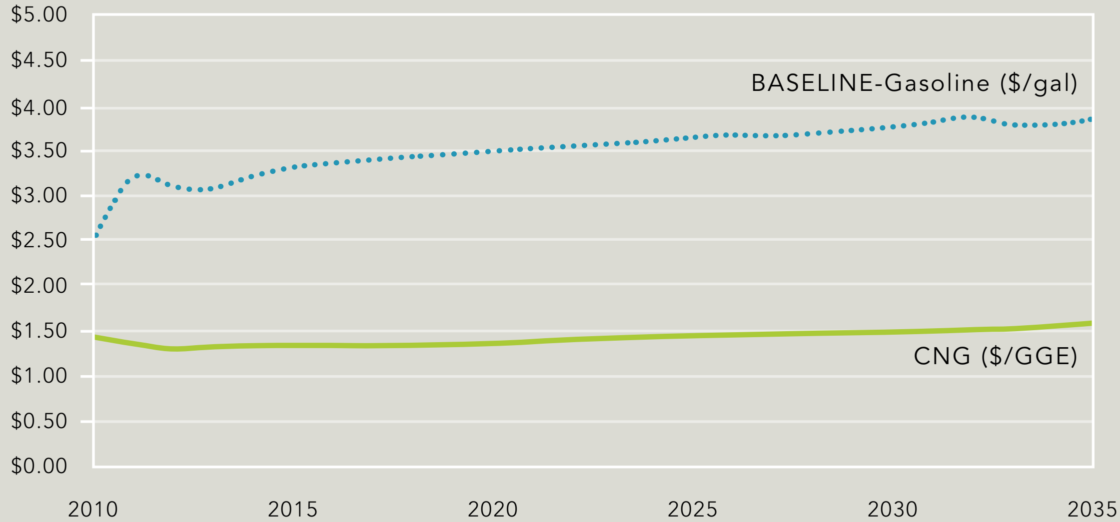
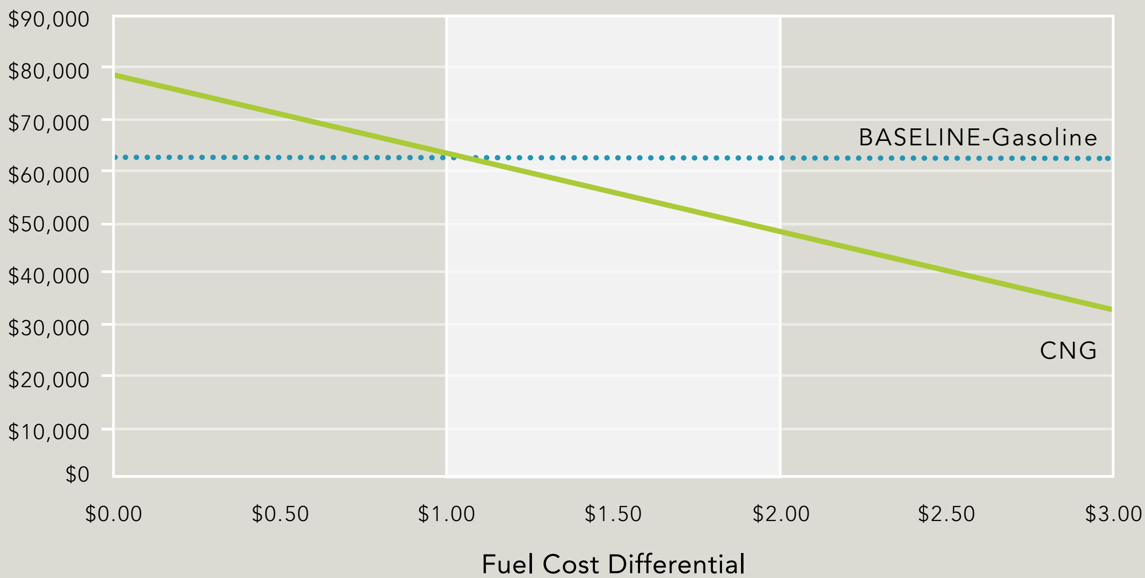


Figure 4.3.1-2

Within the expected fuel cost differential range, medium-duty CNG vans will have lifetime costs similar to or significantly less than their gasoline counterparts, and incentives may accelerate natural gas adoption.

Vehicle and Lifetime Fuel Cost Comparison
(Class 2b Van)



Assumptions:	
Baseline vehicle price[a]	$27,000
CNG vehicle price[b]	$43,150
Annual mileage	13,750 mi
Baseline fuel economy	14.0 mi/gal
CNG fuel economy	14.0 mi/GGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 2b Vans, refer to Section 3.3.

[a] Based on values from Kelley Blue Book "2010 GMC Savana 2500 Cargo Van," http://www.kbb.com/new-cars/gmc/savana-2500-cargo/2010/pricing-report, 2010.
[b] The CARLAB and TIAX LLC. "Light- and Medium-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4 Alternatives to Conventional Transportation Fuels

4.3 Medium-Duty Class 2b Van

4.3.2 Diesel

The incentives needed to make medium-duty diesel vans economically comparable to gasoline vans may be significantly higher than their societal benefits.

Based on EIA projections of gasoline and diesel prices, the fuel cost savings offered by diesel over the next 25 years are expected to be between $0.10 and $0.25 per GGE. Because both fuels are derived from petroleum, their prices are projected to follow the same increasing trend, attributable to increasing global oil demand and decreasing global oil supply (Figure 4.3.2-1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the medium-duty van and fuel over its lifetime is presented in Figure 4.3.2-2. Within the expected fuel cost differential range (highlighted in white), diesel vans will have lifetime costs between $3,500 and $5,500 per vehicle higher than their gasoline counterparts. Thus, in order for diesel vans to offer the same economics, incentives matching these incremental costs are needed. However, as established in Section 3.3, the medium-duty diesel vans provide a societal benefit of $1,400 per vehicle, which is less than the incentive needed to make diesel vans economically attractive. As such, incentives to encourage adoption of diesel vans may not be fully justified by their societal costs relative to gasoline vans.

Figure 4.3.2-1

Diesel prices are expected to track with gasoline prices over the next 25 years, giving fuel cost differentials between $0.10 and $0.25 per GGE.

Efficiency Adjusted Fuel Price
(Class 2b Van)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

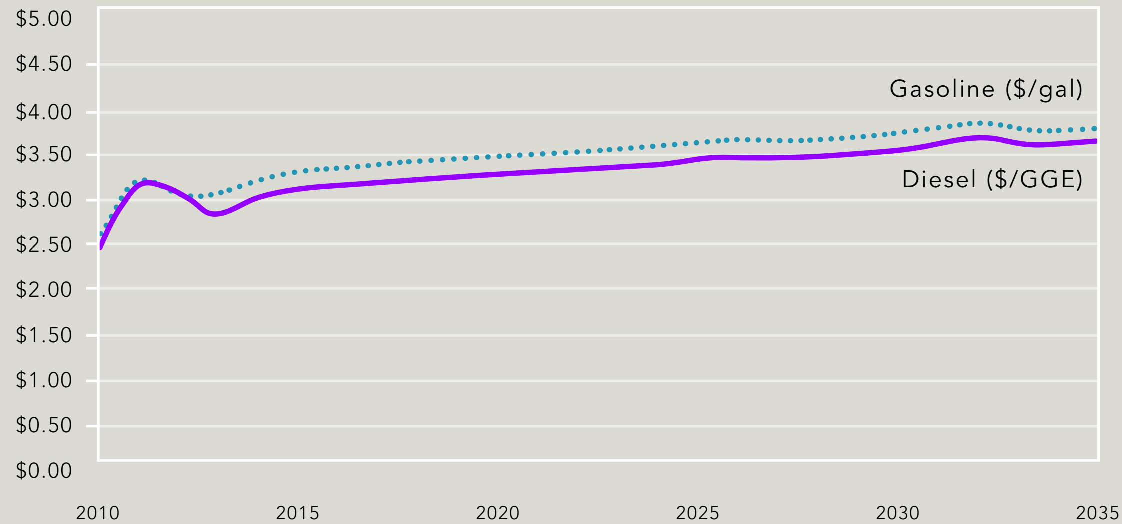
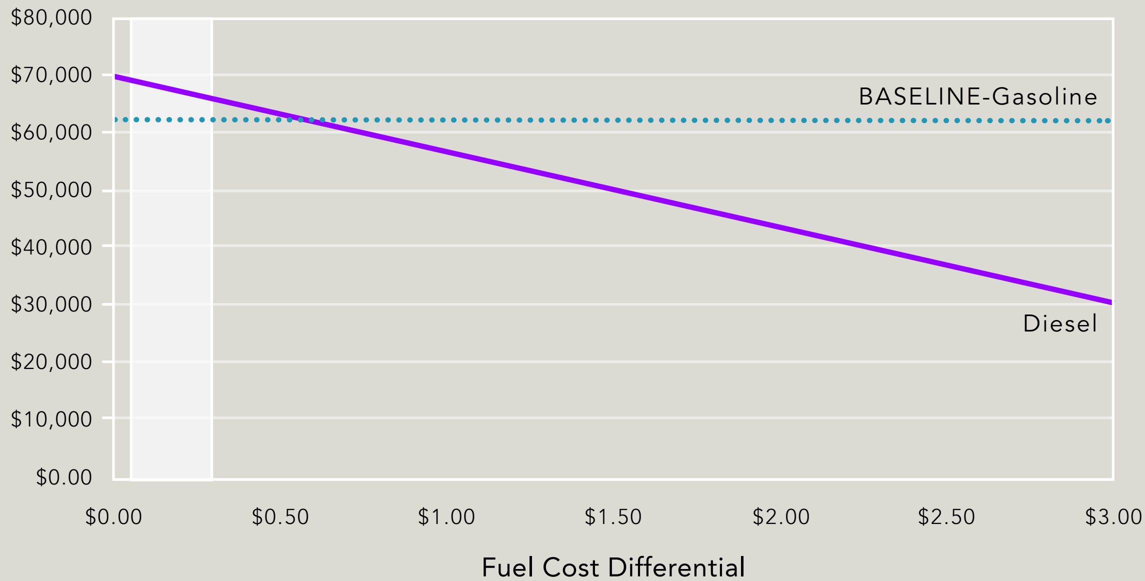


Figure 4.3.2-2

Within the expected fuel cost differential range, medium-duty diesel vans will have lifetime costs $3,500 to $5,500 per vehicle higher than their gasoline counterparts, and incentives may not be fully justified by societal benefits.

Vehicle and Lifetime Fuel Cost Comparison
(Class 2b Van)



Assumptions:	
Baseline vehicle price[a]	$27,000
Diesel vehicle price[a]	$39,000
Annual mileage	13,750 mi
Baseline fuel economy	14.0 mi/gal
Diesel fuel economy	16.1 mi/GGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 2b Vans, refer to Section 3.3.

[a] Based on values from Kelley Blue Book "2010 GMC Savana 2500 Cargo Van," http://www.kbb.com/new-cars/gmc/savana-2500-cargo/2010/pricing-report, 2010.

4.3 Medium-Duty Class 2b Van

4.3.3 Biodiesel

The societal benefits achieved by switching from gasoline to biodiesel in medium-duty Class 2b vans may be less than the incentive needed to make biodiesel vans economically attractive.

Based on EIA projections of gasoline prices and biodiesel prices tracked to EIA diesel projections,[55] the fuel cost savings offered by biodiesel over the next 25 years are expected to be between $0 and $0.10 per GGE. Both gasoline and diesel, the primary blend component of B20, are derived from petroleum, and their prices are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.3.3-1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the medium-duty van and fuel over its lifetime is presented in Figure 4.3.3-2. Within the expected fuel cost differential range (highlighted in white), biodiesel vans will have lifetime costs between $5,500 and $7,500 per vehicle more than their gasoline counterparts. Again, in order for biodiesel vans to offer the same economics, incentives matching these incremental costs are needed. However, as established in Section 3.3, the societal benefit of medium-duty biodiesel vans is $2,500 per vehicle. Hence, the incentive needed to make biodiesel vans economically attractive compared to gasoline vans may be more than the societal benefits that would be achieved by switching to B20. However, the societal benefits previously calculated assume a soybean oil feedstock is used to produce the biodiesel; other feedstocks, such as yellow grease, will result in greater societal benefits that can justify incentives needed to make economics favorable for biodiesel vans.

55 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities "Alternative Fuel Price Report," 2010 tracked to diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

Figure 4.3.3-1

Biodiesel prices are expected to track with gasoline prices over the next 25 years, giving fuel cost differentials between $0 and $0.10 per GGE.

Efficiency Adjusted Fuel Price

Notes:
1) Gasoline prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[56] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes.

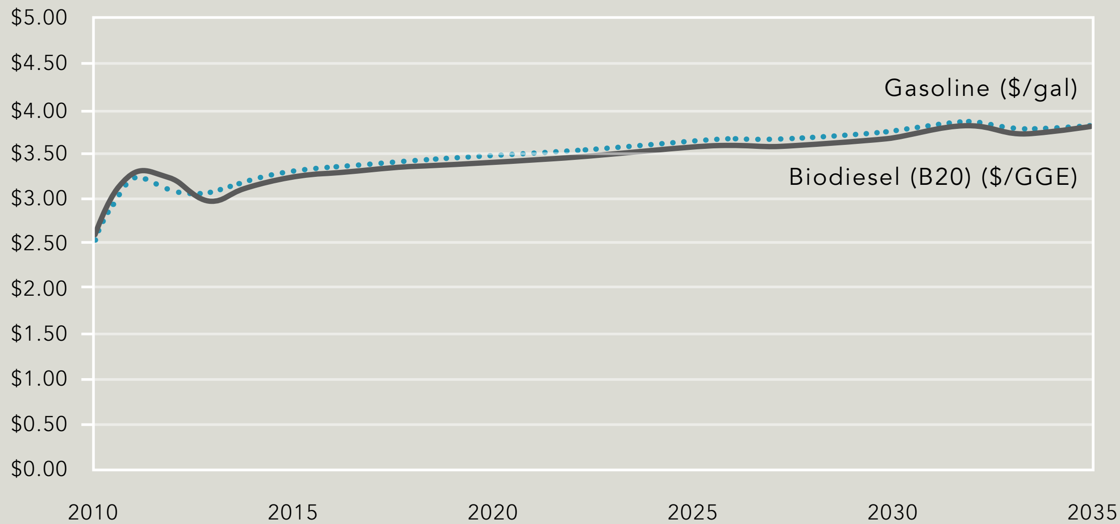
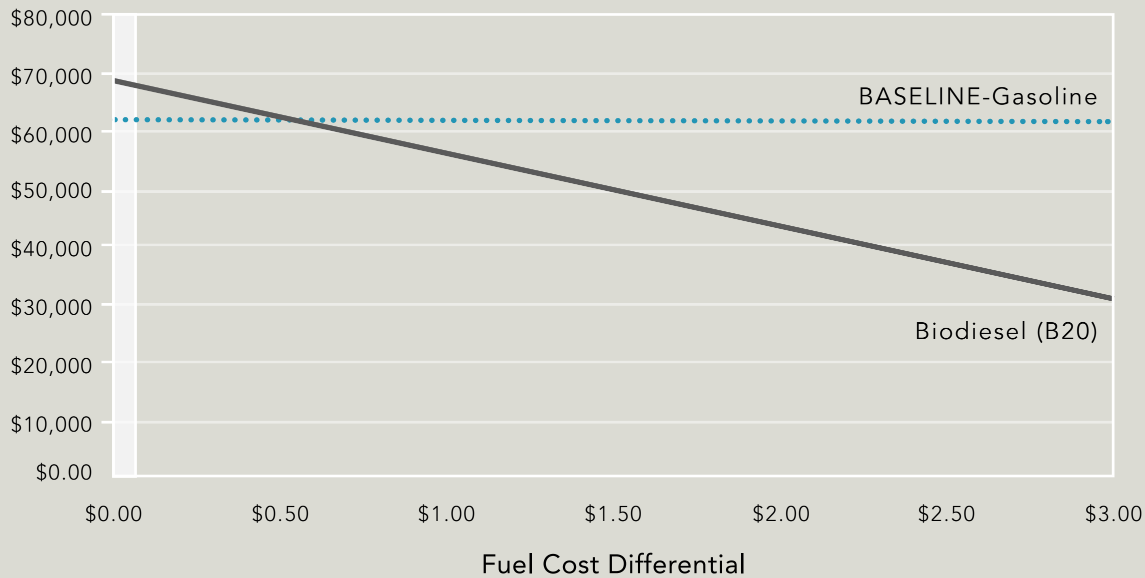


Figure 4.3.3-2

Within the expected fuel cost differential range, medium-duty biodiesel vans will have lifetime costs $5,500 to $7,500 per vehicle higher than their gasoline counterparts, and needed incentives may not be fully justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison (Class 2b Van)



Assumptions:	
Baseline vehicle price[a]	$27,000
B20 vehicle price[a]	$39,000
Annual mileage	13,750 mi
Baseline fuel economy	14.0 mi/gal
B20 fuel economy	16.1 mi/GGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 2b Vans, refer to Section 3.3.

[a] Based on values from Kelley Blue Book "2010 GMC Savana 2500 Cargo Van," http://www.kbb.com/new-cars/gmc/savana-2500-cargo/2010/pricing-report, 2010.

56 Clean Cities. "Alternative Fuel Price Reports." 2010.

4.3 Medium-Duty Class 2b Van

4.3.4 Electricity

The societal benefits achieved by switching from gasoline to electricity in medium-duty Class 2b vans may be significantly greater than the incentive needed to make electric vans economically attractive.

Based on EIA projections of gasoline and transportation electricity prices, the fuel cost savings offered by electricity over the next 25 years are expected to be between $1.00 and $2.25 per GGE. The divergence of prices seen in Figure 4.3.4-1 can be attributed to increasing global demand for transportation fuel and stable domestic sources for electricity generation, including natural gas.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the medium-duty van and fuel over its lifetime is presented in Figure 4.3.4-2. Within the expected fuel cost differential range (highlighted in white), electric vans will have lifetime costs ranging from $1,800 per vehicle more to $4,100 per vehicle less than their gasoline counterparts. As discussed in Section 3.3, the societal benefit of medium-duty electric vans is $16,000 to $17,000 per vehicle. Hence, the incentive needed to make electric vans economically attractive compared to gasoline vans may be significantly less than the societal benefits that would be achieved by switching to electricity. This incentive may be applied to offsetting the initial vehicle costs or establishing infrastructure to serve public and/or fleet-specific charging needs. It is important to note that these economics are assessed without consideration of the operational needs of the user. For example, the Ford Transit Connect Electric, which is the basis of this economic analysis, has a range of 80 miles and requires six to eight hours per charge.[57] If these characteristics are unacceptable to the purchaser, favorable economics will likely not be sufficient for the purchaser to choose the electric van.

57 Crain's Detroit Business. "Azure Dynamics, Ford Begin Shipping Transit Connect Electric Vans." http://www.crainsdetroit.com/article/20101207/FREE/101209879/azure-dynamics-ford-begin-shipping-transit-connect-electric-vans#. Accessed December 2010.

Figure 4.3.4-1

Electricity prices are expected to be $1.00 to $2.25 per GGE less than gasoline prices over the next 25 years.

Efficiency Adjusted Fuel Price

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012. Electricity prices are specifically for transportation.
2) Fuel prices include federal and state taxes.

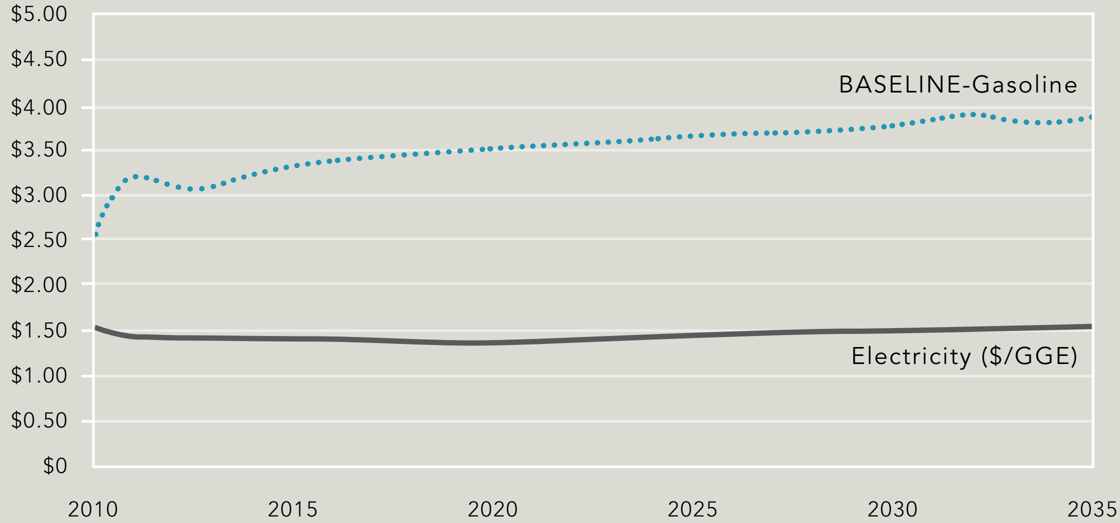
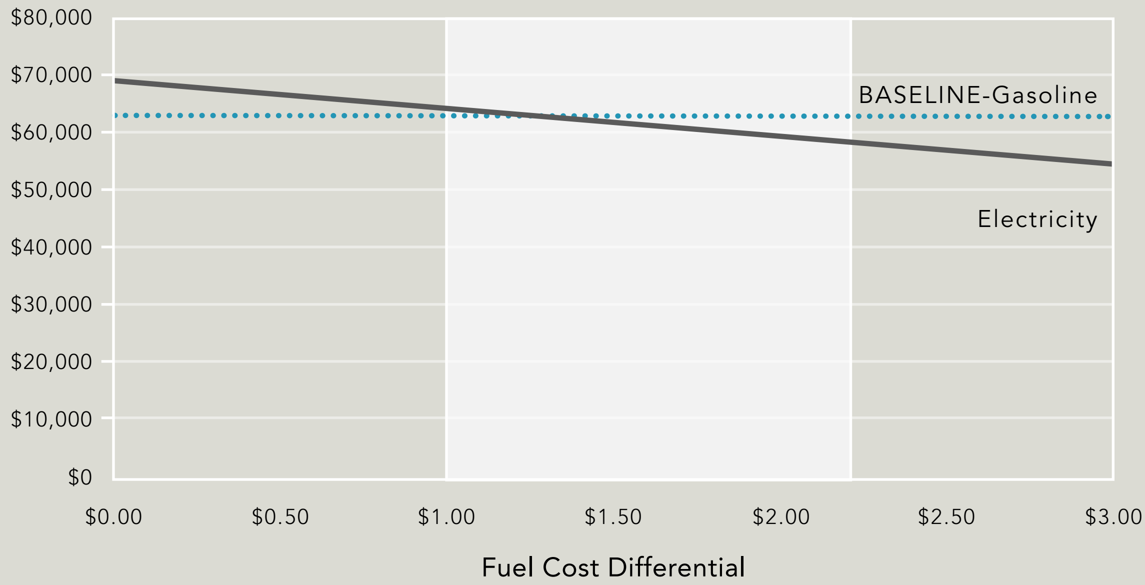


Figure 4.3.4-2

Within the expected fuel cost differential range, medium-duty electric vans will have lifetime costs ranging from $1,800 per vehicle more to $4,100 per vehicle less than their gasoline counterparts, and needed incentives may be fully justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison (Class 2b Van)



Assumptions:	
Baseline vehicle price[a]	$27,000
Electric vehicle price[b]	$57,400
Annual mileage	13,700 mi
Baseline fuel economy	14.0 mi/gal
Electric fuel economy	42.1 mi/GGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 2b Vans, refer to Section 3.3.

[a] Based on values from Kelley Blue Book "2010 GMC Savana 2500 Cargo Van," http://www.kbb.com/new-cars/gmc/savana-2500-cargo/2010/pricing-report, 2010.
[b] Crain's Detroit Business. "Azure Dynamics, Ford Begin Shipping Transit Connect Electric Vans." http://www.crainsdetroit.com/article/20101207/FREE/101209879/azure-dynamics-ford-begin-shipping-transit-connect-electric-vans#. Accessed December 2010.

4.3 Medium-Duty Class 2b Van

4.3.5 Implementation Considerations

Due to increasingly stringent emissions standards, alternatives to transportation fuel are gaining consumer attention in the medium-duty vehicle sector.

Until recently, diesel was well-known among consumers in the medium-duty vehicle sector as the most economical and efficient fuel choice. However, with increasingly stringent federal emissions standards in the U.S., the cost of compliance for diesel technologies has risen, making gasoline a potentially attractive alternative going forward. Diesel, with its newly mandated emissions control devices, is still the most familiar alternative for consumers, although its higher costs may lead consumers to consider biodiesel and CNG (Table 4.3.5-1). Biodiesel is gaining popularity, though at higher blend concentrations, it may exhibit sensitivity to temperature, potentially becoming viscous and causing clogging issues in cold weather. Quality-controlled biodiesel is gaining acceptance among manufacturers, with a growing number of manufacturers accepting B20 blends.[58] As indicated in the Light- and Medium-Duty Vehicle Ownership and Production report in the collection of reports for this TIAX assessment, CNG does not currently appear to suffer from a fossil fuel association with oil among U.S. consumers and is a mature technology that has been proven over the last several decades. Examples of its successful use to date in medium-duty vehicles and expanded original equipment manufacturer NGV options, including the GMC Savana and the Chevrolet Express, will help persuade greater adoption.

In terms of infrastructure availability, diesel has more stations than other alternatives to the baseline fuel by virtue of having historically been the baseline fuel. Compared to gasoline's 118,756 stations in the U.S.,[59] diesel has approximately 32,000 stations total, including both public retail stations (truck stops) and private fleet fueling facilities.[60] The infrastructure for biodiesel, CNG, and electricity are less developed but growing, with 679, 1,091, and 12,542 stations in the U.S., respectively.[61] As with ethanol in light-duty vehicles, RFS targets for biofuels will primarily result in an increasing supply of biodiesel in the U.S. but may also positively impact CNG as well, if natural gas is derived from digester or landfill gas (LFG). Medium-duty vehicles, largely used by commercial fleets, are driven by economics. Large fleets may build their own fueling stations while small fleets rely on publicly accessible retail stations. In the former case, infrastructure to support alternatives to conventional fuel may grow directly with vehicle population, but in the latter case, the transition to alternative technologies depends on the availability of existing infrastructure.

58 McCormick, R.L., T. Alleman, A. Williams, Y. Coy, A. Hudgins, W. Dafoe. "Status and Issues for Biodiesel in the United States." National Renewable Energy Laboratory. October 2009.
59 U.S. Census Bureau. "Economic Census." 2007.
60 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
61 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.

Table 4.3.5-1

Due to increasingly stringent emissions standards, biodiesel and CNG are gaining consumer attention in the medium-duty vehicle sector and will be increasingly attractive as infrastructure expands.

Vehicle Technology	Number of U.S. Stations	Consumer Perception
Gasoline (baseline)	118,756	Relatively familiar replacement for previous diesel baseline that may be more economically attractive than new compliance equipment
Biodiesel[62]	679	Quality-controlled B20 accepted by many manufacturers; potential issues at cold temperatures
CNG[63]	1,091	Mature and proven technology that may be more economically attractive than new compliance equipment for diesel
Diesel	32,000	Familiar and efficient; new equipment required for emissions standards compliance may be costly
Electricity[64]	12,542	Can help enhance green image; economics may be favorable compared to gasoline baseline

62 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
63 Ibid.
64 Ibid.

4.4 Heavy-Duty Class 4 Package Delivery Van

4.4.1 Compressed Natural Gas

CNG package delivery vans may offer vehicle and lifetime fuel savings over hybrid diesel vans, and their societal benefit of $12,000 per vehicle can be applied to the establishment of fleet fueling capability.

Based on EIA projections of diesel and CNG prices, the fuel cost savings offered by CNG over the next 25 years are expected to be between $0 and $1.00 per DGE. The divergence of prices seen in Figure 4.4.1-1 can be attributed to increasing diesel prices, driven by increasing global oil demand and decreasing global oil supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 4 package delivery van and fuel over its lifetime is presented in Figure 4.4.1-2. Within the expected fuel cost differential range (highlighted in white), CNG vans will have lifetime costs ranging from $14,000 per vehicle more to $25,000 per vehicle less than their diesel HEV counterparts. Because their vehicle and fuel costs may be more favorable than those of hybrid diesel vehicles, incentives to target natural gas for package delivery vans should work primarily to encourage the establishment of CNG fueling stations. This vehicle segment relies primarily on private onsite fueling, and incentives to fleet operators for building CNG capacity may accelerate the adoption of natural gas. As established in Section 3.4, the societal benefit of natural gas vans is $12,000 per vehicle. For fleets comprising hundreds or thousands of vehicles, such as FedEx and UPS, the amount of incentives justified by societal benefits may be extremely compelling for fleet to use proven natural gas technology.

Figure 4.4.1-1

CNG prices are expected to be between $0 and $1.00 per DGE less than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price
(Package Delivery Van)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

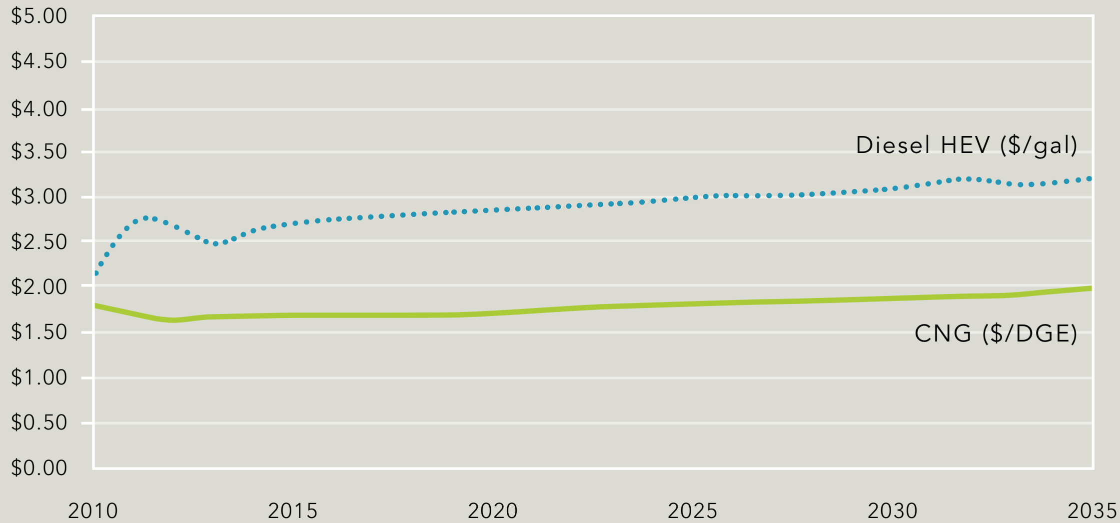
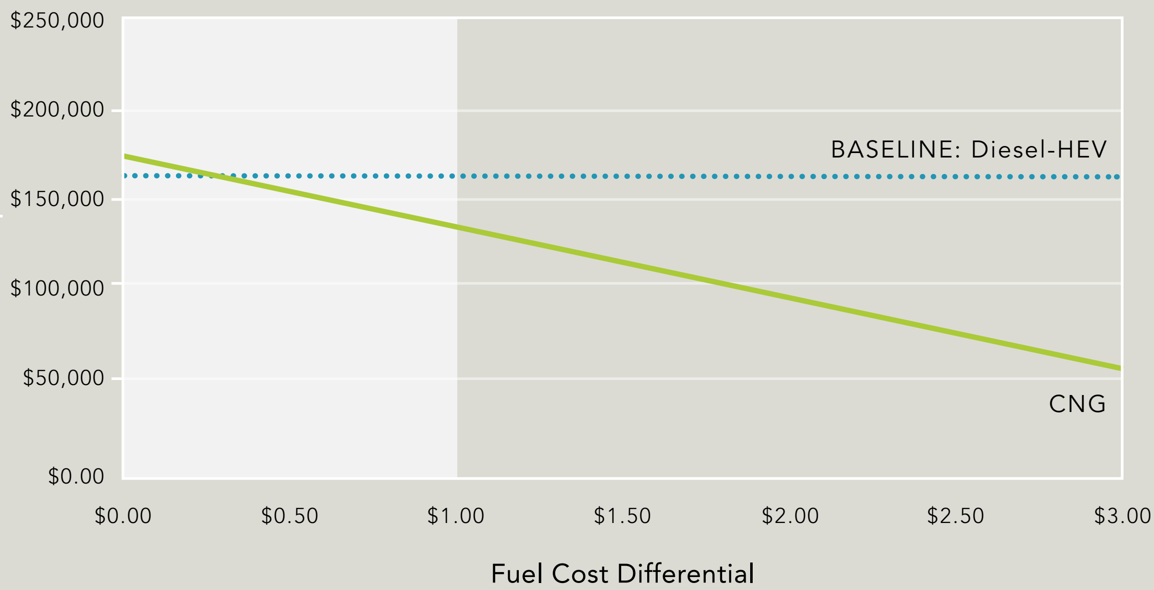


Figure 4.4.1-2

Within the expected fuel cost differential range, CNG package delivery vans will have lifetime costs ranging from $14,000 per vehicle more to $25,000 per vehicle less than their hybrid diesel counterparts, and incentives for fueling stations may accelerate natural gas adoption.

Vehicle and Lifetime Fuel Cost Comparison
(Package Delivery Van)



Assumptions:	
Current vehicle cost (non-HEV)[a]	$53,650
Baseline vehicle cost (HEV)[a]	$92,500
CNG vehicle price (non-HEV)[b]	$78,650
Annual mileage	20,000 mi
Baseline fuel economy (HEV)	15.0 mi/gal
CNG fuel economy (non-HEV)	10.5 mi/DGE
Vehicle lifetime	20 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of package delivery vans, refer to Section 3.4.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010.
[b] TIAX LLC. "Heavy-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.4 Heavy-Duty Class 4 Package Delivery Van

4.4.2 Biodiesel

The societal benefits achieved by switching from diesel to biodiesel in heavy-duty package delivery vans may be equivalent to the incentive needed to make biodiesel vans economically attractive.

Based on EIA projections of diesel prices and biodiesel prices tracked to diesel projections,[65] biodiesel are expected to cost approximately $0.10 per DGE more than diesel over the next 25 years. The prices for both biodiesel and diesel, the primary blend component of B20, are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.4.2 1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 4 package delivery van and fuel over its lifetime is presented in Figure 4.4.2-2. Within the expected fuel cost differential range (highlighted in white), biodiesel HEVs, using technology identical to the diesel baseline, will have lifetime costs approximately $2,700 per vehicle more than their diesel HEV counterparts. As established in Section 3.4, the societal benefit of biodiesel vans is estimated at $2,300 per vehicle. Hence, the incentive needed to make biodiesel vans economically attractive compared to diesel vans may be roughly equivalent to the societal benefits that would be achieved by switching to B20. As with medium-duty vans, biodiesel produced from feedstocks other than the assumed soybean oil may yield even greater societal benefits. Since biodiesel vans have the same initial vehicle cost as diesel vans, the incentives applied to this vehicle segment may best be applied to establishing biodiesel infrastructure.

65 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities "Alternative Fuel Price Report," 2010 tracked to diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

Figure 4.4.2-1

Biodiesel prices are expected to be approximately $0.10 per DGE more than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price
(Package Delivery Van)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[66] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes.

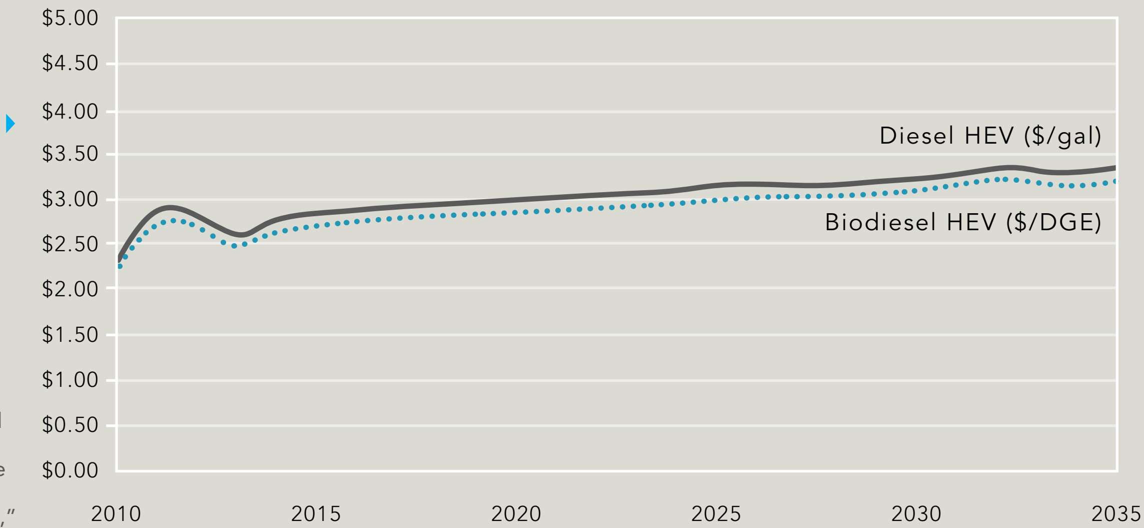
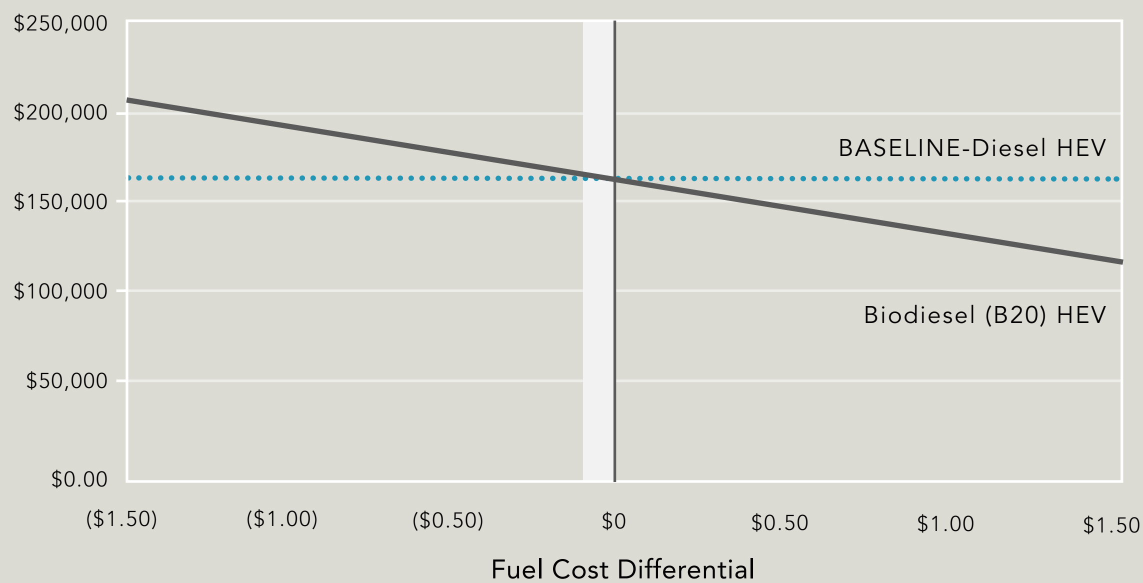


Figure 4.4.2-2

Within the expected fuel cost differential range, biodiesel package delivery vans will have lifetime costs approximately $2,700 per vehicle more than their diesel counterparts, and needed incentives may be justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison
(Package Delivery Van)



Assumptions:	
Current vehicle cost (non-HEV)[a]	$53,650
Baseline vehicle cost (HEV)[a]	$92,500
B20 vehicle price (non-HEV)[a]	$92,500
Annual mileage	20,000 mi
Baseline fuel economy (HEV)	15.0 mi/gal
CNG fuel economy (non-HEV)	15.0 mi/DGE
Vehicle lifetime	20 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of package delivery vans, refer to Section 3.4.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010.

66 Clean Cities. "Alternative Fuel Price Reports." 2010.

4 Alternatives to Conventional Transportation Fuels

4.4 Heavy-Duty Class 4 Package Delivery Van

4.4.3 Electricity

Heavy-duty electric package delivery vans may offer favorable lifetime economics over their diesel counterparts, and their societal benefits may be applied to offsetting initial vehicle purchase costs or establishing electric charging infrastructure.

Based on EIA projections of diesel and transportation electricity prices, the fuel cost savings offered by electricity over the next 25 years are expected to be between $0.50 and $1.50 per DGE. The divergence of prices seen in Figure 4.4.3-1 can again be attributed to increasing global demand for transportation fuel and stable domestic sources for electricity generation, including natural gas.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 4 package delivery van and fuel over its lifetime is presented in Figure 4.4.3-2. Within the expected fuel cost differential range (highlighted in white), electric vans may offer lifetime savings of $31,000 to $37,000 per vehicle over their diesel HEV counterparts. These savings result from lower fuel costs and significantly higher fuel economy than the diesel baseline. As established in Section 3.4, the societal benefit of electric vans is estimated at $30,000 to $33,000 per vehicle. Though lifetime economic incentives are not needed, the societal benefit may be applied used to encourage initial vehicle purchase or to establish the necessary electric charging infrastructure. As with medium-duty electric vans, in addition to the economics, the purchaser must be willing to accept the characteristics of the electric package delivery van, which may offer a range of 100 miles and require eight hours to charge fully.[67]

67 Solar Home & Business Journal. “Navistar Announces First Delivery of Its eStar Electric Truck Will Be to FedEx.” http://solarhbj.com/news/navistar-to-make-first-delivery-of-new-estar-electric-truck-0504. May 13, 2010.

Figure 4.4.3-1

Electricity prices are expected to be $0.50 to $1.50 per DGE less than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price (Package Delivery Van)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012. Electricity prices are specifically for transportation.
2) Fuel prices include federal and state taxes.

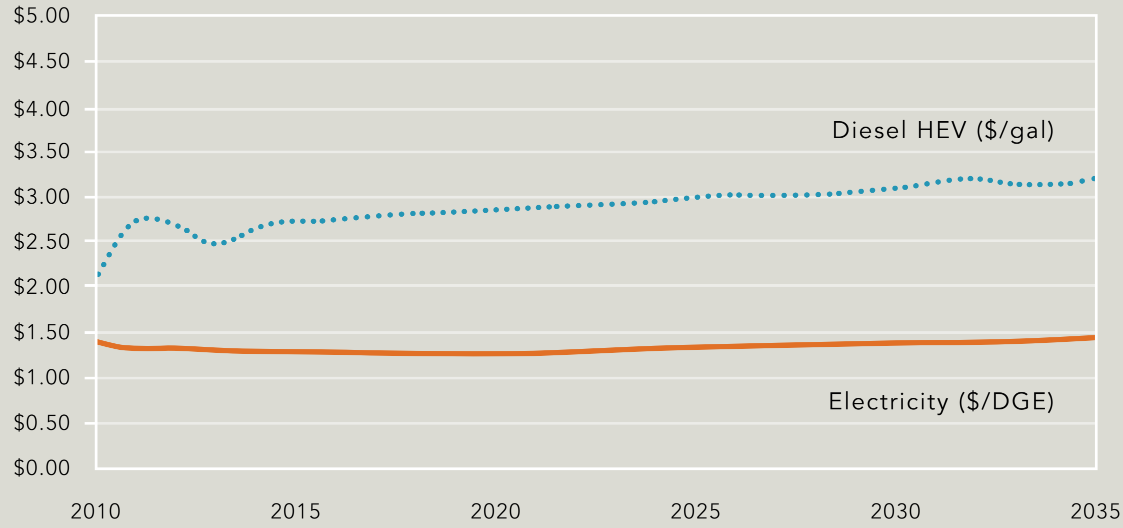
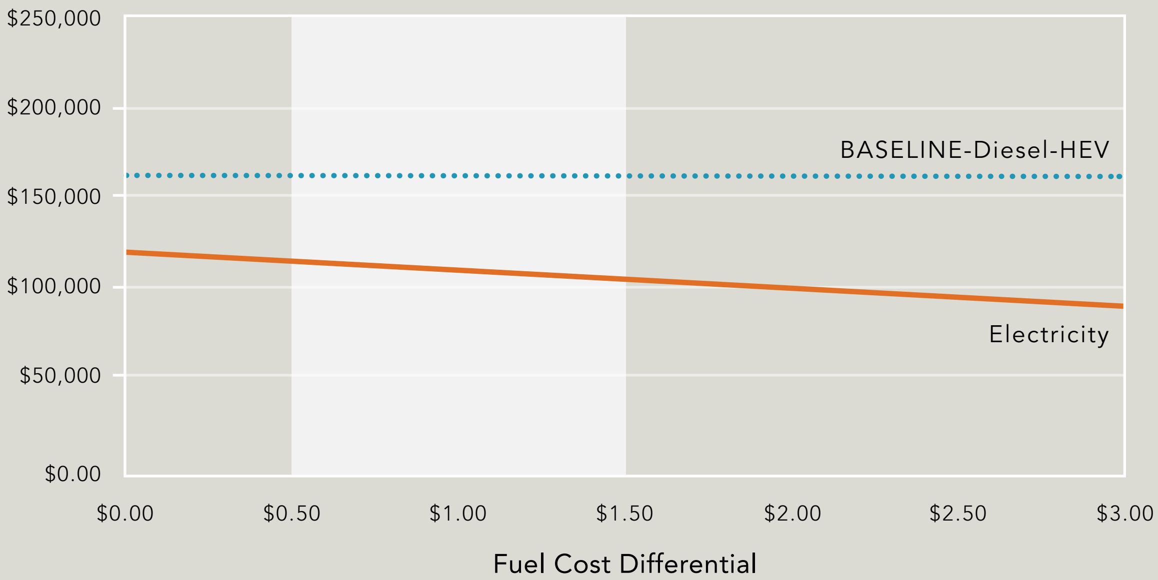


Figure 4.4.3-2

Within the expected fuel cost differential range, electric package delivery vans may offer lifetime savings of $31,000 to $37,000 per vehicle over their diesel counterparts, and their societal benefits may be used to offset vehicle or infrastructure costs.

Vehicle and Lifetime Fuel Cost Comparison (Package Delivery Van)



Assumptions:	
Current vehicle cost (non-HEV)[a]	$53,650
Baseline vehicle cost (HEV)[a]	$92,500
Electric vehicle cost[b,c]	$103,650
Annual mileage	20,000 mi
Baseline fuel economy (HEV)	15.0 mi/gal
Electric fuel economy	33.7 mi/DGE
Vehicle lifetime	20 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of package delivery vans, refer to Section 3.4.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010.
[b] Solar Home & Business Journal. "Navistar Announces First Delivery of Its Star Electric Truck Will Be to FedEx." http://solarhbj.com/news/navistar-to-make-first-delivery-of-new-estar-electric-truck-0504. May 13, 2010.
[c] Electric vehicle price is given for a van of approximately 100 mile range that requires eight hours to fully charge. In addition to the economics presented above, these range and charging requirements must also be acceptable to the purchaser in order for this vehicle to be a viable option.

4.4 Heavy-Duty Class 4 Package Delivery Van
4.4.4 Implementation Considerations

Package delivery van purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can affect customer choices of alternatives.

For owners of package delivery vans, the economics of operating these fleets of vehicles are the primary driver of purchase decisions. As such, the consumer perception of various alternative technologies for package delivery vans depends on their financial tradeoffs. Technologies like CNG that can offer significant savings may be viewed very favorably, while technologies like biodiesel that may slightly increase costs may be met with hesitation by the customer; as discussed previously, biodiesel is also linked to concerns about sensitivity to cold temperatures, which influences customer perception of this fuel. As described in the Heavy-Duty Vehicle Ownership and Production report in the overall TIAX assessment, in combination with economics, commercial fleets such as package delivery fleets may place importance on enhancing their "green" image by reducing air pollutant and GHG emissions. In a recent survey by NAFA Fleet Management Association, four out of every five fleets "currently have sustainability initiatives in place."[68] Thus, quantifications of the economic and green image benefits of various alternative technologies as presented above can help influence customer choices of these technologies (Table 4.4.4-1).

Compared to diesel's approximately 32,000 stations in the U.S.,[69] the availability of fueling stations offering biodiesel, CNG, and electricity is less developed but growing, with 679, 1,091, and 12,542 stations in the U.S., respectively.[70] Again, RFS targets for biofuels will primarily result in an increasing supply of biodiesel in the U.S. but may also positively impact CNG as well, if natural gas is derived from digester or landfill gas. As with medium-duty vehicles, heavy-duty package delivery vans, used by fleets such as UPS and uniform delivery services, are motivated by economics. Large fleets may establish their own fueling stations while small fleets rely on publicly accessible retail stations. In the former case, stations to support alternatives may grow directly with vehicle population, but in the latter case, the transition to alternative technologies depends on the availability of public stations. For biodiesel, new stations are not needed; B20 fuel can be added directly to existing diesel stations. Instead, the needed infrastructure for biodiesel is upstream of the fueling station, at production facilities and blending terminals.

68 NAFA Fleet Management Association. "Corporate Fleet Sustainability Programs Soar." Press release. http://www.nafa.org. October 4, 2010.
69 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
70 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.

Table 4.4.4-1

Package delivery van purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can drive customer perceptions of alternatives.

Vehicle Technology	Number of U.S. Stations	Consumer Perception
Diesel-HEV (baseline)[71]	32,000	Fuel is familiar and efficient; hybridization may be costly
Biodiesel[72]	679	Can help enhance green image; economics may not be favorable compared to diesel HEV baseline; potential issues at cold temperatures
CNG[73]	1,091	Can help enhance green image; economics may be favorable compared to diesel HEV baseline
Electric[74]	12,542	Can help enhance green image; economics may be favorable compared to diesel HEV baseline

71 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
72 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
73 Ibid.
74 Ibid.

4 Alternatives to Conventional Transportation Fuels

4.5 Heavy-Duty Class 6 Beverage Truck
4.5.1 Compressed Natural Gas

The societal benefits of CNG beverage trucks may be sufficient to fully justify incentives that allow them to be economically comparable to diesel beverage trucks

Based on EIA projections of diesel and CNG prices, the fuel cost savings offered by CNG over the next 25 years are expected to be between $0 and $1.00 per DGE. The divergence of prices seen in Figure 4.5.1-1 can be attributed to increasing diesel prices, driven by increasing global oil demand and decreasing global oil supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 6 beverage trucks and fuel over its lifetime is presented in Figure 4.5.1-2. Within the expected fuel cost differential range (highlighted in white), CNG vans will have lifetime costs ranging from $35,000 per vehicle more to $31,000 per vehicle less than their diesel HEV counterparts. As established in Section 3.5, the societal benefit of natural gas beverage trucks is $19,000 per vehicle. Within the expected range of lifetime costs, the societal benefit achieved by switching from diesel to CNG may fully justify incentives to make CNG economics favorable in this vehicle segment. Natural gas use in beverage trucks may be encouraged by applying these incentives to vehicle purchase and public and/or fleet infrastructure.

Figure 4.5.1-1

CNG prices are expected to be between $0 and $1.00 per DGE less than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 6 Beverage Truck)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

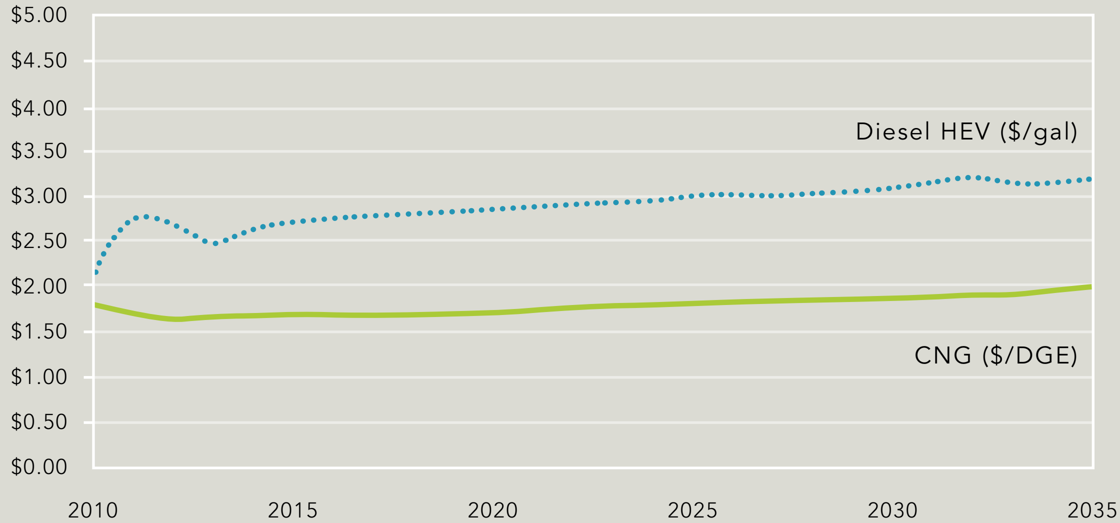
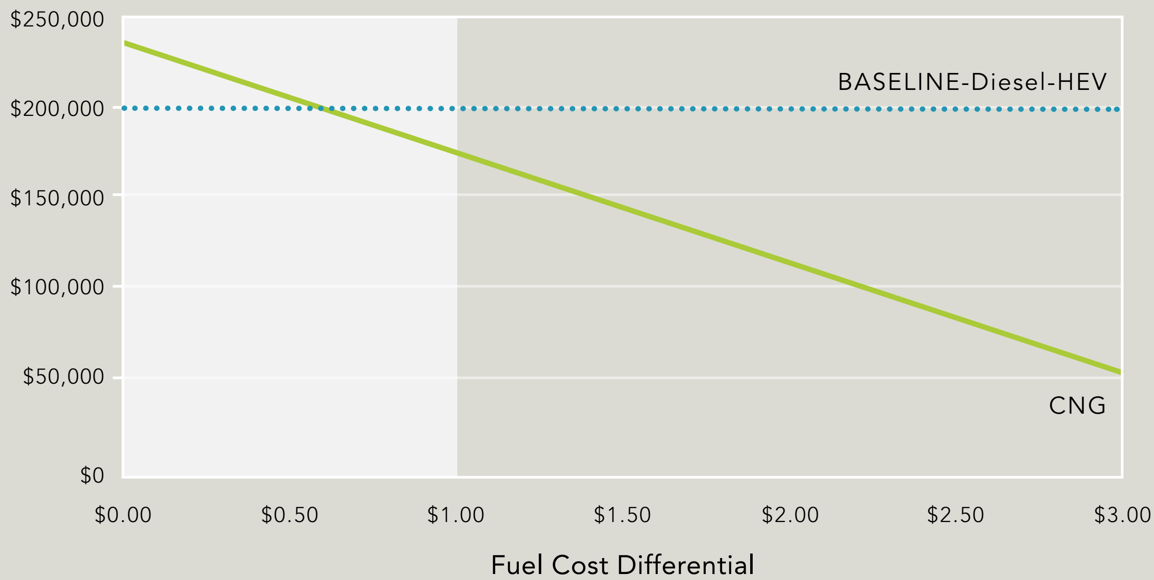


Figure 4.5.1-2

Within the expected fuel cost differential range, CNG beverage trucks will have lifetime costs ranging from $35,000 per vehicle more to $31,000 per vehicle less than their hybrid diesel counterparts, and incentives for CNG trucks may be fully justified.

Vehicle and Lifetime Fuel Cost Comparison

(Class 6 Beverage Truck)



Assumptions:	
Current vehicle cost (non-HEV)[a]	$52,000
Baseline vehicle cost (HEV)[b]	$92,000
CNG vehicle price (non-HEV)[c]	$82,000
Annual Mileage	27,500 mi
Baseline fuel economy (HEV)	9.3 mi/gal
CNG Fuel economy (non-HEV)	6.6 mi/DGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of beverage trucks, refer to Section 3.5.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010.
[b] Green Hybrid Cars. "The First Hybrid Beverage Truck." http://www.greenhybridcars.net/the-first-hybrid-beverage-truck.html. June 20, 2010.
[c] TIAX LLC. "Heavy-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.5 Heavy-Duty Class 6 Beverage Truck

4.5.2 Biodiesel

The societal benefits achieved by switching from diesel to biodiesel in heavy-duty beverage trucks may be equivalent to the incentive needed to make biodiesel trucks economically attractive.

Based on EIA projections of diesel prices and biodiesel prices tracked to diesel projections,[75] biodiesel are expected to cost approximately $0.10 per DGE more than diesel over the next 25 years. The prices for both biodiesel and diesel, the primary blend component of B20, are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.5.2 1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 6 beverage truck and fuel over its lifetime is presented in Figure 4.5.2-2. Within the expected fuel cost differential range (highlighted in white), biodiesel HEVs, using technology identical to the diesel baseline, will have lifetime costs approximately $4,400 per vehicle more than their diesel HEV counterparts. As established in Section 3.5, the societal benefit of hybrid biodiesel beverage trucks is estimated at $3,400 per vehicle. As such, the incentive needed to make biodiesel trucks economically attractive compared to diesel trucks may be roughly equivalent to the societal benefits that would be achieved by switching to B20. Since biodiesel vans have the same initial vehicle cost as diesel vans, the incentives applied to this vehicle segment may best be applied to establishing biodiesel infrastructure.

75 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities "Alternative Fuel Price Report," 2010 tracked to diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

Figure 4.5.2-1

Biodiesel prices are expected to be approximately $0.10 per DGE more than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 6 Beverage Truck)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[76] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes.

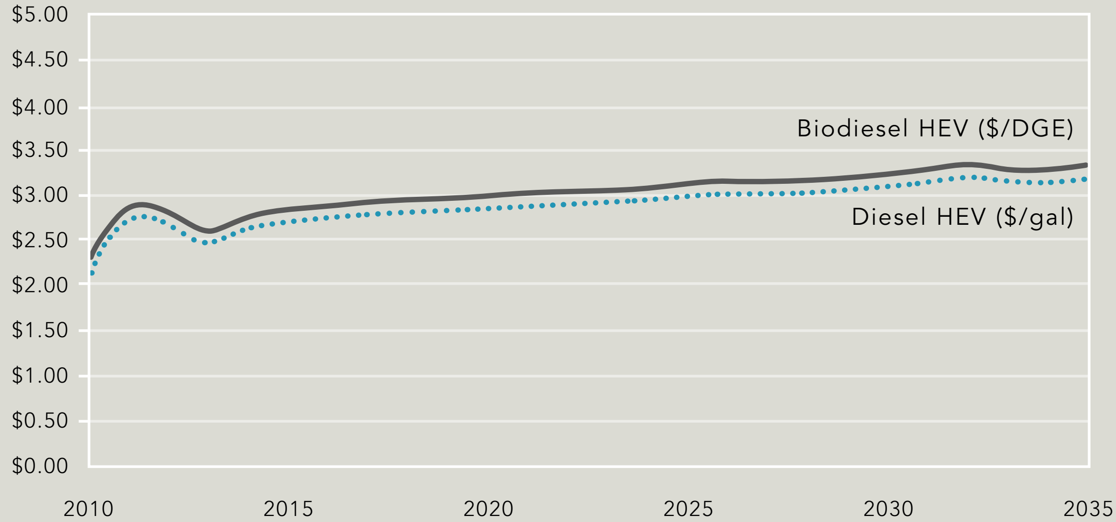
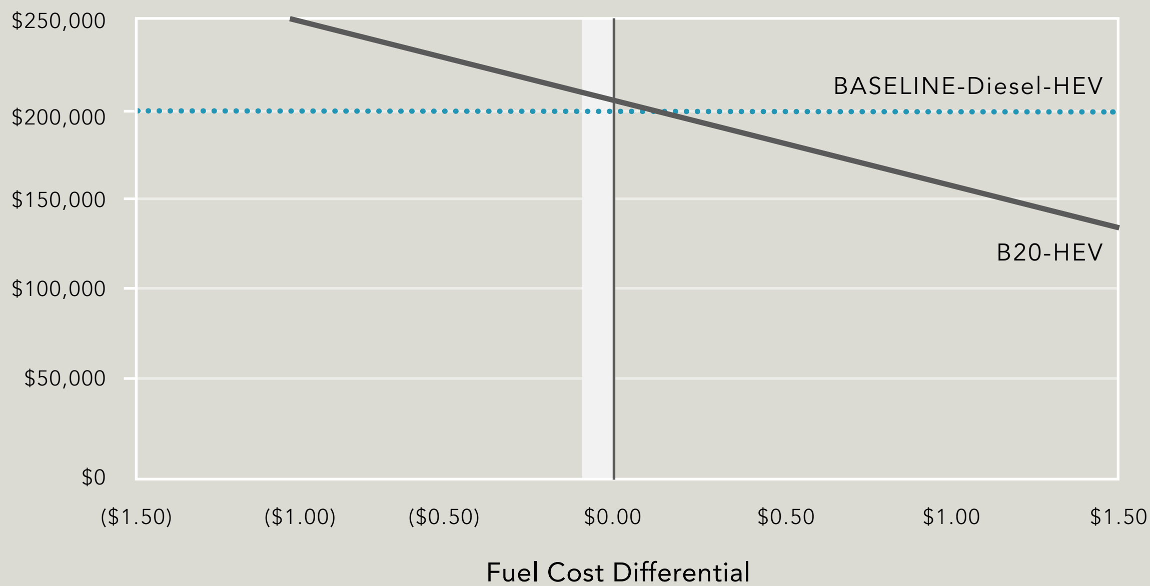


Figure 4.5.2-2

Within the expected fuel cost differential range, biodiesel beverage trucks will have lifetime costs approximately $4,400 per vehicle more than their diesel counterparts, and needed incentives may be justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison

(Class 6 Beverage Truck)



Assumptions:	
Current vehicle cost (non-HEV)[a]	$52,000
Baseline vehicle cost (HEV)[b]	$92,000
B20 vehicle price (HEV)[b]	$92,000
Annual Mileage	27,500 mi
Baseline fuel economy (HEV)	9.3 mi/gal
B20 Fuel economy (HEV)	9.3 mi/DGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of beverage trucks, refer to Section 3.5.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010.
[b] Green Hybrid Cars. "The First Hybrid Beverage Truck." http://www.greenhybridcars.net/the-first-hybrid-beverage-truck.html. June 20, 2010.

76 Clean Cities. "Alternative Fuel Price Reports." 2010.

4.5 Heavy-Duty Class 6 Beverage Truck
4.5.3 Electricity

Heavy-duty electric beverage trucks may offer favorable lifetime economics over their diesel counterparts, and their societal benefits may be applied to offsetting initial vehicle purchase costs or establishing electric charging infrastructure.

Based on EIA projections of diesel and transportation electricity prices, the fuel cost savings offered by electricity over the next 25 years are expected to be between $0.50 and $1.50 per DGE. The divergence of prices seen in Figure 4.5.3-1 is attributed to increasing global demand for transportation fuel and stable domestic sources for electricity generation, including natural gas.

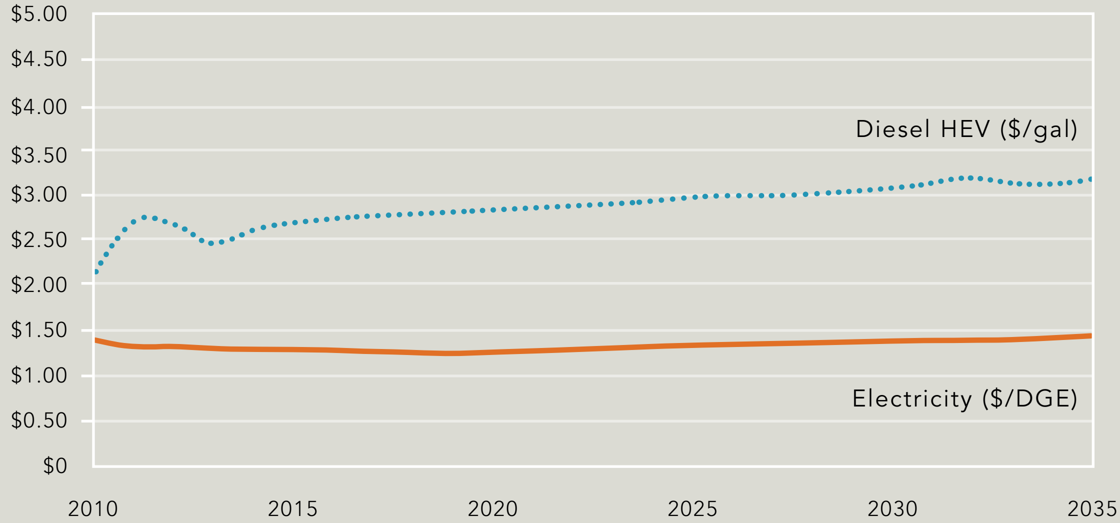
Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 6 beverage truck and fuel over its lifetime is presented in Figure 4.5.3-2. Within the expected fuel cost differential range (highlighted in white), electric beverage trucks will offer lifetime savings of $58,000 to $78,000 per vehicle over their diesel HEV counterparts. These savings again result from lower fuel costs and significantly higher fuel economy than the diesel baseline. As established in Section 3.5, the societal benefit of electric beverage trucks is estimated at $43,000 to $45,000 per vehicle. Though lifetime economic incentives are not needed, the societal benefit may be applied used to encourage initial vehicle purchase or to establish the necessary electric charging infrastructure. Again, as noted in Figure 4.5.3-2, the potential range limitations and time required to charge the vehicle must be considered along with economics for electric beverage trucks.

Figure 4.5.3-1

Electricity prices are expected to be $0.50 to $1.50 per DGE less than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 6 Beverage Truck)



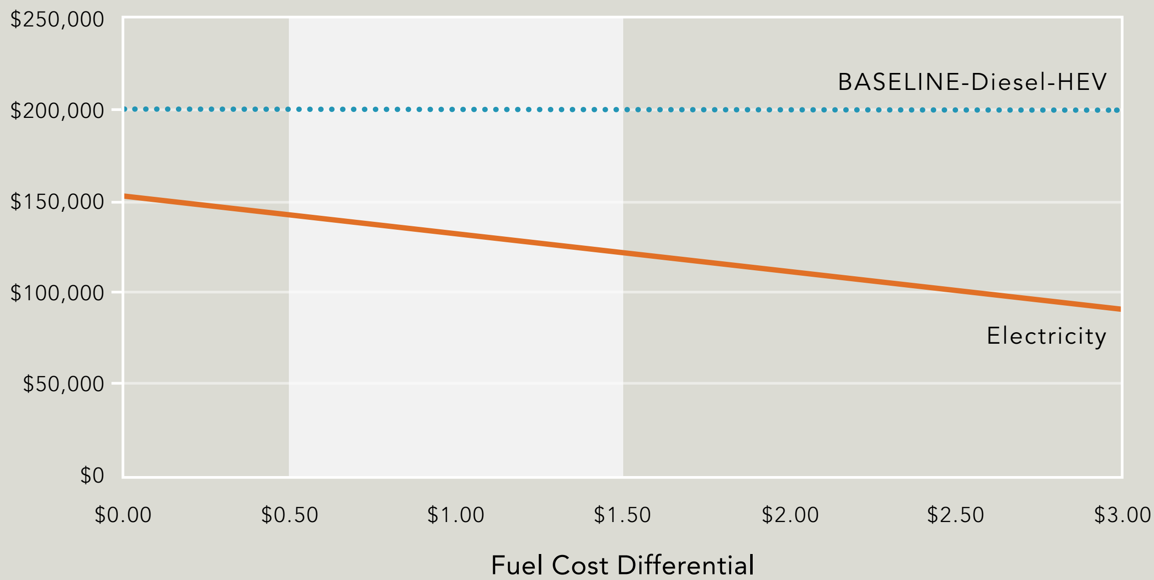
Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012. Electricity prices are specifically for transportation.
2) Fuel prices include federal and state taxes.

Figure 4.5.3-2

Within the expected fuel cost differential range, electric beverage trucks may offer lifetime savings of $58,000 to $78,000 per vehicle over their diesel counterparts, and their societal benefits may be used to offset vehicle or infrastructure costs.

Vehicle and Lifetime Fuel Cost Comparison

(Class 6 Beverage Truck)



Assumptions:

Current vehicle cost (non-HEV)[a]	$52,000
Baseline vehicle cost (HEV)[b]	$92,000
Electric vehicle price[c,d]	$104,000
Annual mileage	27,500 mi
Baseline fuel economy (HEV)	9.3 mi/gal
Electric fuel economy	21.0 mi/DGE
Vehicle lifetime	15 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of beverage trucks, refer to Section 3.5.

[a] Based on actual sales data from CARB Hybrid Vehicle Incentive Program, 2010

[b] Green Hybrid Cars. "The First Hybrid Beverage Truck." http://www.greenhybridcars.net/the-first-hybrid-beverage-truck.html. June 20, 2010.

[c] Clayton, M. "Obama Touts Electric Delivery Truck, But Still a Long Haul to Market?" Christian Science Monitor. http://www.csmonitor.com/Environment/2010/0708/Obama-touts-electric-delivery-truck-but-still-a-long-haul-to-market. July 8, 2010.

[d] If battery costs are assumed to be $600/kWh, this electric beverage truck cost corresponds to a range of approximately 50 miles per charge. Given the annual assumptions for this vehicle segment, this battery range would necessitate charging twice a day or the swapping out of the battery every midday.

4.5 Heavy-Duty Class 6 Beverage Truck

4.5.4 Implementation Considerations

Beverage truck purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can affect customer choices of alternatives.

Like package delivery vans, the economics of operating fleets of beverage trucks are the primary driver of purchase decisions. As such, the consumer perception of various alternative technologies for beverage trucks depends on their financial tradeoffs. Technologies like electricity that can offer significant savings may be viewed very favorably, while technologies like biodiesel that may slightly increase costs may be met with hesitation by the customer. As described in the Heavy-Duty Vehicle Ownership and Production report in the overall TIAX assessment, in combination with economics, commercial fleets such as beverage truck fleets may place importance on enhancing their "green" image by reducing air pollutant and GHG emissions, as revealed in the aforementioned NAFA Fleet Management Association survey.[77] Thus, quantifications of the economic and green image benefits of various alternative technologies as presented above can help influence customer choices of these technologies (Table 4.5.4-1).

Compared to diesel's approximately 32,000 stations in the U.S.,[78] the availability of fueling stations offering biodiesel, CNG, and electricity is less developed but growing, with 679, 1,091, and 12,542 stations in the U.S., respectively.[79] Again, RFS targets for biofuels will primarily result in an increasing supply of biodiesel in the U.S. but may also positively impact CNG as well, if natural gas is derived from digester or landfill gas. Large beverage truck fleets may establish their own fueling stations while small fleets rely on publicly accessible retail stations. In the former case, stations to support alternatives may grow directly with vehicle population, but in the latter case, the transition to alternative technologies depends on the availability of public stations. For biodiesel, new stations are not needed; B20 fuel can be added directly to existing diesel stations. Instead, the needed infrastructure for biodiesel is upstream of the fueling station, at production facilities and blending terminals.

77 NAFA Fleet Management Association. "Corporate Fleet Sustainability Programs Soar." Press release. http://www.nafa.org. October 4, 2010.
78 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
79 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.

Table 4.5.4-1

Beverage truck purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can drive customer perceptions of alternatives.

Vehicle Technology	Number of U.S. Stations	Consumer Perception
Diesel-HEV (baseline)[80]	32,000	Fuel is familiar and efficient; hybridization may be costly
Biodiesel[81]	679	Can help enhance green image; economics may not be favorable compared to diesel HEV baseline; potential issues at cold temperatures
CNG[82]	1,091	Can help enhance green image; economics may be favorable compared to diesel HEV baseline
Electric[83]	12,542	Can help enhance green image; economics may be favorable compared to diesel HEV baseline

80 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
81 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
82 Ibid.
83 Ibid.

4.6 Heavy-Duty Class 7 Transit Bus

4.6.1 Compressed Natural Gas

Including U.S. Federal Transit Administration (FTA) subsidies, CNG transit buses have lifetime costs ranging from $127,000 per vehicle more to $46,000 per vehicle less than hybrid diesel buses. With a societal benefit of $44,000 per vehicle over hybrid diesel buses, CNG buses may be justified in receiving partial incentives that are higher than those of hybrid diesel buses.

Based on EIA projections of diesel and CNG prices, the fuel cost savings offered by CNG over the next 25 years for transit buses, which do not pay taxes, are expected to be between $0 and $1.00 per DGE.[84] The divergence of prices seen in Figure 4.6.1-1 can be attributed to increasing diesel prices, driven by increasing global oil demand and decreasing global oil supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the transit bus and fuel over its lifetime is presented in Figure 4.6.1-2. Costs are presented both before and after substantial FTA subsidies[85] are applied. Because the diesel HEV baseline assumed here is also considered an alternative fuel technology by the FTA, the savings offered by CNG over diesel decrease after the subsidies are applied. Within the expected fuel cost differential range (highlighted in white), CNG buses will have lifetime costs ranging from $127,000 per vehicle more to $46,000 per vehicle less than hybrid diesel buses. As established in Section 3.6, the societal benefit of natural gas buses is $44,000 per vehicle. This benefit over the hybrid diesel baseline suggests that the government may wish to consider offering different levels of incentives for different alternative fuel technologies, rather than combining them into a single category as the FTA currently does. At present, natural gas buses receive the same FTA subsidy as hybrid diesel buses, but as natural gas offer greater societal benefits than diesel, higher subsidies for natural gas may be justified. Like package delivery vans, this vehicle segment relies on private onsite fueling, and partial incentives to transit agencies for building CNG capacity, justified by societal benefits, may accelerate the adoption of natural gas.

84 This fuel cost differential differs from those of other heavy-duty vehicle segments because transit agencies do not pay taxes on fuel.

85 Alternative fuel technologies, including natural gas, biodiesel, and hybrid buses, receive FTA subsidies for 90 percent of incremental vehicle costs, in addition to subsidies for 80 percent of the base vehicle costs that are given to all transit buses

Figure 4.6.1-1

CNG fuel cost differentials for transit fleets are expected to between $0 and $1.00 per DGE.

Efficiency Adjusted Fuel Price

(Class 7 Transit Bus)

Notes:
1) Fuel prices are derived from the reference case of U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices do not include federal and state taxes.

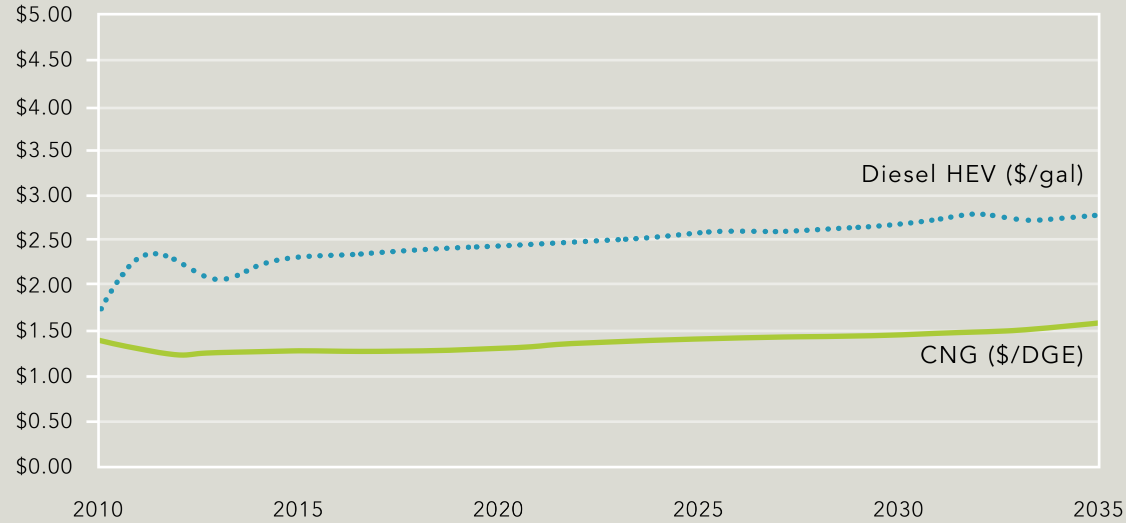
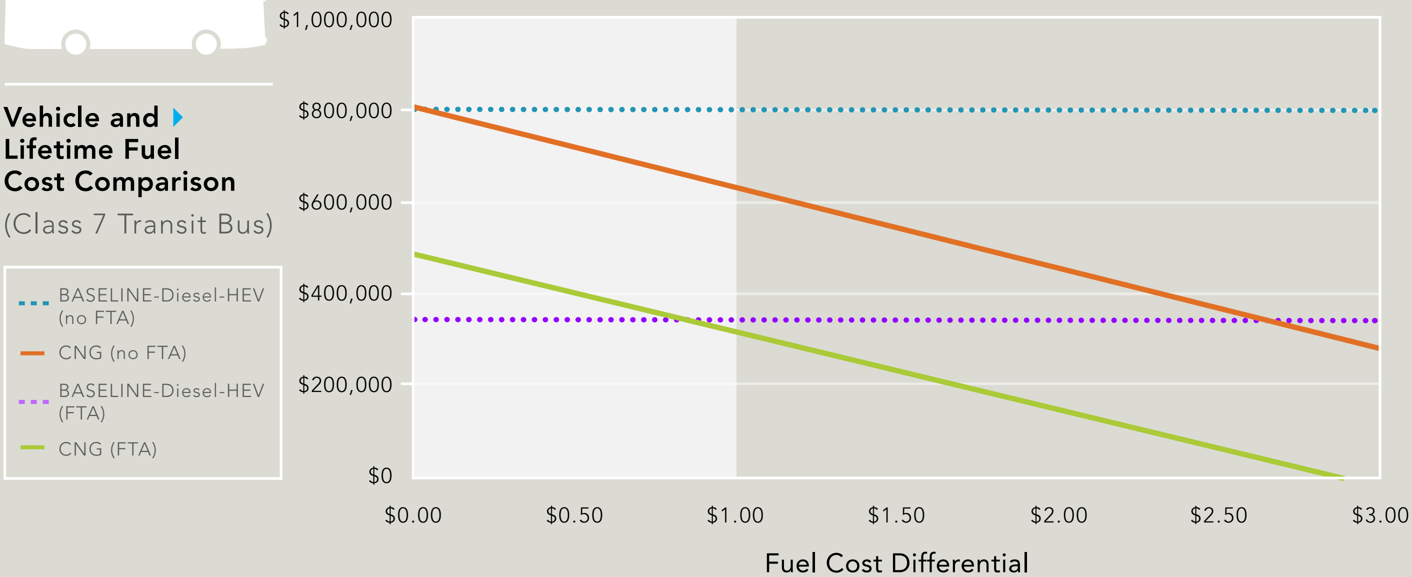


Figure 4.6.1-2

Within the expected fuel cost differential range, CNG transit buses will have lifetime costs ranging from $127,000 per vehicle more to $46,000 per vehicle less than their hybrid diesel counterparts, and incentives for CNG buses over hybrid diesel buses may be partially justified.

Vehicle and Lifetime Fuel Cost Comparison

(Class 7 Transit Bus)



Assumptions:	
Current vehicle price, no FTA subsidy (non-HEV)[a]	$340,000
Current vehicle price, with FTA subsidy (non-HEV)	$68,000
Baseline vehicle price, no FTA subsidy (HEV)[a]	$540,000
Baseline vehicle price, with FTA subsidy (HEV)	$88,000
CNG vehicle price, no FTA subsidy (non-HEV)[b]	$400,000
CNG vehicle price, with FTA subsidy (non-HEV)[b]	$74,000
Annual mileage	44,000 mi
Baseline fuel economy (HEV)	4.9 mi/gal
CNG fuel economy (non-HEV)	3.2 mi/DGE
Vehicle lifetime	12 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of transit buses, refer to Section 3.6.

[a] TIAX LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles." Prepared for National Academy of Sciences. 2009.
[b] TIAX LLC. "Heavy-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.6 Heavy-Duty Class 7 Transit Bus

4.6.2 Biodiesel

Biodiesel transit buses may require incentives of approximately $5,000 per vehicle to be economically equivalent to baseline diesel buses, which are less than the societal benefits that would be achieved by transitioning to B20.

Based on EIA projections of diesel prices and biodiesel prices tracked to diesel projections,[86] biodiesel prices for transit fleets, excluding fuel taxes, is expected to be slightly higher than diesel over the next 25 years.[87] The prices for both biodiesel and diesel, the primary blend component of B20, are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.6.2-1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the transit bus and fuel over its lifetime is presented in Figure 4.6.2-2. Costs are presented both before and after substantial FTA subsidies are applied. Because diesel and biodiesel buses use identical vehicle technologies and receive the same subsidy, the relative costs of the buses before and after subsidization are the same. The lifetime costs of biodiesel buses are approximately $5,000 per vehicle higher than those of diesel, due to the slightly higher biodiesel fuel price over their lifetime. As established in Section 3.6, the societal benefit of biodiesel buses is $7,600 per vehicle. Hence, the incentive needed to make biodiesel buses economically attractive compared to diesel buses is less than the societal benefits that would be achieved by switching to B20; this incentive may be applied to establishing upstream biodiesel infrastructure and ensuring a supply of B20 to existing diesel stations. As discussed previously, societal benefits from biodiesel may be much higher if the fuel is produced from feedstocks other than the assumed soybean oil.

86 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities “Alternative Fuel Price Reports” tracked to diesel price projections from U.S. EIA “Annual Energy Outlook,” 2010.

87 This fuel cost differential differs from those of other heavy-duty vehicle segments because transit agencies do not pay taxes on fuel.

Figure 4.6.2-1

Biodiesel prices for transit fleets are expected to slightly higher than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 7 Transit Bus)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[88] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices do not include federal and state taxes.

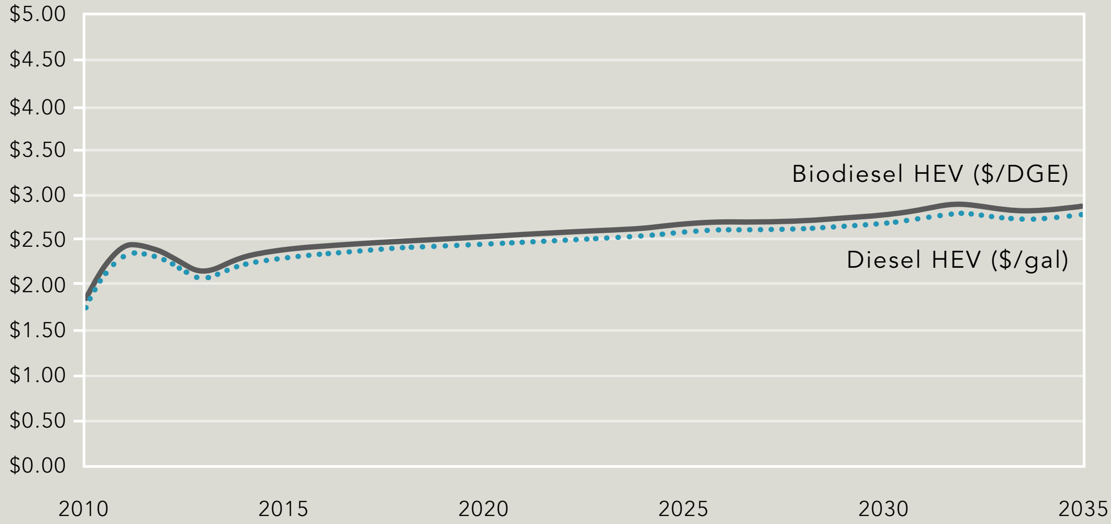


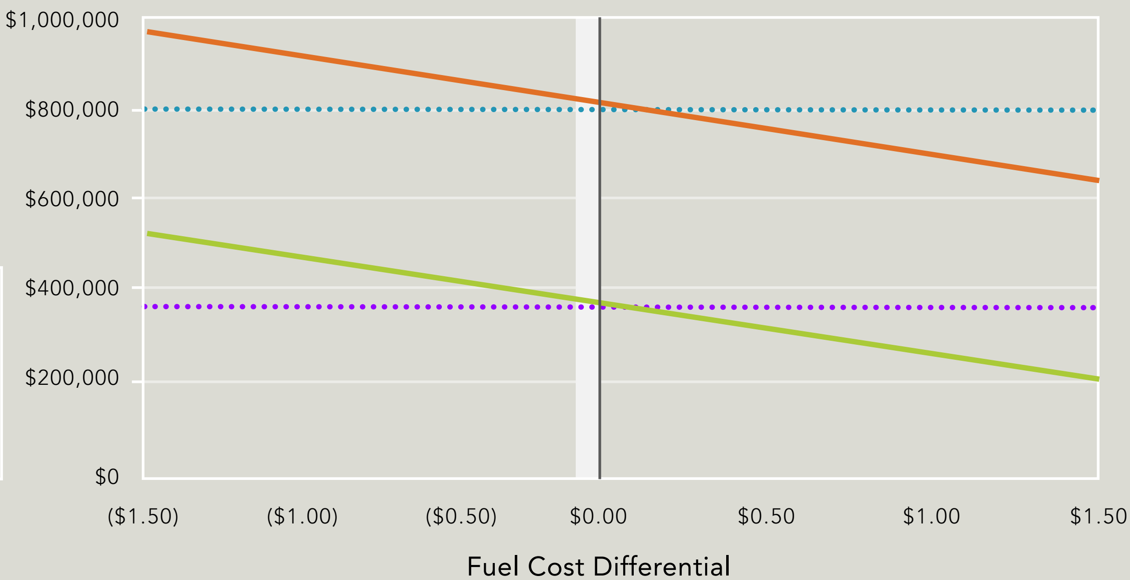
Figure 4.6.2-2

Within the expected fuel cost differential range, CNG transit buses will have lifetime costs ranging from $127,000 per vehicle more to $46,000 per vehicle less than their hybrid diesel counterparts, and incentives for CNG buses over hybrid diesel buses may be partially justified.

Vehicle and Lifetime Fuel Cost Comparison

(Class 7 Transit Bus)

BASELINE-Diesel-HEV (no FTA)
B20-HEV (no FTA)
BASELINE-Diesel-HEV (FTA)
B20-HEV (FTA



Assumptions:	
Current vehicle price, no FTA subsidy (non-HEV)[a]	$340,000
Current vehicle price, with FTA subsidy (non-HEV)	$68,000
Baseline vehicle price, no FTA subsidy (HEV)[a]	$540,000
Baseline vehicle price, with FTA subsidy (HEV)[a]	$88,000
B20 vehicle price, no FTA subsidy (HEV)[a]	$540,000
B20 vehicle price, with FTA subsidy (HEV)[a]	$88,000
Annual mileage	44,000 mi
Baseline fuel economy (HEV)	4.9 mi/gal
B20 fuel economy (non-HEV)	4.9 mi/DGE
Vehicle lifetime	12 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of transit buses, refer to Section 3.6.

[a] TIAX LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles." Prepared for National Academy of Sciences. 2009.

88 Clean Cities. "Alternative Fuel Price Reports." 2010.

Electric transit buses may offer favorable lifetime economics over their diesel counterparts, and their societal benefits may be applied to offsetting initial vehicle purchase costs or establishing electric charging infrastructure.

Based on EIA projections of diesel and transportation electricity prices, the fuel cost savings offered by electricity over the next 25 years for transit agencies are expected to be between $0.25 and $1.00 per DGE. The divergence of prices seen in Figure 4.6.3-1 is attributed to increasing global demand for transportation fuel and stable domestic sources for electricity generation, including natural gas.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the transit bus and fuel over its lifetime is presented in Figure 4.6.3-2. Costs are presented both before and after substantial FTA subsidies are applied. Electric buses offer lifetime savings of $88,000 to $126,000 per vehicle over diesel buses, and these savings result from lower fuel costs and significantly higher fuel economy than the diesel baseline. As established in Section 3.6, the societal benefit of electric buses is $90,000 to $93,000 per vehicle. Though lifetime economic incentives are not needed, the societal benefit may be applied used to encourage initial vehicle purchase or to establish the necessary electric charging infrastructure. In addition to economics, the operating characteristics of electric transit buses are important as well. Recent progress in electric bus technology may offer thirty miles of range with ten minutes of charging,[89] which may or may not align well with the operations of various transit agencies.

89 Rodriguez, M. "Ecoliners Hit Streets; Foothill Transit Introduces Buses." Pomona News. http://www.insidesocal.com/pomonanow/2010/09/ecoliners-hit-streets-foothill.html. September 17, 2010.

Figure 4.6.3-1

Electricity prices are expected to be $0.25 to $1.00 per DGE less than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price
(Class 7 Transit Bus)

Notes:
1) Fuel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012. Electricity prices are specifically for transportation.
2) Fuel prices do not include federal and state taxes.

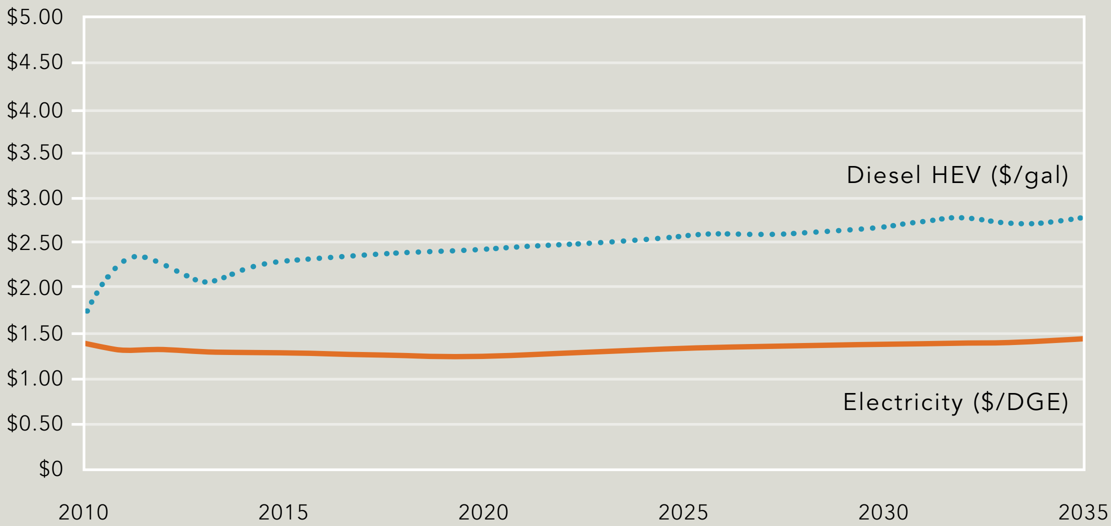
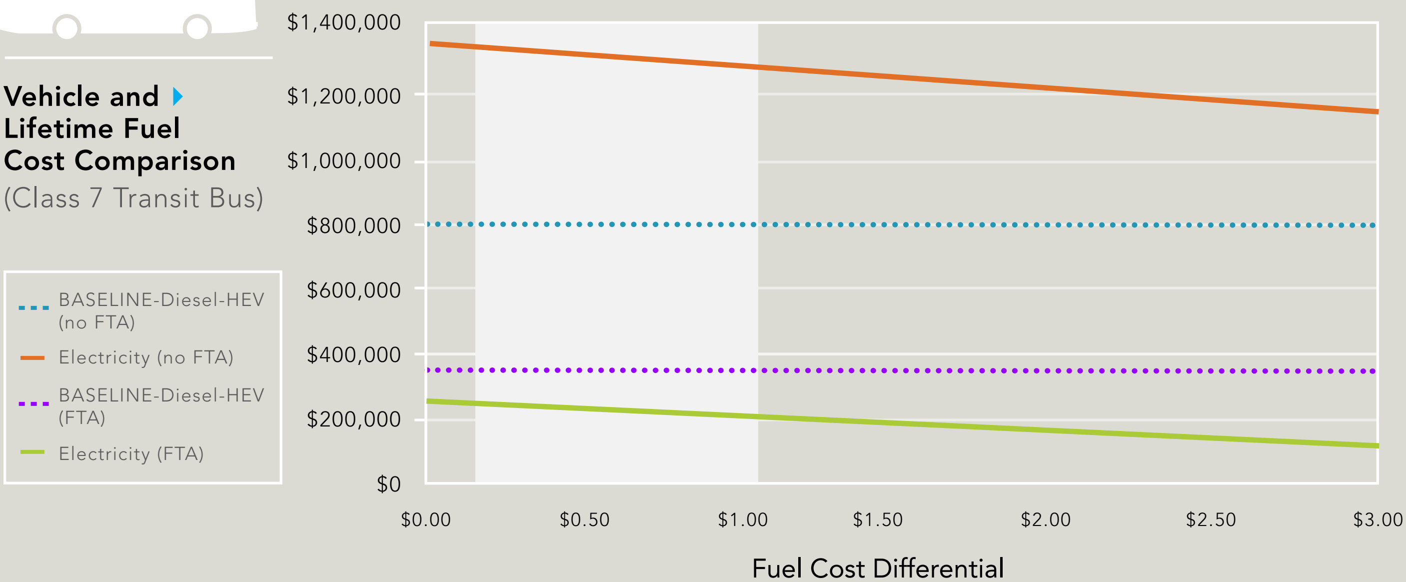


Figure 4.6.3-2

Within the expected fuel cost differential range, electric transit buses may offer lifetime savings of $88,000 to $126,000 per vehicle their diesel counterparts, and their societal benefits may be used to offset vehicle or infrastructure costs.

Vehicle and Lifetime Fuel Cost Comparison
(Class 7 Transit Bus)



Assumptions:	
Current vehicle price, no FTA subsidy (non-HEV)[a]	$340,000
Current vehicle price, with FTA subsidy (non-HEV)	$68,000
Baseline vehicle price, no FTA subsidy (HEV)[a]	$540,000
Baseline vehicle price, with FTA subsidy (HEV)[a]	$88,000
Electric vehicle price, no FTA subsidy[b]	$1,200,000
Electric vehicle price, with FTA subsidy[b]	$154,000
Annual mileage	44,000 mi
Baseline fuel economy (HEV)	4.9 mi/gal
Electric fuel economy	10.3 mi/DGE
Vehicle lifetime	12 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of transit buses, refer to Section 3.6.

[a] TIAX LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles." Prepared for National Academy of Sciences. 2009.
[b] Rodriguez, M. "Ecoliners Hit Streets; Foothill Transit Introduces Buses." Pomona News. http://www.insidesocal.com/pomonanow/2010/09/ecoliners-hit-streets-foothill.html. September 17, 2010.
[c] Electric vehicle price is given for a bus of approximately 30 mile range that requires ten minutes to fully charge. In addition to the economics presented above, these range and charging requirements must also be acceptable to the purchaser in order for this vehicle to be a viable option.

4.6 Heavy-Duty Class 7 Transit Bus
4.6.4 Implementation Considerations

Transit bus purchase decisions to acquire alternative technologies may depend on perceived green image advantages for their fleets.

As described in the Heavy-Duty Vehicle Ownership and Production report in the overall TIAX assessment, in contrast to commercial fleets such as package delivery fleets, transit fleets are less concerned about payback periods for alternative technologies. The incremental costs of these technologies are largely paid for by FTA subsidies, and fuel cost savings quickly recover the small portion of vehicle costs that transit fleets must pay. Instead, transit fleets report being motivated to adopt alternative technologies by concerns over their green image and air pollutant and GHG emissions. In addition, transit fleets are influenced by public decision makers, who may be driven by similar concerns. Accordingly, transit fleet choices of the various alternative technologies may depend on their awareness of the relative societal benefits of each technology (Table 4.6.4 1).

Transit fleets build and operate their own fueling stations or contract with third parties to do so, and thus, as long as the vehicles are economically justified, infrastructure to support alternatives expands with vehicle population. Current abundance of natural gas and growing supply of biodiesel as mandated through the RFS will enable transit fleets to consider these alternatives to diesel.

Table 4.6.4-1

Transit bus purchase decisions to acquire alternative technologies depend primarily on perceived green image advantages for their fleets.

Vehicle Technology	Consumer Perception
Diesel-HEV (baseline)	Fuel is familiar and efficient
Biodiesel	Can help enhance green image; potential issues at cold temperatures
CNG	Can help enhance green image
Electricity	Can help enhance green image

4.7 Heavy-Duty Class 8 Refuse Hauler

4.7.1 Compressed Natural Gas

The societal benefits offered by CNG refuse haulers may justify incentives to provide financial support for fleet fueling infrastructure.

Based on EIA projections of diesel and CNG prices, the fuel cost savings offered by CNG over the next 25 years are expected to be between $0 and $1.00 per DGE. As stated previously, the divergence of prices seen in Figure 4.7.1-1 can be attributed to increasing diesel prices, driven by increasing global oil demand and decreasing global oil supply, and stable natural gas prices, due to reliable domestic fuel resources.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the refuse hauler and fuel over its lifetime is presented in Figure 4.7.1-2. Within the expected fuel cost differential range (highlighted in white), CNG refuse haulers will have lifetime costs ranging from $47,000 per vehicle more to $38,000 per vehicle less than diesel HEV refuse haulers. As established in Section 3.7, the societal benefit of natural gas refuse haulers over diesel HEV refuse haulers is $24,000 per vehicle. The application of this benefit to justify the same amount in incentives can provide financial support for refuse fleet operators to establish the fueling capability necessary to support the CNG vehicles. In addition, fleet operators may invest in hydraulic CNG hybrids to attain greater fuel savings.

Figure 4.7.1-1

CNG fuel cost differentials are expected to be between $0 and $1.00 per DGE over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 8 Refuse Hauler)

Notes:
1) Fuel prices are derived from the reference case of the U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) Fuel prices include federal and state taxes.

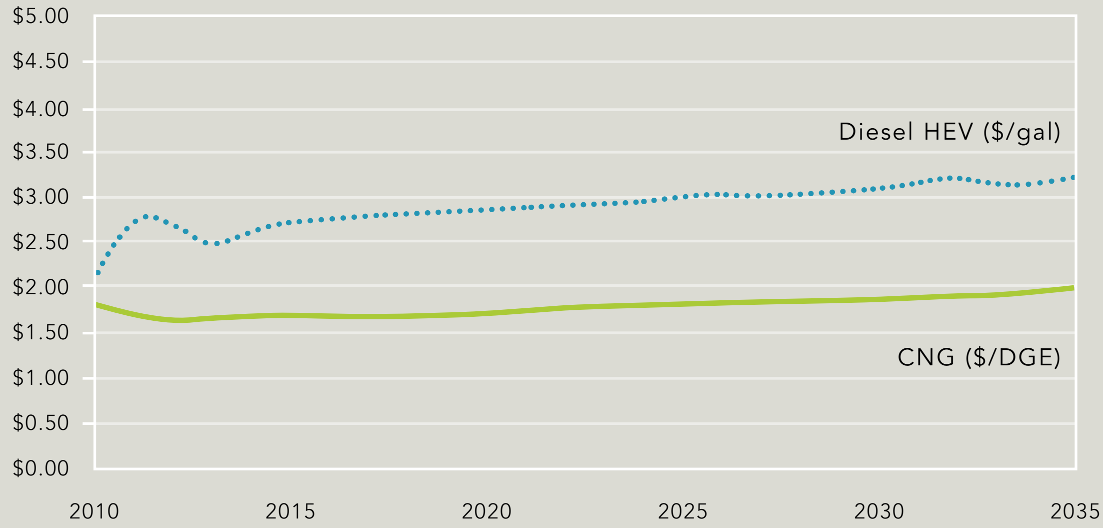
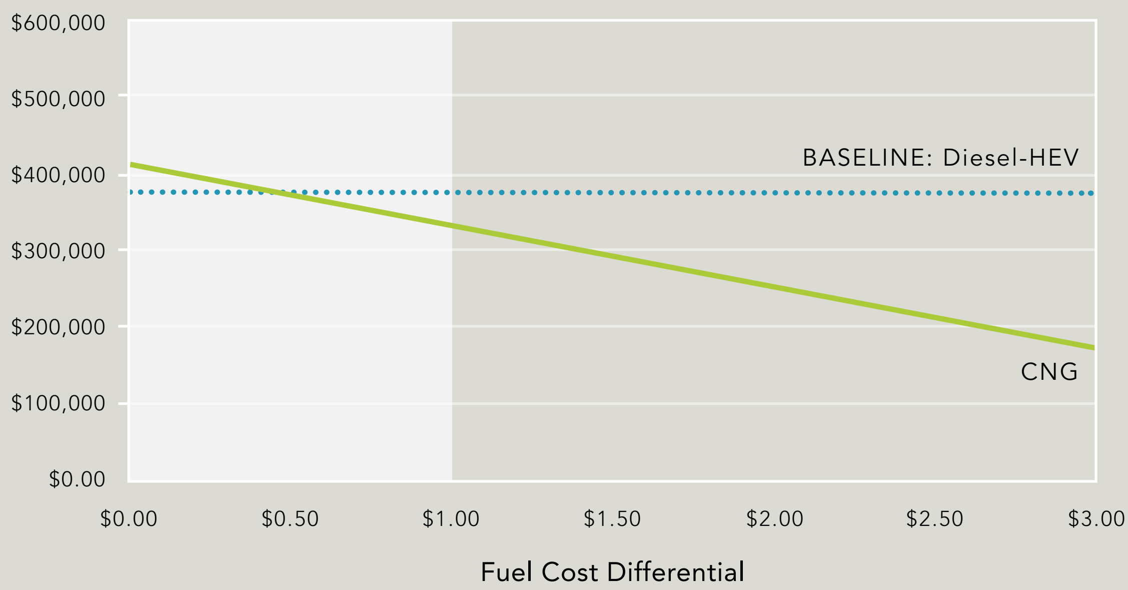


Figure 4.7.1-2

Within the expected fuel cost differential range, CNG refuse haulers will have lifetime costs ranging from $47,000 per vehicle more to $38,000 per vehicle less than their hybrid diesel counterparts, and their societal benefits may justify incentives for fueling infrastructure.

Vehicle and Lifetime Fuel Cost Comparison

(Class 8 Refuse Hauler)



Assumptions:	
Current vehicle price (non-HEV)[a]	$180,000
Baseline vehicle price (HEV)[b]	$232,000
CNG vehicle price (non-HEV)[c]	$220,000
Annual mileage	22,100 mi
Baseline fuel economy (HEV)	4.4 mi/gal
CNG fuel economy (non-HEV)	3.1 mi/DGE
Vehicle lifetime	10 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of refuse haulers, refer to Section 3.7.

[a] TIAX LLC. "Life-Cycle Cost Model and Pollutant Emissions Estimator." Prepared for Westport Innovations, Inc. 2008.
[b] TIAX LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles." Prepared for National Academy of Sciences. 2009.
[c] TIAX LLC. "Heavy-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

4.7 Heavy-Duty Class 8 Refuse Hauler

4.7.2 Biodiesel

Biodiesel refuse haulers may require incentives of approximately $5,700 per vehicle to be economically equivalent to diesel refuse haulers, which nearly equal the societal benefits that would be achieved by transitioning to B20.

Based on EIA projections of diesel prices and biodiesel prices tracked to diesel projections,[90] biodiesel are expected to cost approximately $0.10 per DGE more than diesel over the next 25 years. The prices for both biodiesel and diesel, the primary blend component of B20, are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.7.2 1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the refuse hauler and fuel over its lifetime is presented in Figure 4.7.2-2. The lifetime costs of biodiesel refuse haulers are approximately $5,700 per vehicle higher than those of baseline diesel vehicles (both assumed to be HEVs), due to the slightly higher biodiesel fuel price over their lifetime. As with transit bus fleets, refuse hauler fleets are able to establish their own B20 stations and lower fuel costs relative to the national average assumed by the EIA projections and Clean Cities cost differential, but the tradeoff is that the fleets must absorb the costs of building and operating the station.

As established in Section 3.7, the societal benefit of biodiesel refuse haulers is $3,900 per vehicle. Hence, the incentive needed to make biodiesel refuse haulers economically attractive compared to diesel refuse haulers may nearly match the societal benefits that would be achieved by switching to B20, and this incentive may be used to add B20 to existing diesel stations and establish upstream biodiesel infrastructure. Again, if biodiesel is produced from feedstocks such as yellow grease or waste oils that do not require arable land, societal benefits from biodiesel may be much higher.

90 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities "Alternative Fuel Price Report," 2010 tracked to diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

Figure 4.7.2-1

Biodiesel prices are expected to be approximately $0.10 per DGE higher than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price
(Class 8 Refuse Hauler)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[91] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes.

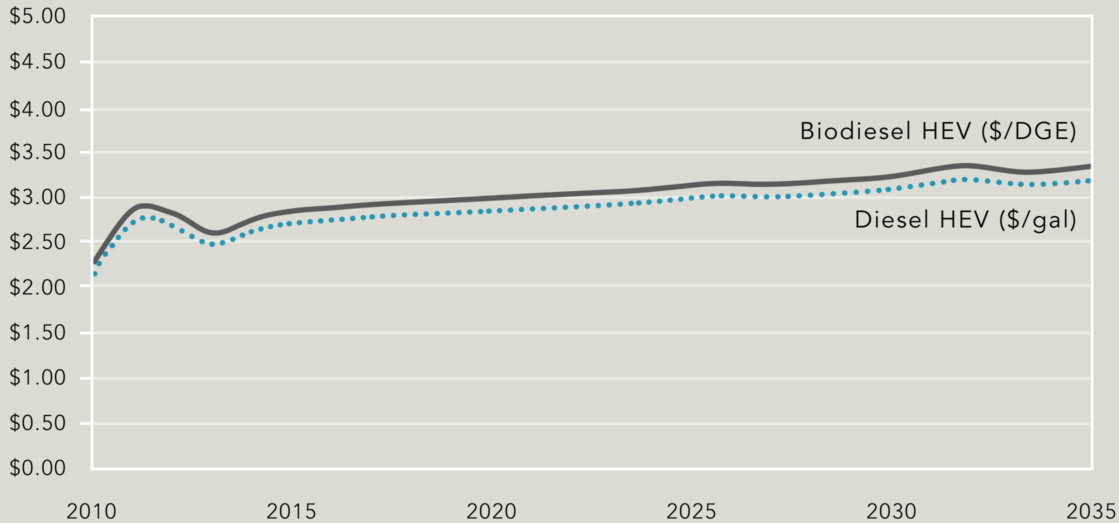
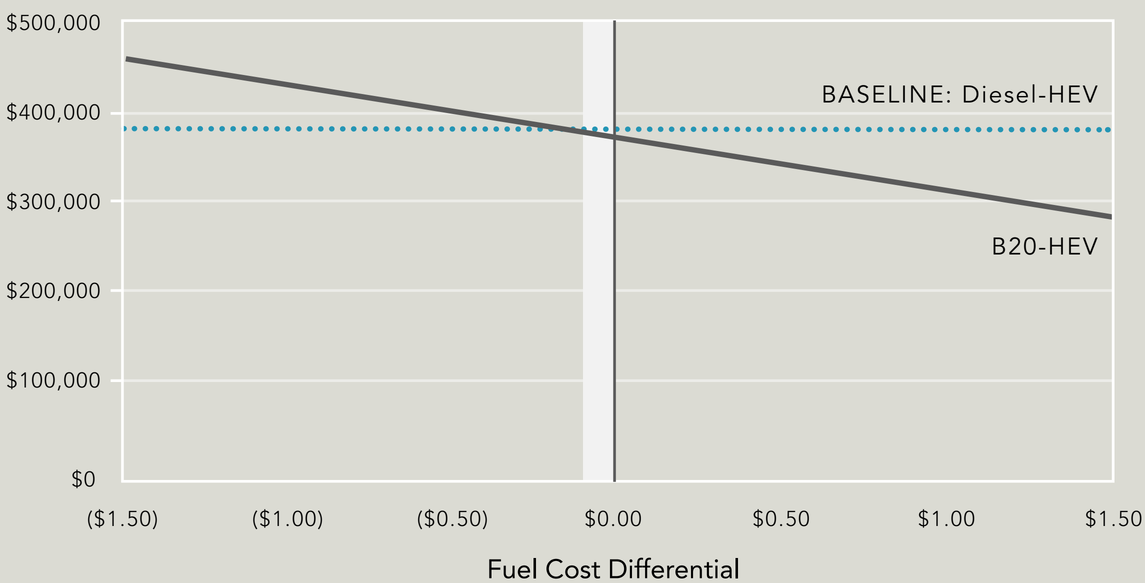


Figure 4.7.2-2

Within the expected fuel cost differential range, biodiesel refuse haulers will have lifetime costs approximately $5,700 per vehicle more than their diesel counterparts, and needed incentives may be justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison
(Class 8 Refuse Hauler)



Assumptions:	
Current vehicle price (non-HEV)[a]	$180,000
Baseline vehicle price (HEV)[b]	$232,000
B20 vehicle price (HEV)[b]	$232,000
Annual mileage	22,100 mi
Baseline fuel economy	4.4 mi/gal
B20 fuel economy	4.4 mi/DGE
Vehicle lifetime	10 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of refuse haulers, refer to Section 3.7.

[a] TIAX LLC. "Life-Cycle Cost Model and Pollutant Emissions Estimator." Prepared for Westport Innovations, Inc. 2008.
[b] TIAX LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles." Prepared for National Academy of Sciences. 2009.

91 Clean Cities. "Alternative Fuel Price Reports." 2010.

4.7 Heavy-Duty Class 8 Refuse Hauler
4.7.3 Implementation Considerations

In addition to government mandates, refuse hauler purchase decisions depend on economics, green image advantages for their fleets, and noise concerns, all of which can affect customer choices of alternatives.

Aside from government mandates, the basic motivators for refuse hauler fleets to consider alternatives are the same as those for package delivery fleets: economics and green image. As described in the Heavy-Duty Vehicle Ownership and Production report in the overall TIAX assessment, reducing lifecycle costs, enhancing their green image, and reducing foreign transportation fuel dependence all rank as "important" for some refuse fleets. In addition, reducing air pollutant emissions and reducing GHG emissions ranks as "very important." Accordingly, refuse fleet choices of alternatives may be directly influenced by their economics and societal air quality and GHG benefits. Another customer decision factor unique to refuse haulers is the issue of noise. Operating primarily in residential areas, refuse haulers that are quieter enjoy greater client satisfaction. Anecdotally, natural gas refuse haulers have been reported to be quieter than diesel and biodiesel counterparts, which may factor into fleet perceptions and purchase decisions (Table 4.7.3-1).

Like transit fleets, refuse hauler fleets build their own fueling stations, and thus, as long as the vehicles are economically justified, infrastructure to support alternatives expands with vehicle population. Current abundance of natural gas and growing supply of biodiesel as mandated through the RFS will enable transit fleets to consider these alternatives to diesel.

Table 4.7.3-1

In addition to government mandates, refuse hauler purchase decisions depend on economics, green image advantages for their fleets, and noise concerns, all of which can drive customer perceptions of alternatives.

Vehicle Technology	Consumer Perception
Diesel-HEV (baseline)	Fuel is familiar and efficient; hybridization may be costly
Biodiesel	Can help enhance green image; economics may not be favorable compared to diesel HEV baseline; potential issues at cold temperatures
CNG	Can help enhance green image; may be quieter than diesel engines; economics may be favorable compared to diesel HEV baseline

4.8 Heavy-Duty Class 8 Tractor

4.8.1 Liquefied Natural Gas

The societal benefits offered by LNG Class 8 tractors may be sufficient to justify incentives that ensure favorable vehicle economics for both local- and line-haul applications. The necessity of pre-established fueling corridors is unique to line-haul tractors.

Based on EIA projections of diesel prices and LNG prices tracked to CNG projections,[92] LNG is expected to cost between $0.75 and $1.75 per DGE less than diesel over the next 25 years. As diesel prices rise with increasing global oil demand and decreasing global oil supply, natural gas prices are expected to remain stable, anchored by domestic resources, leading to a divergence of prices seen in Figure 4.8.1-1.

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 8 tractor and fuel over its lifetime is presented in Figure 4.8.1-2. Costs are presented for tractors in both local- and line-haul duty cycles to provide bounds on the economics for this vehicle segment. As described in Section 3.8, Class 8 tractors are intended for various applications, and thus initial vehicle costs, including engine size and fuel storage capacity, annual mileage, fuel economy, and lifetime fuel costs will span the range defined by the shortest and longest distance applications.[93]

LNG tractors in local-haul applications will have lifetime costs ranging from $18,000 per vehicle more to $44,000 per vehicle less than diesel tractors. LNG tractors in line-haul applications will have lifetime costs ranging from $23,000 per vehicle more to $58,000 per vehicle less than diesel tractors. Regional-haul tractors, with annual mileage between that of local- and line-haul, are expected to see lifetime costs within these ranges. As established in Section 3.8, the societal benefit of LNG tractors ranges from $27,000 (local-haul) to $36,000 (line-haul) per vehicle. Therefore, the incentives needed for Class 8 tractors may be fully justified by their societal benefits and used to offset initial vehicle costs and establish fueling infrastructure, public and/or fleet owned. A unique consideration for line-haul tractors is their long distance operation, which requires public fueling infrastructure along major cross-country routes. Unlike other vehicle segments, line-haul tractors must have a complete fueling corridor in place before they can operate, rather than waiting for gradual build out of individual stations.

92 Ratio of LNG to CNG price of 1.04 applied to CNG price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
93 Annual mileages for local- and line-haul applications are assumed to be 10,000 miles and 200,000 miles, respectively.

Figure 4.8.1-1

LNG prices are expected to diverge from diesel prices over the next 25 years, giving fuel cost differentials between $0.75 and $1.75 per DGE.

Efficiency Adjusted Fuel Price

(Class 8 Tractor)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) LNG prices are based on bottom-up fuel costs[94] and tracked to CNG price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes

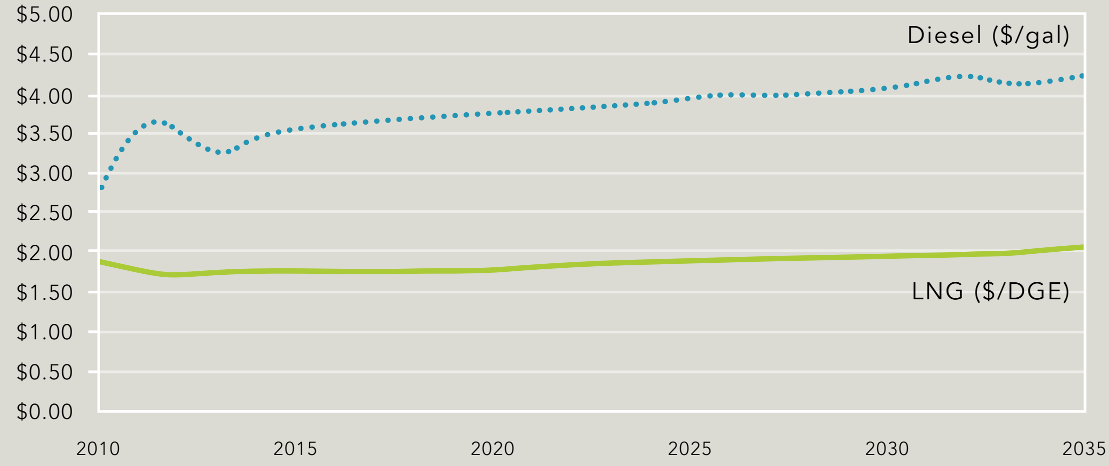


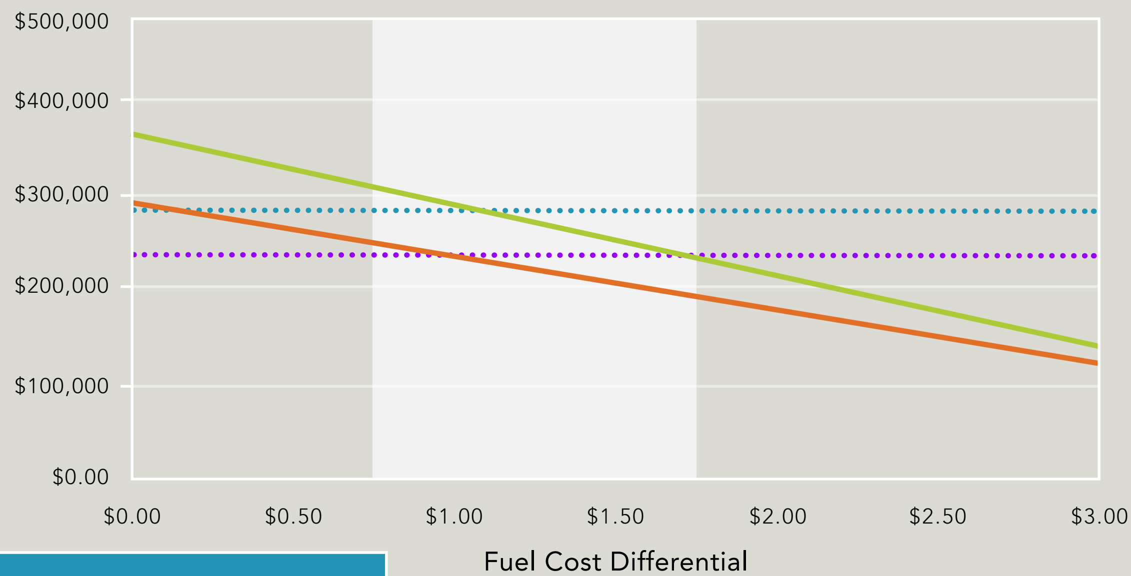
Figure 4.8.1-2

Within the expected fuel cost differential range, LNG Class 8 tractors will have lifetime costs ranging from $23,000 per vehicle more to $58,000 per vehicle less than their diesel counterparts, and their societal benefits may fully justify needed incentives.

Vehicle and Lifetime Fuel Cost Comparison

(Class 8 Tractor)

- BASELINE-Diesel (line)
- LNG (local)
- BASELINE-Diesel (local)
- LNG (line)



Assumptions:	
Baseline vehicle price, local[a]	$95,000
Baseline vehicle price, line[a]	$105,000
LNG vehicle price, local[b]	$150,000
LNG vehicle price, line[b]	$177,500
Annual mileage, local	40,000 mi
Annual mileage, line	120,000 mi
Baseline fuel economy, local	4.3 mi/gal
Baseline fuel economy, line	6.5 mi/gal
LNG fuel economy, local	4.1 mi/DGE
LNG fuel economy, line	6.2 mi/DGE
Vehicle lifetime, local	6 years
Vehicle lifetime, line	4 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 8 tractors, refer to Section 3.8.

[a] TIAX LLC. "Life-Cycle Cost Model and Pollutant Emissions Estimator." Prepared for Westport Innovations, Inc. 2008.
[b] TIAX LLC. "Heavy-Duty Vehicle Ownership and Production." Prepared for ANGA. December 2010.

94 Ratio of LNG to CNG price of 1.04 applied to CNG price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

4.8 Heavy-Duty Class 8 Tractor

4.8.2 Biodiesel

Biodiesel Class 8 tractors may require incentives between $5,600 and $7,400 per vehicle to be economically equivalent to baseline diesel tractors, which may be more than the societal benefits gained by transitioning to B20.

Based on EIA projections of diesel prices and biodiesel prices tracked to diesel projections,[95] biodiesel is expected to cost approximately $0.10 per DGE more than diesel over the next 25 years. The prices for both biodiesel and diesel, the primary blend component of B20, are projected to rise with increasing global oil demand and decreasing global oil supply (Figure 4.8.2 1).

Given these fuel prices, the relationship between the fuel cost differential and total cost of the Class 8 tractor and fuel over its lifetime is presented in Figure 4.8.2-2. Again, costs are presented for tractors in both local- and line-haul duty cycles to provide bounds on the economics for this vehicle segment. At the expected fuel cost differential, biodiesel tractors will have lifetime costs between $5,600 (local-haul) and $7,400 (line-haul) per vehicle more than diesel tractors, attributable to higher fuel costs. Regional-haul tractors, with annual mileage between that of local- and line-haul, are expected to see lifetime costs within these ranges. As established in Section 3.8, the societal benefit of biodiesel tractors ranges from $3,600 (local-haul) to $5,100 (line-haul) per vehicle. Hence, the incentive needed to make biodiesel Class 8 tractors economically attractive compared to diesel tractors may be more than the societal benefits gained in by switching to B20. As with the previous vehicle segments, the societal benefits offered by biodiesel may be much higher than those assumed in this assessment if feedstocks other than soybean oil are used.

95 Average B100 fuel cost differential of $0.63 per gallon from Clean Cities "Alternative Fuel Price Report," 2010 tracked to diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.

Figure 4.8.2-1

Biodiesel prices are expected to be approximately $0.10 per DGE higher than diesel prices over the next 25 years.

Efficiency Adjusted Fuel Price

(Class 8 Tractor)

Notes:
1) Diesel prices are derived from the reference case in U.S. EIA "Annual Energy Outlook 2012," June 2012.
2) B20 prices are weighted between average B100 fuel cost differential of $0.63 per gallon[96] and diesel price projections from U.S. EIA "Annual Energy Outlook 2012," June 2012.
3) Fuel prices include federal and state taxes.

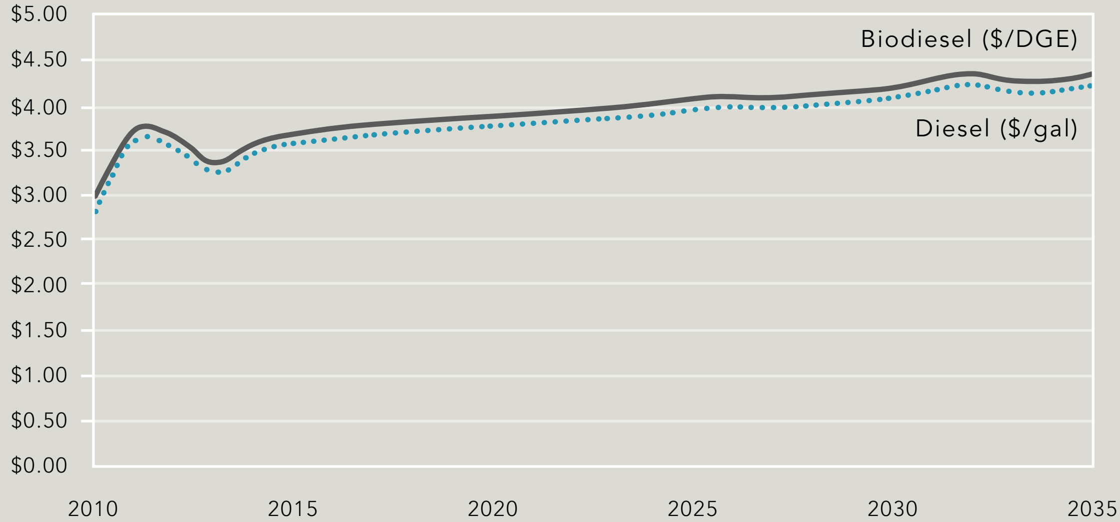
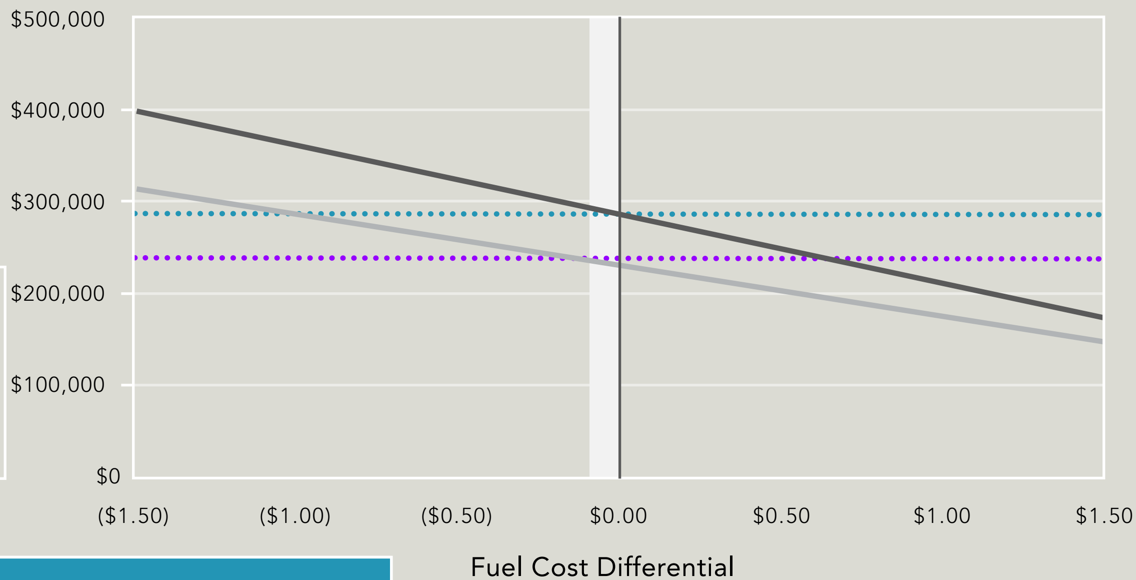


Figure 4.8.2-2

Within the expected fuel cost differential range, biodiesel Class 8 tractors will have lifetime costs approximately $5,600 to $7,400 per vehicle more than their diesel counterparts, and needed incentives may not be fully justified by their societal benefits.

Vehicle and Lifetime Fuel Cost Comparison

(Class 8 Tractor)



Assumptions:	
Baseline vehicle price, local[a]	$95,000
Baseline vehicle price, line[a]	$105,000
B20 vehicle price, local[a]	$95,000
B20 vehicle price, line[a]	$105,000
Annual mileage, local	40,000 mi
Annual mileage, line	120,000 mi
Baseline fuel economy, local	4.3 mi/gal
Baseline fuel economy, line	6.5 mi/gal
B20 fuel economy, local[b]	4.3 mi/DGE
B20 fuel economy, line[b]	6.5 mi/DGE
Vehicle lifetime, local	6 years
Vehicle lifetime, line	4 years

For details and sources for annual mileage, fuel economy, and vehicle lifetime of Class 8 tractors, refer to Section 3.8.

[a] TIAX LLC, "Life-Cycle Cost Model and Pollutant Emissions Estimator," prepared for Westport Innovations, Inc, 2008

96 Clean Cities. "Alternative Fuel Price Reports." 2010.

4.8 Heavy-Duty Class 8 Tractor
4.8.3 Implementation Considerations

In addition to compliance with emissions rules, Class 8 tractor purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can affect customer choices of alternatives.

Aside from compliance with emissions rules, for owners of Class 8 tractors across all duty cycles, the economics of operating these fleets of vehicles are the primary driver of purchase decisions. As such, the consumer perception of various alternative technologies for tractors depends on their financial tradeoffs. Technologies like LNG that can potentially offer lifetime savings may be viewed with interest, while technologies like biodiesel that may slightly increase costs may be met with hesitation by the customer. As described in the Heavy-Duty Vehicle Ownership and Production report in the overall TIAX assessment, these fleets may require payback periods of three to five years, and therefore, incremental vehicle costs cannot be too high and/or fuel cost savings must be substantial. In combination with economics, local-, regional-, and line-haul fleets may also place importance on enhancing their "green" image by reducing air pollutant and GHG emissions. As a result, if technologies offering societal benefits can also offer reasonable economics, Class 8 tractor fleets may view these technologies favorably (Table 4.8.3-1).

Depending on whether the vehicles are used in local, regional, or line-haul applications, tractors can be fueled at private fleet stations or public truck stops. Local- and regional-haul applications generally operate within a defined area and are thus conducive to refueling at both public stations and central fleet locations. Line-haul applications, on the other hand, travel for long distances over variable routes and accordingly rely on truck stops along the way. For vehicles that rely on centralized fueling at fleet-established stations, infrastructure to support alternatives will grow directly with vehicle population as long as the economics are favorable. For vehicles that rely on public infrastructure, the transition to alternative technologies depends on its existing availability. Compared to diesel's total of approximately 32,000 stations in the U.S., including both public retail stations (truck stops) and private fleet fueling facilities,[97] the infrastructure for biodiesel is less developed but growing, with 679 stations[98] in the U.S. at present that will likely expand to meet RFS biofuel targets. There are just 58 LNG stations in North America today,[99] all of which are in the U.S., but this number is also expected to grow as efforts to expand LNG infrastructure, including the Canadian government's planned natural gas fueling corridors along Highways 1, 2, and 401,[100] are implemented.

97 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
98 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
99 Ibid.
100 Neandross, E. "LNG Case Studies in the U.S. and Canadian Opportunities." Gladstein, Neandross and Associates presentation at the 2010 Canadian NGV Summit – Calgary, Canada. October 29, 2010.

Table 4.8.3-1

In addition to compliance with emissions rules, Class 8 tractor purchase decisions depend on economics and may be influenced by green image advantages for their fleets, both of which can drive customer perceptions of alternatives.

Vehicle Technology	Number of U.S. Stations	Consumer Perception
Diesel (baseline)[101]	32,000	Fuel is familiar and efficient
Biodiesel[102]	679	Can help enhance green image; economics may not be favorable compared to diesel baseline; potential issues at cold temperatures
LNG[103]	58	Can help enhance green image; economics may be favorable compared to diesel baseline for line-haul applications

101 TIAX LLC. "SCR-Urea Implementation Strategies Update." Prepared for Engine Manufacturers Association. 2006.
102 Alternative Fuels and Advanced Vehicles Data Center. "Alternative Fueling Station Counts by State." http://www.afdc.energy.gov/fuels/stations_counts.html. July 31, 2012.
103 Ibid.

4.9 Dependence on Other Foreign Materials

In addition to dependence on foreign transportation fuel, dependence on transportation fuel from geopolitically unstable regions of the world, particularly rare-earth minerals and platinum-group metals, may affect the North American transportation market.

One of the key social benefits of alternatives to conventional fuels is increased security through reduced dependence on geopolitically unstable regions of the world. However, these alternatives may also incur similar risks stemming from dependence on foreign materials other than oil (Table 4.9-1). Reliance on materials that are supply-constrained or largely controlled by a small number of foreign countries potentially poses volatility and uncertainty concerns for North America.

It is important to note that while diesel and biodiesel, which contains 80 percent diesel, are considered to be alternative fuels compared to the assumed baselines in this assessment, both will continue to rely on imported transportation fuels.

Rare-earth minerals are used in electric motors for HEVs, PHEVs, and BEVs[104] and are used in some fuel cell technologies as well. It has been recently reported that China may be blocking exports of rare-earth minerals. Given that China mines 95 percent of the world's rare-earth minerals, its export quota reductions will constrain supply of these materials, drive up prices, and hinder EV production.[105] Though rare-earth minerals are not actually particularly rare, mines are well-established in China, and their low costs have led other suppliers to shut down operations.[106] Uncertainty in the stability of rare-earth mineral supplies may affect the cost of EVs, including hybrid vehicles, and manufacturer decisions across multiple vehicle segments. A similar risk may be expected for lithium used for EV batteries, the majority of which is produced and located in Chile and Bolivia.[107] Recognition of the risks associated with foreign material reliance is now leading to increased efforts to develop and reopen domestic mines as well as seek material substitutes.[108]

Platinum-group metals include platinum, palladium, and rhodium, all of which are used as oxidation catalysts in vehicle catalytic converters to control exhaust emissions.[109] These metals can be found in light-, medium-, and heavy-duty vehicles that employ combustion technology, including gasoline, diesel, biodiesel, and natural gas vehicles. Some fuel cell technologies also require platinum-group metals. Though Canada and the U.S. produce some platinum, the majority of platinum-group metal supplies for North America come from Russia, South Africa, Germany, and the United Kingdom.[110] As with rare-earth minerals, disruptions of foreign supplies of these metals may also affect vehicle costs and manufacturer decisions across multiple vehicle segments.

104 Aston, A. "China's Rare-Earth Monopoly." MIT Technology Review. October 15, 2010.
105 Bradsher, K. "China is Said to Halt Exports to U.S. of Some Key Minerals." New York Times. October 19, 2010.
106 Aston, A. "China's Rare-Earth Monopoly." MIT Technology Review. October 15, 2010.
107 U.S. Geological Survey. "Mineral Commodity Summaries." http://minerals.usgs.gov/minerals/pubs/mcs/2010/mcs2010.pdf. 2010.
108 Aston, A. "China's Rare-Earth Monopoly." MIT Technology Review. October 15, 2010.
109 U.S. Geological Survey. "Mineral Commodity Summaries." http://minerals.usgs.gov/minerals/pubs/mcs/2010/mcs2010.pdf. 2010.
110 Ibid.

Table 4.9-1

Alternative vehicle technologies depend on key supply-constrained foreign materials, particularly transportation fuels, rare-earth minerals, and platinum-group metals, to various degrees.

Alternative Vehicle Technology		**Foreign Materials Dependence**			
		Petroleum	**Rare-Earth Minerals**	**Lithium**	**Platinum-Group Metals**
Light-Duty Passenger Car	Gasoline (baseline)	✓	None	None	✓
	BEV	None	✓	✓	None
	NGV	None for dedicated	None	None	✓
	E85 FFV	✓	None	None	✓
	Hydrogen FCV	None	✓	None	✓
	PHEV	✓	✓	✓	✓
Medium-Duty Class 2b Van	Gasoline (baseline)	✓	None	None	✓
	Biodiesel	✓	None	None	✓
	CNG	None	None	None	✓
	Diesel	✓	None	None	✓
	Electric	None	✓	✓	None
Heavy-Duty Class 4 Package Delivery Van	Diesel-HEV (baseline)	✓	✓	✓	✓
	B20-HEV	✓	✓	✓	✓
	CNG	None	None	None	✓
	Electricity	None	✓	✓	None
Heavy-Duty Class 6 Beverage Truck	Diesel-HEV (baseline)	✓	✓	✓	✓
	B20-HEV	✓	✓	✓	✓
	CNG	None	None	None	✓
	Electricity	None	✓	✓	None
Heavy-Duty Class 7 Transit Bus	Diesel-HEV (baseline)	✓	✓	✓	✓
	B20-HEV	✓	✓	✓	✓
	CNG	None	None	None	✓
	Electricity	None	✓	✓	None
Heavy-Duty Class 8 Refuse Hauler	Diesel-HEV (baseline)	✓	✓	✓	✓
	B20-HEV	✓	✓	✓	✓
	CNG	None	None	None	✓
Heavy-Duty Class 8 Tractor	Diesel (baseline)	✓	None	None	✓
	Biodiesel	✓	None	None	✓
	LNG	None	None	None	✓

5 Justification for Incentives

Comparisons of the direct costs and societal benefits of alternatives to conventional fuel indicate that vehicle, fuel, and/or infrastructure incentives may be fully justified for CNG, hydrogen, electricity, ethanol, biodiesel, and LNG across various vehicle segments.

One key role of the U.S. and Canadian federal government is to protect society as a whole, especially when the actions and economically-driven decisions of individuals may not. In addition to regulations and mandates, a major tool that the government uses is incentives that promote desired benefits to society. The amount of incentives, which affect direct costs seen by individual decision makers, should be justified by that society gains as a result. In the case of transportation, different alternatives offer different societal benefits, thus logically, each should receive tailored incentives commensurate with its benefits.

The comparisons of the direct costs and societal benefits of alternatives in the preceding discussions suggest that lifetime economics can be made favorable by justifiable incentives for some but not all alternative fuels (Table 5-1). Furthermore, these incentives may be applied to the vehicle, fuel, and/or infrastructure, but not all are necessary for all technologies. For light-duty passenger cars, the societal benefits of CNG vehicles, FCVs, BEVs, and FFVs may exceed their incremental vehicle and lifetime fuel costs over the gasoline baseline. Therefore, applying the monetized societal benefit to these technologies is justified. NGVs and BEVs may benefit from financial support to offset high initial vehicle costs and public and/or home refueling infrastructure costs. FCVs, under the commercial scale assumptions made in this assessment, may benefit from incentives for initial vehicle costs and expansion of public fueling infrastructure. For FFVs, vehicle costs are already generally favorable, so incentives would be best applied to the fuel to ensure E85 use and/or establish greater availability of public E85 infrastructure.

For medium-duty vans, the societal benefits of CNG and electric vehicles exceed their incremental vehicle and lifetime fuel costs over the gasoline baseline, and incentives equal to their societal benefits are justified. Natural gas and electric vans will benefit from financial support to offset both high initial vehicle costs and infrastructure costs for public and fleet stations.

For heavy-duty package delivery vans, beverage trucks, refuse haulers, and Class 8 tractors, the societal benefits of NGVs exceed their incremental vehicle and lifetime fuel costs over the diesel baselines. For all heavy-duty segments except Class 8 tractors, the benefits of biodiesel vehicles exceed their incremental costs. For heavy-duty package delivery vans, beverage trucks, and transit buses, the benefits of electric vehicles exceed their incremental costs. For all instances where benefits exceed incremental costs, the justified incentives can be applied to establishing fueling infrastructure. For tractors and package delivery vans, beverage trucks, and transit buses, incentives may also be applied to offsetting initial vehicle costs to encourage alternative fuel adoption.

Table 5-1

Comparisons of the direct costs and societal benefits of alternatives indicate the types of incentives, if any, that are justified for each alternative.

Vehicle Segment *(baseline)*	**Alternative Fuel**	**Incremental Vehicle and Lifetime Fuel (Costs) or Saving ($ per Vehicle)**[a]	**Societal Benefit ($ per Vehicle)**[b]	**For the Given Assumptions, if Expected Societal Benefit ≥ Incremental Cost, Where May Incentive Be Needed?**
Light-duty Passenger Car *(gasoline, MY2016)*	CNG (dedicated)[c]	(1,500) to 3,000	3,100	Vehicle Infrastructure (public, home)
	CNG (bi-fuel)[c]	2,500 to 7,000	2,600	
	Hydrogen[d]	(1,000) to 1,500	2,900	Vehicle Infrastructure (public)
	Electric (BEV)[e]	(3,000) to (5,000)	3,400 to 4,500	Vehicle Infrastructure (public, home)
	Electric (PHEV)[e]	(10,500) to (15,000)	1,500 to 2,200	
	E85[f]	500	2,100 to 3,400	Fuel Infrastructure (public)
Medium-duty Class 2b Van *(gasoline, MY2010)*	CNG[c]	(500) to 13,000	7,800	Vehicle Infrastructure (public, fleet)
	Diesel[g]	(3,500) to (5,500)	1,400	
	B20[h]	(5,500) to (7,500)	2,500	
	Electric[e]	(1,800) to 4,100	16,000 to 17,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 4 Package Delivery Van *(diesel-HEV, MY2010)*	CNG[c]	(14,000) to 25,000	12,000	Infrastructure (fleet)
	B20 (HEV)[h]	(2,700)	2,300	Infrastructure (upstream)
	Electric[e]	31,000 to 37,000	30,000 to 33,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 6 Beverage Truck *(diesel-HEV, MY2010)*	CNG[c]	(35,000) to 31,000	19,000	Vehicle Infrastructure (public, fleet)
	B20 (HEV)[h]	(4,400)	3,400	Infrastructure (upstream)
	Electric[e]	58,000 to 78,000	43,000 to 45,000	Vehicle Infrastructure (public, fleet)
Heavy-duty Class 7 Transit Bus *(diesel-HEV, MY2010)*	CNG[c]	(127,000) to 46,000	44,000	
	B20 (HEV)[h]	(5,000)	7,600	Infrastructure (upstream)
	Electric[e]	88,000 to 126,000	90,000 to 93,000	Vehicle Infrastructure (fleet)
Heavy-duty Class 8 Refuse Hauler *(diesel-HEV, MY2010)*	CNG[c]	(47,000) to 38,000	24,000	Infrastructure (fleet)
	B20 (HEV)[h]	(5,700)	3,900	Infrastructure (upstream)
Heavy-duty Class 8 Tractor *(diesel, MY2010)*	LNG[c]	(23,000) to 58,000	27,000 to 36,000	Vehicle Infrastructure (public, fleet)
	B20[h]	(5,600) to (7,400)	3,600 to 5,100	

a As compared to baseline vehicle
b As quantified by energy security premiums and environmental costs in Section 2.2
c Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from pipeline gas
d Assuming vehicle price at 85,000 vehicles/yr (not yet commercialized), DOE $3/GGE fuel price target (not yet available at scale), fuel from natural gas reforming
e Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from U.S. and California grid mixes
f Assuming zero incremental cost for FFV, EIA fuel price projections, fuel from corn and cellulosic biomass
g Assuming vehicle price at current production volumes, EIA fuel price projections, fuel from crude oil
h Assuming zero incremental cost for biodiesel vehicle, EIA fuel price projections, fuel from soybean oil

This assessment was sponsored by America's Natural Gas Alliance with the support of participating American Gas Association companies.

For questions, please contact:

TIAX LLC
20813 Stevens Creek Blvd, Suite 250
Cupertino, CA 95014

http://www.tiaxllc.com/services/

The opinions expressed within the Executive Summaries of Modules 1 and 2 of this market assessment are the work product of America's Natural Gas Alliance (ANGA) and participating American Gas Association (AGA) companies based upon data provided by TIAX LLC.

The Final Reports of Modules 1 through 5 are the work of TIAX LLC as a market assessment sponsored by ANGA with the support of participating AGA companies.