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16. Abstract

This report attempts to contribute to the timely area of alternative vehicular fuels. It addresses the analysis of fleet operation on alternative fuels, specifically compressed natural gas (CNG) and propane, in terms of both fleet economics and societal impacts. Comprehensive information on engine technology, fueling infrastructure design, and societal impacts are presented. An evaluation framework useful for decisions between any vehicular fuels is developed. The comprehensive fleet cost-effectiveness analysis framework used in previous Project 983 reports is discussed in great detail. This framework/model is flexible enough to allow substantial sensitivity and scenario analysis. The model is used to perform sample analyses of both fleet economic and societal impacts.

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VEHICULAR FLEET OPERATION ON NATURAL GAS AND PROPANE: AN OVERVIEW

by

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Research Report 983-5F

Research Project 3-4-90/2-983

Conversion of the SDHPT Automotive Fleet to Alternative Fuels

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1992

NOT INTENDED FOR CONSTRUCTION,
BIDDING OR PERMIT PURPOSES

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LIST OF REPORTS

Documentation for CNG Fleet Conversion Cost-Effectiveness Model, 983-1, December 1991.
Cost Effectiveness Analysis of TxDOT CNG Fleet Conversion, 983-2, Volume 1, August 1992.
Cost Effectiveness Analysis of TxDOT CNG Fleet Conversion, 983-2, Volume 2, August 1992.
Documentation for Propane Fleet Conversion Cost-Effectiveness Model, 983-3, October 1991.
Cost Effectiveness Analysis of TxDOT LPG Fleet Conversion, 983-4, Volume 1, November 1992.
Cost Effectiveness Analysis of TxDOT LPG Fleet Conversion, 983-4, Volume 2, November 1992.

ABSTRACT

This report attempts to contribute to the timely area of alternative vehicular fuels. It addresses the analysis of fleet operation on alternative fuels, specifically compressed natural gas (CNG) and propane, in terms of both fleet economics and societal impacts. Comprehensive information on engine technology, fueling infrastructure design, and societal impacts are presented. An evaluation framework useful for decisions between any vehicular fuels is developed. The comprehensive fleet cost-effectiveness analysis framework used in previous Project 983 reports is discussed in great detail. This framework/ model is flexible enough to allow substantial sensitivity and scenario analysis. The model is used to perform sample analyses of both fleet economic and societal impacts.

SUMMARY

This report discusses at length the potential of natural gas and propane as alternative transportation fuels for TxDOT. A comprehensive framework for cost analysis and societal impacts is presented. This framework will assist policymakers in developing strategies for promoting the use of alternative fuels in Texas.

IMPLEMENTATION STATEMENT

The objective of project 983 is to assist TxDOT in evaluation of compressed natural gas (CNG) and propane as alternative transportation fuels. The first two reports (983-1 and 983-2, Volumes 1 and 2) present the results of a cost-effectiveness evaluation of CNG for TxDOT fleets. Similarly, the third and fourth reports (983-3 and 983-4, Volumes 1 and 2) present the results of cost-effectiveness for propane. This final report presents a comprehensive overview of CNG and propane as alternate fuels, including a discussion of the cost-effectiveness models, as well as a discussion of broader societal impacts. A framework is presented that should assist policy makers in exploring strategies for implementation of alternative fuels. The cost data presented in this report are for illustrative purposes. Detailed cost analyses and model assumptions/formulas for all TxDOT fleets can be found in the earlier reports.

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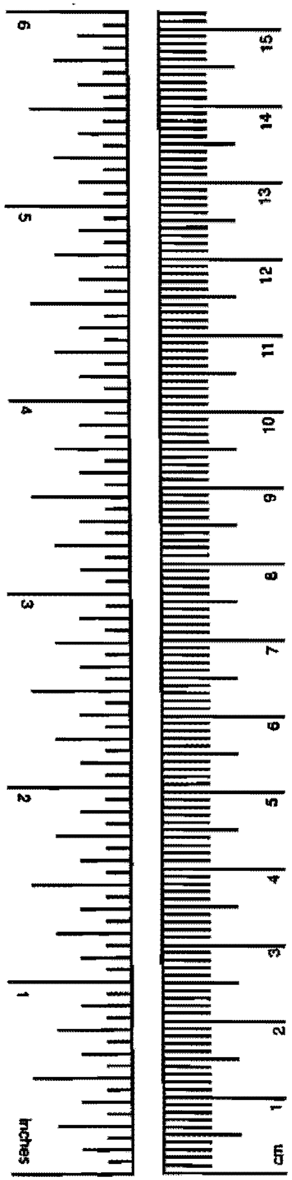
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.0765	meters cubed	m^3

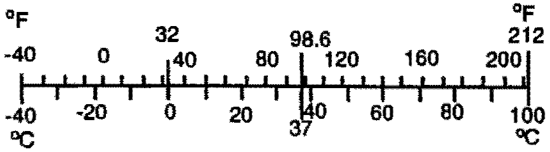
NOTE: Volumes greater than 1,000 L shall be shown in m^3.

Symbol	When You Know	Multiply by	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.20	square yards	yd^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1,000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

CHAPTER 1. INTRODUCTION

1.1 PROBLEM DEFINITION

In the last few decades environmental and energy security concerns, along with the more traditional congestion and mobility issues, have become prominent drivers of transportation planning and policy. Since motor vehicle fuels are predominantly petroleum-based and are the greatest source of transportation-related pollution, a number of initiatives to replace petroleum fueled vehicles with alternative fueled vehicles have been undertaken. The alternative fuels currently receiving the most attention are: methanol, ethanol, electricity, natural gas, propane, and hydrogen. These fuels have varying and uncertain impacts on both the environment and energy security, but are generally believed to offer benefits over petroleum-based gasoline/diesel fuels in both areas. There are also differing barriers to the introduction of the various fuels in the U.S. vehicular market. To generate more information towards answering these questions, a growing number of alternative fuel research and demonstration projects have been designed and undertaken to determine the impacts of alternative fuel use and the possibilities of introducing them into U.S. markets.

Much recent state and federal government legislation is impacting alternative fuel use. Chief among federal legislation are the 1990 Clean Air Act Amendments and the recently adopted national energy bill (H.R. 776). By mandating areas in non-attainment of National Ambient Air Quality Standards (NAAQS) to come into attainment, the Clean Air Act Amendments provide a strong impetus for low-emission alternative fueled vehicles. The newly adopted energy bill looks to domestic alternative transportation fuels to replace some of the less reliable foreign sources of petroleum that the U.S. currently relies on. Numerous incentives for alternate fuels are included in this legislation, including tax incentives for private owners and mandates for federal, state, and local fleets.

Initiatives to increase alternative fuel use have been enacted in several states, chief among them California and Texas. In California, air quality problems have driven the California Air Resources Board (CARB) to establish more stringent vehicular emission standards than the national standards set by the Environmental Protection Agency (EPA). Auto manufacturers are expected to use a variety of fuels and technologies to meet these standards. The standards define four groups of vehicles and require increasing numbers of these vehicles to be introduced over time. The four vehicle groups are:

1) Transitional low emission vehicles (TLEV): 10 to 20 percent of new car production between 1994 and 1996
2) Low emission vehicles (LEV): 25 to 75 percent of new car production between 1997 and 2003
3) Ultra low emission vehicles (ULEV): 2 to 15 percent of new car production between 1997 and 2003
4) Zero emission vehicles (ZEV): 2 to 10 percent of new car production between 1998 and 2003

The emission standards for these vehicles (at 50,000 miles) are shown in Table 1.1. The standards at 100,000 miles are 20 to 25 percent higher for non-methane organics (NMOG), nitrogen oxides (NO_x), and carbon monoxide (CO).

Table 1.1 CARB emission standards at 50,000 miles (grams per mile)

Vehicle Category	NMOG	NO_X	CO	Benzene	Fomaldehyde
Current	0.41	0.4	3.4	None	0.015
EPA 1994	0.25	0.4	3.4	None	0.015
TLEV	0.125	0.4	3.4	0.006	0.015
LEV	0.075	0.2	3.4	0.004	0.015
ULEV	0.04	0.2	1.7	0.002	0.008

It should be noted that under the 1990 Clean Air Act Amendments, other non-attainment areas may adopt the California program as one method of gaining federal approval of their air quality plans.

In Texas, environmental as well as regional economic considerations (the state is a large producer of natural gas) motivated the passing of Texas Senate Bill 740. This bill, which took effect September 1, 1991, requires that all new vehicles purchased by school districts with more than 50 buses, state agencies with more than 15 vehicles (excluding law enforcement and other emergency vehicles), and metropolitan transit authorities be capable of operating on natural gas or on a fuel with "similar emission characteristics". The Texas Air Control Board (TACB) subsequently ruled that propane, methanol, and electricity also qualify. Affected agencies can receive a waiver to these requirements if they can demonstrate that 1) the effort for operating a fleet on alternative fuels is more expensive than the effort for operating a gasoline/diesel fleet over its useful life or 2) alternative fuels or equipment (vehicles, fueling infrastructure, etc.) are not available in sufficient supply. These fleets are required to be operating 30 percent of their vehicles on qualifying alternative fuels by 1994, 50 percent by 1996, and, if deemed effective in lowering vehicular emissions by TACB, 90 percent by 1998.

In addition to legislative activity, private industry, trade groups, environmental organizations, and others are involved in promoting alternative fueled vehicle use. These entities are using a variety of promotional, research, and demonstration initiatives to accomplish their goals. Some of the entities involved include: American Gas Association, Natural Gas Vehicle Coalition, Gas Research Institute, Institute of Gas Technology, International Association of Natural Gas Vehicles, many local gas companies, Texas Propane Association, many local propane distributors, and the Environmental Defense Fund.

Significant barriers have prevented widespread use of alternative transportation fuels in the U.S.; the previously described initiatives are attempts to remove some of these. Currently, there are only about 350,000 propane, 30,000 natural gas, 6,000 methanol, and a handful of electric and ethanol vehicles operating in the U.S. (DOE, 1988a; J.E. Sinor, 1991). Ethanol and methanol are also currently blended into gasoline, but account for only about 0.8 percent of the total volume of gasoline used (Bush Administration, 1991). Barriers to increased alternative fuel use and their principal dimensions can be classified as follows:

1) Vehicle availability and attractiveness
    - Cost
    - Performance
    - Incentives

2) Fuel availability and attractiveness
    - Cost
    - Fueling infrastructure network
    - Supply

3) The vehicle/fuel availability paradox

4) Institutional inertia
    - Auto manufacturers
    - Oil companies
    - General public
    - Government

Different fuels face different barriers for use in transportation, just as they offer varying advantages over gasoline and diesel in terms of environmental and energy security aspects. These barriers are directly related to the areas where gasoline and diesel fuels have advantages over the alternatives. A thorough discussion of the barriers for all the different alternative fuels is outside the scope of this introduction. Instead, examples of each of the major barrier categories for some of the fuel types are presented, to give the reader an appreciation of these barriers. For more detail, the reader may refer to Sperling (1988a), various Department of Energy reports (1988a; 1988b; 1988c; 1989a; 1989b; 1990a; 1990b), or some of the other studies noted in the background review section of this chapter.

As an example of alternative fueled vehicle availability and attractiveness, consider the case of a compressed natural gas (CNG) dual-fueled pickup truck. Today, one could convert a gasoline pickup truck to run on CNG at a cost of about $2500. If original equipment manufacturers (OEM) were to design and build a dedicated optimized CNG pickup truck, the projected cost is about $900 more than a comparable gasoline vehicle (EPA, 1990a). These higher costs serve as a disincentive for purchasing CNG vehicles. Additionally, performance of the converted dual-fuel vehicle will be inferior to the original gasoline vehicle (power loss of about 10 percent, slight decrease in fuel efficiency, and comparable emissions), because the conversion would not take advantage of the unique attributes of natural gas. On the other hand, the OEM dedicated CNG vehicle should perform better than a comparable gasoline vehicle (similar power, better fuel efficiency, and reduced emissions). Further explanation of automotive engine technology is given in Chapter Three. Incentives such as pollution pricing and tax breaks for alternative fueled vehicle purchases would also affect the attractiveness of alternative fueled vehicles to potential users.

To continue the above CNG example for fuel availability and attractiveness, it can be shown that on an energy equivalent basis, natural gas costs less than gasoline and will probably continue to do so (AGA, 1989a; Taylor, Euritt & Mahmassani, 1992a). This produces an economic incentive for natural gas vehicle use. Yet, fueling infrastructure (i.e., filling stations) is currently inadequate to distribute natural gas to vehicles. There were only about 15 public and 260 private CNG filling stations throughout the U.S. in 1989, and with an estimated cost of $320,000 per station (300 vehicles per day capacity), there are economic disincentives to enlarging this network (DOE, 1990a). The long term supply of each fuel is also a factor, as is partial government financing for setting up fueling stations. Canada's government provided $50,000 towards each new CNG fueling station for up to 175 new stations (Cumming, 1986).

The previous discussion is a prelude to the next major barrier: how can one encourage users to buy vehicles or manufacturers to produce them when the infrastructure is not available to fuel them, and how can one encourage fuel suppliers to invest in filling stations when there are too few vehicles? As with all barriers, the various fuels are affected differently. This barrier has been particularly damaging to natural gas, because no significant gaseous fueling infrastructure is in place, and it is generally assumed that it would be easier to modify the existing liquid fueling infrastructure for ethanol and methanol than to add the required gaseous fueling infrastructure.

Finally, there is significant institutional inertia in the U.S. favoring gasoline and diesel fuels. Our society has grown accustomed to these fuels over the last century. Auto manufacturers and oil companies are major economic players and have much invested in gasoline/diesel vehicle usage. This is not to imply that profits from alternative fuels are unattainable. Oil companies are also heavily involved in natural gas and propane production and auto manufacturers are uniquely structured to engineer and produce efficient low-emission alternative fuel vehicles. Government and the general public have also grown used to gasoline/diesel vehicles. They both will require some changes for alternative fueled vehicle usage to become widespread.

It is generally agreed that some changes in current gasoline/diesel vehicle usage need to occur for the U.S. to attain its environmental and energy security goals. In addition to reducing vehicle miles travelled, improving vehicular fuel efficiencies, inspection and maintenance programs, congestion relief programs, and other measures, alternative vehicular fuels will continue to be pursued. Yet, it is also true that many barriers to alternative fuel usage exist. Many factors must be taken into account in order to decide which fuel or fuels to utilize and in what proportion. Analyses that address these factors and aid the various decision makers in the alternative fuels arena are currently being undertaken, but are still in short supply. This report is a contribution to that supply.

1.2 OBJECTIVES, SCOPE, AND FEATURES OF APPROACH

The general objective of this report is to develop a framework to aid decision makers (such as policy makers and fleet operators) in the evaluation of vehicular operation on alternative fuels and the formulation of a strategy in this regard. Towards this end, the following more specific objectives are pursued:

1) To develop procedures that can be used by decision makers to evaluate monetary costs and benefits of operation on alternative fuels and to formulate strategies to comply with alternative fuel legislation in the most cost-effective manner.
2) To provide a conceptual approach for dealing with the trade-offs between user cost/benefit considerations and broader societal goals.

3) To develop procedures for estimating the cost of the fleet fueling infrastructure necessary for alternative fuel operation.
4) To assess both current and future alternative fuel automotive engine technology, with regards to emissions, fuel efficiency, and performance.

In defining the scope of the research, the following items need to be specified: the decision factors to consider, the target decision maker, the fuels to which the analysis is applicable, and the users (fleets or individuals) to consider.

A multiobjective evaluation framework is appropriate for this study, since there are a variety of factors behind the push toward alternative fuel use (e.g., environment and energy security) and many other factors behind the barriers to their use. This report attempts to identify and incorporate all these factors into a comprehensive evaluation framework. In order to operationalize the framework for practical use, some of these factors are developed to a lesser extent than others. The nature of these factors and the manner they are incorporated into a practical evaluation framework are discussed in detail in Chapter Two.

Decision makers can be divided into users (fleets or individuals) or policy makers. This report concentrates on fleets and policy makers.

There are several fuels to consider, including methanol, ethanol, propane, natural gas, electricity, hydrogen, reformulated gasoline, and low-sulfur diesel. The particular focus of this study is on compressed natural gas and propane, relative to gasoline/diesel. These two fuels are being pursued vigorously in Texas and in most areas attempting to introduce alternative fuels. Recent Texas legislation (Senate Bills 740 and 769) was passed in order to promote fleet use of natural gas, propane, and/or electric vehicles. It is probably best to pursue all fuels to some degree in different geographical areas (Taylor, Euritt & Walton, 1991).

Although the evaluation framework is applicable to both individual and fleet usage of alternative fueled vehicles, the detailed analysis methodology is intended for fleet operations. One reason is that neither natural gas nor propane have large public fueling networks, so fleets which can provide their own fueling infrastructure are viewed as prime early targets for these fuels. Another is that Texas legislation mandating alternative fuel usage is at the fleet level, as are many other legislative efforts. Finally, there is not much in the literature specifically on fleet operations under alternative fuels.

Several approaches are helpful in evaluating decisions and policies in the alternative fuels arena. The features of the approach utilized in this study are as follows:

1) A multiobjective evaluation framework that identifies and highlights the principal criteria affecting decisions relating to alternative fuel vehicle usage.
2) Detailed economic cost/benefit evaluation methodology for use in analyzing fleet operation on CNG or propane. Its principal features are that it: a) is based on a life-cycle consideration of fleet operation on the alternative fuel versus gasoline/diesel, b) includes detailed accounting of costs incurred in connection with acquisition, operation, and maintenance of equipment, c) considers both near-term converted vehicles and future original equipment manufactured (OEM) vehicles, d) estimates fueling infrastructure costs based on fleet characteristics, e) gives the analyst great flexibility and the ability to conduct scenario and sensitivity analyses by allowing input of fleet characteristics, conversion factors, fuel price scenarios, vehicle costs, fueling infrastructure design constants, etc.
3) Methodology is applied to conduct sensitivity analyses under various scenarios for both real and hypothetical fleets, in order to draw some general conclusions and demonstrate the use of the methodologies.
4) Cost and sizing estimation procedures for fueling infrastructure that are based on engineering principles.
5) No attempt to place a value on controversial or difficult to quantify factors, such as the value of clean air or U.S. energy security. Instead, this approach seeks to derive the value one would have to place on these factors in order for operation on the alternative fuel to become cost-effective.
6) A qualitative discussion of the various societal impacts of CNG use, since these are not totally incorporated into the quantitative methodology.
7) A review of current and possible future CNG and propane automotive engine technology, since the social benefits and operational considerations of these fuels use depend on this technology.

1.3 BACKGROUND REVIEW

This section discusses some of the research work performed to analyze alternative fuels for roadway vehicles. This body of work can be divided into two main categories. First, works that summarize the state of knowledge to date on various alternative fuels in a qualitative manner. Second, works that attempt to quantify measures of effectiveness of the various fuels for comparative purposes.

1.3.1 Summary Studies

Summary studies, which qualitatively describe the current knowledge on alternative fuels, are very useful as references or as educational information. The International Association for Natural Gas Vehicles (1990) has produced a summary study on natural gas consisting of various sections: 1) the fuel itself (supply, properties, refueling operations), 2) natural gas vehicle technology, 3) operational aspects, 4) economics, 5) markets and market development, and 6) current use in different countries. The Environmental Protection Agency (1989; 1990a; 1990b; 1990c) has conducted similar studies for natural gas, methanol, and ethanol. Their studies concentrate on the economic and environmental impacts of those fuels, but also touch on safety, operational aspects, and associated factors, such as the impact of natural gas use on the home heating market and the agricultural side effects of ethanol use.

The Interagency Commission on Alternative Motor Fuels (1990), established by the Alternative Motor Fuels Act of 1988 (P.L. 100-494), has summarized the current state of knowledge on natural gas, methanol, ethanol, propane, and electricity. In the Commission's own words, the purpose of the summary is to "establish certain facts about alternative motor fuels. By reaching a consensus on these facts, we can project certain effects that use of alternative motor fuels would have. After reaching a consensus on these projected effects, we can develop a long-term plan that would produce the most desirable outcome in terms of environmental benefits and improved energy security." As a coordinated group of federal agencies, the Commission is attempting to plan long-term use of alternative fuels in the U.S. The various components in their summary are:

1) fuel properties,
2) production processes, feedstocks, and sources of supply,
3) fuel production and distribution costs,
4) vehicle technology and costs, and
5) environmental and safety issues.

The above is by no means all of the summary studies performed to date, though these studies are among the most complete of those reviewed by the authors. In addition, many of the comparative studies discussed in the next section provide excellent qualitative information.

1.3.2 Comparative Studies

No study performed to date has quantified all the impacts of alternative fuel use and compared all fuels. This section will present the studies according to which factors are considered, which fuels are analyzed, and how the comparison between fuels is made.

The California Energy Commission (1989) performed what is basically a user cost/benefit analysis, considering several different classes of users:

1) individual,
2) small private fleet,
3) large private fleet, and
4) government fleet.

They did not attempt to account for societal impacts. Their study was conducted for gasoline, methanol, ethanol, CNG, propane, and electricity.

Two studies reviewed attempted to analyze economic and environmental factors for natural gas relative to gasoline/diesel. First, the American Gas Association (AGA) (1989b) accounted for the wellhead, distribution, and public filling station costs influencing the price of CNG to individual users. By also including vehicle costs to the user, they computed the difference in costs between operation of vehicles on gasoline/diesel and CNG. By estimating the difference in emissions of reactive hydrocarbons and carbon monoxide between CNG and gasoline/diesel vehicles, they computed the cost (or savings) to remove a ton of each via conversion to CNG.

With a methodology very similar to the American Gas Association's, Radian (1990a and 1990b) performed two studies analyzing CNG as a replacement fuel. They used scenarios from several of the proposed federal alternative fuel legislative efforts of that time. The study differs from the AGA study in that fleets are converted, not individual vehicles. The study also incorporated nitrogen oxide emissions, in addition to non-methane hydrocarbons and carbon monoxide.

The U.S. Department of Energy (1988a; 1988b; 1988c; 1989a; 1989b; 1990a; 1990b) has published a series of reports on their ongoing study investigating the replacement of gasoline/diesel with alternative fuels for energy security reasons. Though they intended to treat other impacted areas, such as the environment, these areas are not central to the study. The study addresses questions related to the "comparative economics and down-to-earth implications of using various fuels, the nature and adequacy of their likely sources, and the costs of putting into place the 'infrastructure' of vehicles and fuel distribution outlets that could make their general introduction possible during the next 12 to 15 years." The research is directed to predict:

1) where the various alternative vehicular fuels will come from,
2) how large a share of the U.S. transportation market the supply will satisfy, and
3) all economic costs and benefits associated with a fuels switch.

The study considers methanol, CNG, electricity, and ethanol (as a blending agent) as fuels with the potential to significantly impact energy security in the near- and mid-term. At the time of this writing, the study has not been completed, so no final conclusions have been reached.

A study by DeLuchi, Johnston, and Sperling (1988) takes a more complete multiobjective approach in comparing natural gas (both liquified and compressed) to methanol. The study considers resource supply, vehicle performance, vehicle emissions, vehicle refueling, fuel storage, safety, financial costs, and the feasibility and implications of transitions to those fuels. The methodology entails a detailed life-cycle cost/benefit analysis including vehicle and fuel costs. It is then combined with qualitative evaluations of the other criteria to reach a value judgement conclusion that natural gas vehicles may offer slight economic and environmental advantages over methanol, but that a transition to natural gas would be more difficult.

Another multiobjective study was performed by Wyman (1988). Though the author does not select a fuel from those analyzed (ethanol, methanol, natural gas, and propane), he introduces the concept of a relative ranking system to compare the various fuels along certain criteria. The ranking is performed for various health, safety, and environmental criteria, in addition to vehicle performance and operational criteria. Radian (1989) uses a similar ranking system to evaluate the environmental, health, and safety issues associated with the use of gasoline, diesel, CNG (dedicated and dual-fuel), gasoline blends, M85 (85 percent methanol, 15 percent gasoline), M100 (100 percent methanol), and propane.

Sperling (1988a) performed a very thorough multiobjective study on all the prime alternative fuels, which addressed most of the factors generally considered to be of importance. This study was unique in its historical review of alternative fuel experiences, the depth in which it addressed feedstocks for the various fuels, and introducing the concept of pathways as a general organizing framework for analysis. Five possible future pathways are discussed (atomistic biomass fuels, petroleum-like mineral fuels, mineral methanol fuels, methane from mineral feedstocks, and hydrogen), along with the values and beliefs underlying these paths. The study uses a combination of quantitative and qualitative measures to determine preferred near-term choices in various geographic regions of the world, in addition to discussing the five future pathways.

Though by no means exhaustive, the studies presented in this section give a good review of:

1) which fuels have been analyzed to date,
2) what combinations of criteria have been analyzed, and
3) the various techniques used to perform the analyses.

1.4 OVERVIEW

This report is structured in a progressive way from development of an evaluation framework up to some sample analyses. The evaluation framework is developed in Chapter Two. Chapters Three and Four discuss the most important technical engineering considerations in the conversion to propane or CNG. The first of these is engine technology, which is addressed in Chapter Three. The next is fueling infrastructure, which is addressed in Chapter Four. In Chapter Five, a detailed cost/benefit analysis methodology is developed for assessing various criteria related to fleet operation on alternative fuels. This methodology is then applied for both actual and hypothetical fleets in Chapter Six. Scenario and sensitivity analyses are performed in order to draw conclusions relative to the cost-effectiveness of operating fleets on CNG and propane versus gasoline/diesel. Next, an attempt is made to account for societal considerations of CNG or propane use. Chapter Seven includes both a qualitative analysis of the societal impacts of CNG and propane use and a quantitative application of the methodology in order to derive the value that society would have to place on certain benefits for fleet conversion to CNG to become "cost-effective". Finally, Chapter Eight presents concluding comments.

CHAPTER 2. EVALUATION FRAMEWORK

This chapter describes the evaluation framework developed to aid in deciding whether to operate vehicles on an alternative fuel or gasoline/diesel. First, one must identify the various decision criteria. The first section identifies and explains these criteria. In order to choose between alternative fuels and gasoline/diesel one must jointly assess the criteria, but the measures of effectiveness for some criteria may be non-commensurable. For example, consider the comparison of the tons of a pollutant that could be reduced to the additional cost in dollars required for operation on a particular alternative fuel. The second section discusses the problems which are inherent in the joint consideration of the various criteria. The third section presents the applicable evaluation framework used in the rest of the report.

2.1 DECISION CRITERIA

Criteria were chosen based on the following: 1) a possible difference exists between operation on an alternative fuel and gasoline/diesel and 2) there are important reasons for these differences. All criteria are presented here, regardless of whether or not they are easy to use or are encompassed by the practical framework used in later chapters. It is convenient to divide these criteria into two broad categories: 1) user (individuals or fleets) and 2) societal. This division will facilitate evaluation by different decision makers: for instance, fleet operators are more concerned with fleet impacts, whereas government officials may have a mandate to consider societal criteria. Of course, this does not mean that users are not concerned with the societal criteria or vice-versa.

2.1.1 User Criteria

The user criteria described in the following paragraphs are as follows:

1. Monetary
2. Operational
3. Safety
4. Alternative fuel market failure risk
5. Public relations

Users are obviously concerned with any monetary differences between operation on alternative fuels and gasoline/diesel, as there are many differences in costs when operating on different fuels. The major cost differences for CNG and propane are discussed in great detail in subsequent chapters. It is sufficient for now to briefly discuss the following five cost categories relevant to all alternative fuels:

1. Fuel Price
2. Vehicle maintenance
3. Fueling infrastructure
4. Capital Vehicle
5. Miscellaneous operating

Fuel savings can be expected for CNG and propane fleets, since they are cheaper on an energy equivalent basis than gasoline/diesel, whereas hydrogen is currently more expensive, as are most of the other alternative fuels. Next, there is much theoretical and anecdotal evidence supporting claims of maintenance cost savings on some fuels, such as CNG, propane, and hydrogen, because of their "clean-burning" properties. Vehicles running on some fuels (CNG and electricity, for example) do not have the benefit of a large public fueling infrastructure. Therefore, users must provide their own at a cost. There are obvious differences in vehicle engine and fuel storage technologies for the various alternative fuels, which lead to different vehicle prices than comparable gasoline/diesel vehicles. Finally, there are other miscellaneous operating expenses, which vary according to fuel type. On-board storage tank recertification for CNG vehicles is one such expense.

A user is also concerned with any operational differences between alternative fuels and gasoline/diesel. Vehicular performance is one area where differences may occur. Depending on the fuel, these differences may occur in engine power, fuel efficiency, driving range, and decreased storage capacity in trunks or pickup truck beds due to the added fuel storage tank(s). Until alternative fuel use becomes more widespread, user concerns will include the expertise available for repair and maintenance. Fueling changes are also incurred. Fleet conversion to CNG usually implies building some sort of fueling station on-site, which will differ in performance from a gasoline/diesel station. An individual using an electric vehicle can recharge at home and may never have to use a public filling station. Finally, there are an assortment of maintenance changes that will occur, such as periodic inspection of high pressure onboard CNG storage tanks to comply with current regulations.

Differences in safety are of concern to users for many reasons, besides the obvious, such as liability, public relations (for companies that are users), and insurance. There are varying safety differences among all the fuels. These differences are mostly based on the combustion properties of the fuel, the manner of storing it on-board a vehicle, the method of refueling the vehicle, and the fuel's toxicity.

If vehicle market failure were to occur for any of the alternative fuels, any user already operating on that fuel would have to phase back into other fuels and incur a financial loss on any equipment purchased whose life could not be fully utilized.

Good public relations are a concern of most entities that operate vehicular fleets; public entities seek to avoid the consequences of a poor public image, and private companies know that a good public image contributes to their ability to remain profitable. Currently, in the U.S. both "buy American" and "environmentally sensitive" are marketable slogans and operating fleets on many of the alternative fuels allows the entity to use one or both in public relations campaigns.

2.1.2 Societal Criteria

The societal criteria described in this section are:

1. Urban environmental
2. Global environmental
3. Energy security
4. Foreign debt
5. Regional economic development
6. Lead-in to future vehicular fuels
7. Fuel availability

The passing of the 1990 Clean Air Act Amendments by the U.S. Congress and many state and regional air quality related regulations, along with increased public outcry at environmental degradation, illustrate the importance of the urban environmental criteria. These criteria envelope urban air, water, and land pollution. Air pollution is the key factor, because over half the U.S. population lives in urban areas that fail to meet the National Ambient Air Quality Standards (NAAQS) established by the Environmental Protection Agency (EPA) (Beckham, Reilly & Becker, 1990). Because vehicular sources contribute greatly to urban air pollution, the potential of alternative fuels for reducing, to varying degrees, point-source emissions relative to gasoline/diesel is a major reason for the interest in these fuels.

The global environmental criteria encompass global warming, acid rain, and land and water pollution. Though both the severity and consequences of global warming are still in doubt, sufficient evidence exists to make it an intensely debated topic, especially as some of the predicted consequences are of great magnitude. Several alternative fuels offer possible reductions in carbon dioxide (CO2) emissions, a gas that increases the warming effect. In addition, acid rain is an environmental problem that has been in the public eye for many years. Sulfur dioxide (SO2) emissions are a precursor to sulfuric acid in acid rain and some alternative fuels (natural gas and hydrogen) contain no sulfur, thereby eliminating SO2 vehicular emissions. Additionally, nitrogen oxides (NOx) are precursors to nitric acid, and the various fuels have differing impacts on emissions of these compounds.

U.S. energy security would be achieved if an energy supply is available at low and stable prices in sufficiently large and constant enough volume to keep the U.S. society satisfied and productive. One way of attaining national energy security is to replace some of the petroleum the U.S. currently imports from politically unstable areas (e.g. the Middle East) with fuels from secure sources, such as the U.S. and Canada. During 1989, 46.2 percent of the total amount of petroleum used in the U.S. was imported. The Department of Energy (DOE) expects this percentage to be 50 percent or higher through the year 2000 (ITE, 1991). Of the total U.S. petroleum use, about 50 percent is for roadway vehicles (DOE, 1988a; Bush Administration, 1991). Therefore, replacing petroleum fueled vehicles with vehicles fueled with domestic resources would contribute to the goal of energy security. One can envision scenarios where almost all alternative fuels could be produced domestically.

U.S. foreign debt is also a criterion, because it is large and growing annually. Since a significant sum goes towards the purchase of imported petroleum, any substitution with domestic fuels in vehicular use would contribute to decreasing foreign debt.

The potential for economic development in propane and natural gas producing regions (such as Texas, Oklahoma, and Louisiana) makes propane, CNG, or methanol vehicles attractive for these regions, as ethanol is for farming regions. A study conducted by researchers at Southern Methodist University claims that recent Texas alternative fuels legislation (Senate Bills 740 and 769) could create 8,000 new jobs in the state and increase personal income by $500 million per year (Texas General Land Office, 1990).

Alternative fueled vehicles as a lead-in to a sustainable vehicular fuel future (such as hydrogen from water or methane from biomass) is an area to consider, since the current use of gasoline/diesel vehicles has led to significant environmental and energy security problems, and petroleum is a non-renewable resource with a limited supply. It is sometimes projected that the use of natural gas and/or propane vehicles could put the U.S. on a social and technological path towards other gaseous vehicular fuels like hydrogen and methane from biomass, whereas gasoline, diesel, methanol and/or ethanol fuels might keep the U.S. on a liquid fuels path leading to the use of coal based liquid fuels (Sperling, 1988a; DeLuchi, Johnston & Sperling, 1988; Taylor, Euritt & Walton, 1991; Webb & Delmas, 1991). Producing environmentally sensitive gaseous fuels from renewable resources like water and biomass should be more sustainable than continuing to draw on environmentally damaging non-renewable resources like petroleum and coal.

Fuel availability is a decision criterion for two reasons. First, conversion of large numbers of vehicles to alternative fuels does not make sense unless the fuels will be available in large enough quantities for a long period of time. Second, the user's perception of a fuel supply deficiency may exist even in the absence of such a deficiency. Two such cases are: 1) the "energy crisis" in the early 1970's, where perceptions of small petroleum supplies spurred conservation efforts and 2) the years of regulating natural gas markets for fear of losing natural gas heating in the winter. Supply is a concern for all fuels. For example, propane supply is often questioned, because it is a by-product of both natural gas and petroleum refining. Electricity generation capacity is often cited as a constraint to electric vehicles, as is farm capacity for ethanol production.

2.2 OVERALL EVALUATION

In order to aid in decisions regarding the operation of fleets on different fuels, one must be able to jointly assess many (or ideally all) of the criteria presented in the previous section. Two problems are encountered in this process. First, it is probable that the measures of effectiveness of different criteria are non-commensurable. For example, urban air pollution is most readily described in terms of tons of pollutants emitted. Whereas, user monetary considerations are most readily described by dollars. Comparing or combining dollars with tons of a certain air pollutant is not straightforward, nor is there a universally accepted conversion factor between the two units. Secondly, some of the criteria may be difficult to quantify, such as the value of alternative fuel operation on fleet public relations or as a lead-in to a sustainable vehicular fuel future. Proxy measurements could be used, such as the profits attributed to a similar public relations campaign for a similar entity. Obviously, these measurements are highly subjective and therefore, could be quite inaccurate.

2.3 APPLICABLE EVALUATION FRAMEWORK

The evaluation framework of interest to this study considers the perspectives of different decision makers. For instance, a fleet operator will most likely accord only limited importance to the societal decision criteria, but will obviously be very concerned with user criteria. On the other hand, a government official will be concerned with both, since societal considerations are part of his/her mandate or mission, and interest in user issues is required, because the means of gaining the societal benefits is through users. Therefore, the framework must allow the analysis of different combinations of criteria from different perspectives in order to be of relevance to each particular decision maker.

The four types of decision makers supported by the framework are:

1) government (local, state, or federal),
2) fleet operator,
3) individual (standard), and
4) individual ("green").

A distinction between standard and "green" individuals is made to account for that proportion of the population that could be considered "green consumers" (i.e., those with enough environmental or social concerns to impact their purchase decisions). Table 2.1 is a presentation of the ideal combination of criteria required by each of the four types of decision makers.

Table 2.1 Ideal joint consideration of criteria

Criteria	Government	Fleet	Indivual Standard	Indivual Green
Urban Environmenta	X			X
Global Environmental	X			X
Energy Security	X			X
Foreign Debt	X			X
Regional Economic Development	X			X
Future Fuel Lead-In	X			X
Fuel Availability	X	X	X	X
Monetary	X	X	X	X
Operational	X	X	X	X
Safety	X	X	X	X
Market Failure Risk	X	X	X	X
Public Relations	X	X		

The following approaches to the previously mentioned non-commensurability and quantification problems involving the joint consideration of all the criteria were investigated. First, one could use a normalized relative ranking system for each fuel on each criterion. The decision maker could then provide their own weight to each criteria and a fuel decision could be made. A few studies using this approach for a selected subset of the aforementioned criteria have been examined (Radian, 1989; Urban Consortium Energy Task Force, 1990). This approach was not pursued, because alternative fuels legislation in Texas is largely based on monetary cost-effectiveness and the framework developed herein is targeted to assist in that evaluation. In addition, monetary considerations are usually fairly dominant in U.S. society.

Second, one could convert as many criteria measures as possible into units of dollars and use a standard monetary life cycle cost/benefit analysis procedure. This procedure was not adopted, because of the difficulty and controversy involved in assigning dollar values to societal criteria.

Third, one could provide qualitative information on the criteria to decision makers for assimilation and appropriate use. While a concise up-to-date qualitative discussion of the various fuels would be useful, this information is already largely available.

Finally, one could use a standard monetary life cycle cost/benefit analysis framework to analyze those criteria which are commonly measured in dollars and then compute the amount a decision maker would have to value a societal consideration, in order for operation on the alternative fuel to be cost-effective. This would facilitate comparison with the costs of other methods of achieving the same societal goal, while emphasizing the monetary decision criterion that is most pervasive in the U.S. free-market environment. This framework was chosen for use in this report.

The applicable evaluation framework encompasses monetary and some operational criteria (such as fuel efficiency, fueling differences, and maintenance) in a life-cycle cost/benefit analysis, while urban environmental, global environmental, energy security, foreign debt, and regional economic development criteria take on the dollar value one would have to place on these criteria's measures in order to achieve monetary cost-effectiveness. This framework does not specifically handle future fuel lead-in, fuel availability, safety, market failure risk, or public relations criteria. The decision maker must use value judgements to incorporate these into the decision.

2.4 CLOSURE

The ideal evaluation framework presented earlier in this chapter facilitates alternative fuel decision making by:

1) allowing the decision maker to look at the criteria important to them and
2) dividing these criteria into blocks (user and societal) convenient for the major decision makers in the alternative fuels arena (users and government officials).

The applicable evaluation framework utilized in the rest of this report is based on economic criteria. Yet, it allows the decision maker to analyze several decision criteria that are currently rivaling financial issues and which are the driving forces behind current pushes toward alternative fuel use in the U.S., environment and energy security.

CHAPTER 3. ENGINE TECHNOLOGY

Gaseous fueled engine technology is not as well developed as gasoline fueled technology. It is desirable for an early converter to a new technology to know something of the state of the current technology and the potential for future improvements. In this spirit, this chapter presents an overview of some of the key engine design factors for any spark ignition internal combustion engine, how these factors relate to gaseous fueled engine design, and insight into the current and future state of gaseous fueled automotive engine technology. This discussion emphasizes natural gas, yet propane is addressed to a lesser degree. Also, the discussion is limited to spark ignition engine technology, as it is more developed at this time than compression ignition (used to ignite diesel fuel) gaseous fuel technologies.

The first section discusses one of the key design parameters of internal combustion engines, the air/fuel mixture. Combustion in the engine's combustion chamber is presented next, followed by a discussion of emissions. The following section examines engine design trade-offs required between emissions, fuel efficiency, and power. Finally, an assessment of current and future gaseous fueled engine technologies is presented.

3.1 AIR/FUEL MIXTURE

In order to power an internal combustion engine, fuel is burned in the presence of the oxygen contained in air. The ratio of the amount of air to the amount of fuel (air/fuel or A/F ratio) is a key engine design factor. The stoichiometric A/F ratio is the chemically correct ratio. A rich mixture has a lower A/F ratio than stoichiometric, meaning there is less air per unit mass of fuel, and a lean mixture has a higher ratio, meaning more air per unit mass of fuel. The stoichiometric equation for octane (C_8H_{18}) combustion is shown here and can be used as a simple representation of gasoline combustion.

$C_8H_{18} + 12.5O_2 + 47N_2 \Rightarrow 8CO_2 + 9H_2O + 47N_2$
15.1/1 A/F ratio by mass; 59.5/1 by volume (1)

Since gasoline is actually a mixture of hydrocarbon molecules (C_XH_Y, where X and Y take on several values), its stoichiometric A/F ratio by mass is closer to 14.7/1 and by volume is only slightly different than 59.5/1. The stoichiometric equations for HD-5 Propane (where HD-5 indicates the fuel meets minimum specifications for spark ignition engines), pure propane, and methane (which constitutes approximately 85 to 95 percent of the volume of pipeline-quality natural gas) are shown below for comparison.

HD-5 Propane

$0.9C_3H_8 + 0.05C_3H_6 + 0.05C_4H_{10} + 5.05O_2 + 19N_2 \Rightarrow 3.05CO_2 + 4H2O + 19N2$ 15.8/1 A/F ratio by mass; 24/1 by volume (2)

Propane

$C_3H_8 + 5O_2 + 18.8N_2 \Rightarrow 3CO_2 + 4H_2O + 18.8N_2$
15.6/1 A/F ratio by mass; 23.8/1 by volume (3)

Methane

$CH_4 + 2O_2 + 7.52N_2 \Rightarrow CO_2 + 2H_2O + 7.52N_2$
17/1 A/F ratio by mass; 9.5/1 by volume (4)

Notice that the A/F ratios by volume of HD-5 Propane, propane, and methane are much less than that of gasoline. This illustrates how much less dense they are than gasoline.

By comparing an equal volume of Air/Methane mixture (60.5 moles), which is what one will get in the cylinder of an engine, to the above Air/Octane mixture, the emissions advantage of natural gas over gasoline is highlighted. The combustion equation for this equal volume of Air/Methane is:

$5.75CH_4 + 11.5O_2 + 43.25N_2 \Rightarrow 5.75CO_2 + 11.5H_2O + 43.25N_2$ (5)

The output of CO_2 in equation (5) is only 5.75 moles compared to 8 moles from octane combustion in equation (1), which is of course representative of gasoline combustion, for a decrease of 28 percent in CO_2 emissions. On a per unit of energy basis, CO_2 emissions decrease 24.0 percent from methane combustion and 10.4 percent from propane combustion relative to gasoline (IANGV, 1990). The same principle can be applied to carbon monoxide (CO) emissions. Methane releases a greater percentage of its energy through the combustion of hydrogen than does gasoline, producing more water emissions, which is obviously not of concern. The next two largest constituents of pipeline-quality natural gas, ethane (C_2H_6) and propane (C_3H_8), which together make up 5 to 10 percent by volume of the gas, also have lower carbon to hydrogen ratios than gasoline. Therefore, their combustion also produces less CO_2 and CO than gasoline, though the percentage reduction is not as large as that from methane. Since methane, ethane, and propane constitute around 98 percent (by volume) of natural gas, it follows that natural gas combustion has the potential to produce significantly less CO_2 and CO than gasoline combustion. Finally, propane has the potential to reduce CO_2 and CO emissions over gasoline, but not as much potential as natural gas.

3.2 COMBUSTION

It is desired to have normal combustion of this A/F mixture in the combustion chamber. *Normal* combustion is a smooth burning of the mixture with the flame front propagating outward from the spark in all directions. *Premature detonation* of some of the mixture before the flame front gets to it may occur if combustion temperatures get too high. This phenomenon, commonly known as knock, causes performance degradation and engine wear. A fuel's octane rating is an indication of its resistance to knock, with higher octane numbers indicating greater resistance. *Misfiring,* another type of abnormal combustion, occurs when the mixture is too lean to ignite or the spark too weak. This causes obvious performance degradation and high emissions of unburned fuel. Combustion is most efficient in a homogeneous A/F mixture, since every fuel molecule would then be in close reaction proximity to oxygen. Since homogeneity is more attainable when mixing two gases than when mixing a liquid and a gas, both propane and natural gas have an advantage over gasoline.

3.3 EMISSIONS

Whether combustion is "perfect", thereby converting all fuel to CO_2 and H_2O, or not, CO_2 will be emitted to the atmosphere. Since CO_2 is the most prominent greenhouse gas contributing to global warming, the inherent advantage of natural gas and propane over gasoline in limiting this emission is important. Since combustion is never "perfect", compounds other than CO_2 and H_2O are always formed. The three most prevalent harmful engine emissions from either gasoline, natural gas, or propane are hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_X). Consequently, these emissions must be controlled.

3.3.1 Hydrocarbon Emissions

Hydrocarbon emissions consist of a variety of C_XH_Y molecules and as a group are commonly referred to as HC. HC emissions occur because not all of the fuel, itself composed of HC molecules, is consumed during combustion. Quenching of combustion in certain parts of the combustion chamber, namely along the walls where the metal's surface may be cool and in crevices, such as those between the piston and rings, into which the mixture is forced by high compression pressures, causes HC emissions at all engine operating conditions. HC emissions are higher at rich mixtures, because there is not enough air to combine with all the fuel. Rich mixtures are used in current gasoline engine designs at idle, acceleration, and deceleration to offset either dilution of the mixture with exhaust gases or the non-homogeneity of the mixture. At these operating conditions, the better homogenizing properties of natural gas and propane are again an advantage over gasoline. The likelihood of high HC emissions due to misfiring is also lessened with gaseous fuels, because their homogenizing properties allow combustion of leaner mixtures than gasoline. It should also be noted that natural gas' most prevalent HC emission is methane, which has for all practical purposes zero photochemical reactivity in ozone (smog) production. Since the principal concern about HC emissions is their role in producing ozone, only the non-methane hydrocarbon (NMHC) emissions should be of significance. Natural gas has a much greater potential for lowering NMHC emissions than does gasoline.

3.3.2 Carbon Monoxide Emissions

CO is created when not enough oxygen is present to oxidize the carbon completely to CO_2. CO emissions are dependent on the A/F mixture. The leaner the mixture the better, as there is then more oxygen available to combine with the carbon; as mentioned already, gaseous fuels lend themselves to lean combustion. Additionally, both natural gas and propane combustion will emit less

CO than gasoline, because of their lower carbon to hydrogen ratios.

3.3.3 Nitrogen Oxide Emissions

The last major emission to control is NO_X, which consists mainly of NO and some NO_2. It is formed from nitrogen, which makes up approximately 78 percent of air, combining with the leftover oxygen after the flame has passed. NO_X increases with both combustion temperature and duration. Combustion temperatures depend on ambient air temperature, coolant temperature losses, ignition timing, and A/F ratio among others. The highest temperatures occur at approximately stoichiometric A/F mixtures, so this is where NO_X emissions are the greatest, and they lessen for both rich and lean mixtures. The flame temperature of the fuel is also a factor. As both methane and propane burn cooler than gasoline, these fuels gain an advantage in reducing NO_X. However, the flame propagation rate is slower for natural gas than for gasoline, and the resulting longer combustion duration is a disadvantage. Increasing the compression ratio will cause combustion temperatures to rise, which increases NO_X. By allowing leaner mixtures, gaseous fuel NO_X emissions can be decreased. It is obvious that a natural gas engine, depending on what design trade-offs are made, could possibly increase or decrease NO_X emissions relative to gasoline. NO_X is therefore the major emission problem for natural gas engines, and not surprisingly, natural gas engine designs to control NO_X are receiving a growing proportion of the available research resources. The dependence of NO_X, CO, and HC emissions on A/F ratio is illustrated graphically in Figure 3.1. This figure illuminates the emissions trade-offs necessary in the design of A/F mixture control systems.

3.4 ENGINE DESIGN TRADE-OFFS

Engine design must consider trading off control of emissions with desired features such as fuel efficiency and power. Trade-offs are necessary, because fuel efficiency is best at lean A/F mixtures, where all fuel molecules have a good chance of combining with oxygen, thus getting the most out of the fuel. On the other hand, power is greatest at rich mixtures, where more fuel molecules will actually burn. As noted earlier, trade-offs that usually cause higher emissions must be made at certain engine operating conditions such as idle, acceleration, and deceleration in order to achieve necessary engine performance. Also, trade-offs against low emissions must be made to ensure that every cylinder has a combustible Air/Gasoline mixture. In order to ensure that no single cylinder has too lean a mixture some cylinders get too rich a mixture, which leads to higher HC and CO emissions from those cylinders. Gaseous fuels mix more thoroughly, and therefore help to reduce the conflict underlying these trade-offs.

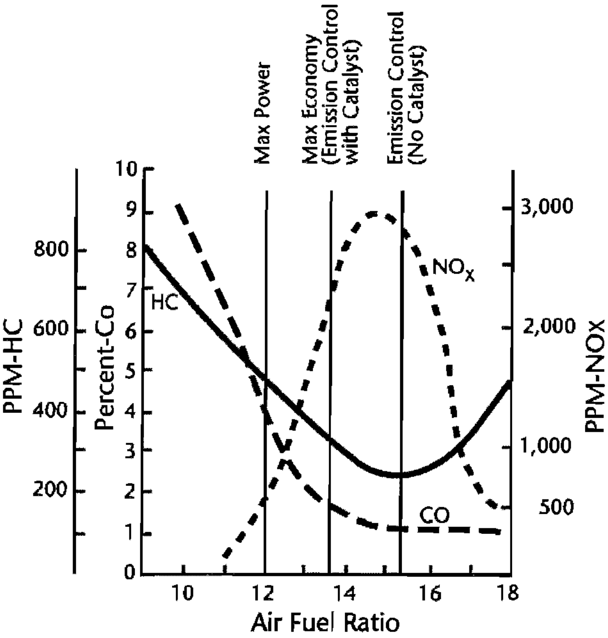


Figure 3.1 ***The shape of typical HC, CO, and NO_x exhaust emission curves from an uncontrolled gasoline engine (Ellinger, 1981)***

The power produced by an engine is proportional to the energy content of the volume of A/F mixture in the cylinder, assuming the mixture is combustible. The energy density of various stoichiometric A/F mixtures of interest are:

Gasoline	-	84.6 MJ/kmol of A/F mixture
HD-5 Propane	-	82.6 MJ/kmol of A/F mixture
Natural Gas	-	75.5 MJ/kmol of A/F mixture

These values show that power output will be less with both propane and natural gas than with gasoline, if used in the same engine. The theoretical power losses of 2.3 percent for propane and 10.8 percent for natural gas can only be used as baselines, because of other changes that occur during an engine conversion or optimization, such as changes in volumetric efficiency, A/F ratio, and ignition timing (Topaloglu & Elliot, 1986; Wallace, 1989).

One method of recovering this power loss is by increasing the engine's compression ratio. This is the ratio of the volume of the cylinder/combustion chamber area when the piston is at the bottom of its stroke to the volume when the piston is at the top of its stroke. The effect of increasing this ratio is to increase the combustion pressure, thereby increasing both output power and combustion temperature. The maximum attainable compression ratio is limited by knock, because of the direct relationship between rising combustion temperatures and premature detonation. High octane fuels, like natural gas and propane with octane numbers of about 120 and 98, respectively, compared to premium unleaded gasoline's rating of around 93, limit knock and allow significantly higher compression ratios. Turbocharging, which compresses more A/F mixture into the cylinder and hence more energy, can also be used to increase power.

3.5 CURRENT AND FUTURE GASEOUS FUELED ENGINE TECHNOLOGY

Several studies and reports have concluded that gaseous fueled vehicles have the potential to perform at least as well, obtain better fuel efficiencies, and produce fewer emissions than gasoline vehicles, for the following reasons (Durbin, 1989; Sierra, 1989; Wallace, 1989). First, it is easier to create a homogeneous A/F mixture with gaseous fuels, which allows more complete combustion and combustion of leaner mixtures. Second, the low carbon content of natural gas and propane will produce less CO and CO_2 for the same energy output. Finally, their high octane ratings will allow natural gas and propane engines to use higher compression ratios to increase power to at least that attainable by gasoline engines.

The emissions discussed thus far are measured at the output of the exhaust valve of the cylinder and are referred to as engine-out emissions. These emission levels are quite different from those that are emitted to the atmosphere from the tailpipe of most modern (late 1970's and beyond) gasoline powered automobiles. In modern automobile designs a catalytic converter is used to catalyze the following reactions of the engine-out emissions:

$$NO_X \Rightarrow N_2 + O_2$$
$$CO + O_2 \Rightarrow CO_2$$
$$C_XH_Y + O_2 \Rightarrow CO_2 + H^2O$$

The catalysts (rhodium, platinum, and palladium) and the design of the converter have been optimized to reduce stoichiometric gasoline combustion emissions. Very effective feedback control systems have been developed to monitor the oxygen levels in the engine-out exhaust and automatically keep the A/F mixture stoichiometric, where catalyst efficiency is highest and the "drivability" that consumers demand can be met. Sophisticated exhaust gas recirculation (EGR) systems reduce NO_X emissions by reducing combustion temperatures through the dilution of the A/F mixture with exhaust gases, but do so only when high engine power is not needed. Gaseous fuel combustion is better than gasoline combustion in such dilute mixtures, because gases mix more thoroughly. These and other automatic adjustments, such as ignition timing controls, are used to minimize the performance compromises necessary to meet today's low emission standards.

Since very few factory built gaseous fueled automobiles have been produced, gasoline vehicles are typically retrofit to operate on either propane or natural gas. These converted vehicles may produce unfavorable emission levels relative to gasoline, even though the gaseous fuel itself offers better emissions potential than gasoline. The primary reasons for this are that most of the control systems used in current conversion equipment are at a mid-1970's technology level and the catalytic converter used is the one already on the car, which was designed for gasoline emissions. Results of several emissions tests on converted natural gas vehicles bear this out (Sierra, 1989; Siesler, 1989; EPA, 1990a). The tests are not entirely conclusive, showing emissions sometimes better and sometimes worse with natural gas, but generally the trend is for lower HC and CO and somewhat higher NO_X. There is a definite power loss on converted natural gas vehicles, since an Air/Natural Gas mixture has less energy than an equal volume of Air/Gasoline mixture, unless the conversion consists of increasing the compression ratio or turbocharging, neither of which is done very often. A smaller loss of power is incurred for a propane conversion. Improvements in natural gas conversion technologies are forthcoming. Sierra Research (1989) reports that a few systems similar to the closed-loop carburetor systems of the early 1980's are now commercially available and that two of the systems tested by the EPA showed favorable emissions performance. They also report that several systems with technology like that of modern fuel-injected cars are in the late stages of development.

In the near term (1992-1994) it appears that spark ignition natural gas vehicles, both converted models and manufactured originals, will improve by using technologies similar to today's gasoline vehicles (Sierra, 1989; Gauthier, 1989). This involves optimizing timing, air/fuel ratio, and EGR control systems for all ranges of engine operating conditions, in addition to developing catalyst systems optimized to reduce post combustion natural gas emissions, while using conventional stoichiometric Air/Natural Gas mixtures. In all probability, they will use high compression ratios to increase power, if dedicated to operate on natural gas. Sierra Research (1989) expects that a vehicle designed as such for natural gas will match current gasoline vehicle NO_X emissions, while significantly improving NMHC and CO emissions and increasing fuel efficiency by 15 to 20 percent. They point out that this is speculative based on current knowledge and may be overly optimistic.

Much current and planned future work is centered on lean-burn engine technology for natural gas. As noted previously, natural gas lends itself to this technology, because it will successfully combust at leaner mixtures than gasoline, thus reducing NO_X, HC, and CO engine-out emissions as well as improving fuel efficiency. This technology should be especially useful in lowering NO_X emissions and is particularly important given the current problems natural gas engines have with NO_X. Control systems, which provide richer mixtures when higher power is required, will be incorporated into these designs. Also, catalytic converters will need to be optimized to catalyze the reduction reactions of lean-burn natural gas emissions. Much of the current work on lean-burn technology is in the area of heavy-duty engines, and Sierra Research (1989) predicts that these heavy-duty lean-burn engines will emit significantly less HC, CO, and NO_X than their gasoline counterparts. They predict the same for light-duty lean-burn engines, but at a later date.

The same technology improvements discussed above are also possible for propane engines. With these advances, propane engines should be able to achieve emissions and fuel efficiency improvements over gasoline, but not quite as large as those possible with natural gas. In addition, the power output from future propane engines should be comparable to both natural gas and gasoline (Wallace, 1989).

CHAPTER 4. FUELING INFRASTRUCTURE

The large gasoline and diesel fueling infrastructure network in the U.S. services both fleet and individual vehicles. Numerous public fueling stations allow easy access to these fuels. In addition, many fleets find it less expensive and/or more convenient to operate their own on-site gasoline/diesel fueling stations. As discussed in Chapter One, alternative fuels do not currently have a large fueling infrastructure network, and this is one of the major barriers to their use.

This chapter discusses the fueling infrastructure required for both natural gas and propane. The discussion concentrates on the fueling of fleet vehicles, not individual vehicles, though the discussion of public fueling is applicable to both.

The first five sections discuss compressed natural gas (CNG) fueling infrastructure. A fleet considering operation on CNG has several fueling options. The first of these, use of public fueling stations, is discussed in the first section. If the fleet wishes to provide its own on-site fueling, several possibilities exist: slow-fill, fast-fill, combination slow/fast-fill, and nurse-truck. These options are discussed in this order in the next four sections. The only other fueling option for CNG, the home compressor unit, is not addressed.

The fleet operator faces two principal concerns when making decisions pertaining to the feasibility of purchasing and operating a CNG station. First, the station must meet the operational needs of the fleet. This is of particular significance because CNG stations operate differently than traditional liquid fueling stations. Secondly, this fueling capability should be provided economically. Each of the four alternatives has varying operational and cost ramifications. In order to better assess whether or not a CNG station can meet these two concerns, the four sections pertaining to on-site CNG fueling explain how the various types of CNG stations function, identify the cost components incurred in setting up and operating a station, and discuss some of the criteria affecting the design of a station. In the case of fast-fill, a methodology for estimating the station costs for a particular fleet is also presented. Greater emphasis is placed on fast-fill station design, because this mode of fueling provides service that is most comparable to that of current gasoline/diesel stations.

A fleet considering operation on propane can also either use public fueling stations or provide its own on-site station, for which only one possible technology is available. These two options are discussed in this order in the next two sections. As for on-site CNG fueling, the discussion of on-site propane fueling explains how a propane station functions, identifies the cost components incurred in setting up and operating a station, discusses some of the criteria affecting the design of a station, and presents a methodology for estimating the station costs for a particular fleet.

4.1 CNG PUBLIC FUELING

In 1990, there were only about 15 public CNG fueling stations in the United States (DOE, 1990a). Although more opened in 1991 and more are planned for the future, it is still uncertain whether there will be an adequate number within the near- and mid-term to support large scale CNG fleet operations. Even if public CNG fueling service was equivalent to that of gasoline/diesel, the extra labor and fuel costs incurred by a fleet in order to use public fueling stations have been considered as significant enough for many fleets to provide their own fueling stations. Consequently, it is probable that the implementation of CNG as an alternative fuel for fleets will require the development of on-site fill stations.

4.2 SLOW-FILL

In a slow-fill operation a compressor compresses natural gas from the pipeline (typically 5 to 50 psig) directly into the vehicle's storage vessel (typically 3000 psig). Any number of vehicles may be filled in parallel and the fueling session time is on the order of hours. The session time is best thought of as the amount of down-time between vehicle shifts, which for most fleets is overnight or approximately 12 hours. A fuel probe and hose must be provided at the location where every vehicle requiring fueling is parked during the down-time. A fuel probe is connected to each vehicle as the latter is parked. The compressor starts automatically when the first vehicle is connected. As each vehicle's storage becomes full, its fuel probe automatically shuts off the gas flow to that vehicle. When all vehicles are full, the compressor automatically shuts off. Drivers disconnect the fuel probe before using the vehicle.

The four major cost components for setting up a CNG slow-fill fueling station are:

1) compressor costs,
2) dispenser costs,
3) miscellaneous component costs, and
4) construction/installation costs.

Following set up, two other costs are incurred:

5) operating costs and
6) maintenance costs.

Compressor costs are dependent on the amount of fuel required daily by the fleet and the amount of time to deliver it (the fleet down-time). Dispenser costs are related to the number of vehicles fueling per session, as each vehicle requires a fill hose and fuel probe. If metering of gas to each vehicle is required a significant cost is incurred, since each hose then requires a meter. Miscellaneous component costs consist mainly of the piping required to connect the compressor to the fuel hoses and some electronics.

Construction/installation costs include the concrete and structural work necessary to house the compressor, in addition to labor and materials required to install the piping connecting the compressor to the fuel hoses. This piping is sometimes run underground with fuel posts protruding up from the ground to which the fuel hose/probe is attached. Otherwise, the piping is run above ground underneath a canopy covering the vehicle parking spaces. In this case, the fuel hoses drop down from above. In addition to the type (underground or overhead) of facility desired, the cost is dependent on the number of parking places and their location in relation to the compressor. Finally, this cost includes the administrative overhead necessary to set up the station.

Operating costs are those incurred to power the compressor. Maintenance costs are also mostly compressor related, although minor maintenance to structures and piping will be necessary.

In order to meet fleet fuel demands, the compressor must be sized to provide at least the average daily fleet demand for natural gas (the session demand in standard cubic feet (scf), $D_{session}$) in the down-time allowed (the session time in minutes, $T_{session}$). The minimum compressor size in standard cubic feet per minute (scfm) required, C_{min}, is computed from:

$$C_{min} = D_{session}/T_{session} \qquad (1)$$

This compressor size is the minimum required for two reasons. First, $D_{session}$ is based on average daily demands, so on days where demand is higher than average some vehicles will not be filled completely. Secondly, $T_{session}$ is the fleet down-time allowed. If a vehicle finishes late one evening and/or starts out early the next morning, then it will not be filling over the entire session time and therefore, may not fill completely. A fleet may wish to account for this variability by oversizing the compressor or by providing a minimal fast-fill capability in combination with slow-fill. The latter is discussed in a later section.

The number of fuel hoses required is based on the number of vehicles in the fleet, their daily fuel demand, and the amount of on-board storage on the vehicles. This is illustrated best via an example, which also illustrates how to use equation (1) to size the compressor. Consider a fleet with 20 vehicles all of the same type. Each vehicle has an on-board storage capacity of 600 scf and utilizes on average 300 scf of natural gas per day, for a session demand of 6000 scf (20 x 300). The vehicles are utilized between 7:00 AM and 9:00 PM, so the session time is 10 hours (or 600 minutes). The minimum compressor size required for this fleet is 10 scfm (6000/600). One can provide 20 fuel hoses and top off each vehicle daily. However, significant savings occur if fleet operations allow vehicles to alternate fueling every other day, since each vehicle has two days worth of fuel onboard. In this case only 10 fuel hoses are required. This reduction in the number of fuel hoses, probes, posts, and meters (if required), along with the reduced length of piping required and subsequent reduction in construction/installation costs can be significant. The trade-offs between onboard storage capacity and the number of fuel hoses required is interesting, but outside the scope of this study.

4.3 FAST-FILL

Many companies (vendors) design and construct CNG fast-fill fueling stations. To be able to analyze different designs and choose one that provides for the fleet's needs in the most cost effective manner, the fleet operator needs to know how a fast-fill station works. There are two main fast-fill station design types. The first, which can be referred to as *pure compression,* uses a compressor with a large enough flow rate, usually defined in standard cubic feet per minute (scfm), to fill the fleet's representative vehicle in a time similar to gasoline/diesel. The other, which can be referred to as *compression/storage,* compresses natural gas into storage containers at a higher pressure (nominally 3600 psig) than the vehicle storage pressure (nominally 3000 or 2400 psig). When the vehicle is filled, the higher pressure gas in storage equalizes into the lower pressure vehicle tank(s), thereby providing fill times comparable to gasoline/diesel.

A compression/storage station design relies on the compressor filling a volume of storage much greater than the representative fleet vehicle's tank while the station is inactive. The compressor required is smaller (meaning a lower flow rate and motor horsepower) and therefore, less expensive to purchase and maintain than that for a pure compression station design. The reduced compression costs normally outweigh the additional storage costs, so the compression/storage design is usually preferable economically. Pure compression designs usually become economically preferable only in fleets requiring very large amounts of fuel, such as transit bus fleets.

The operation of a pure compression design is relatively easy to understand. The compressor's *flow rating* is the volume of natural gas delivered to the vehicle per minute up to a certain pressure. For example, a 350 scfm compressor rated at or above 3000 psig will fill an empty vehicle with total on-board storage of 1400 scf at 3000 psig in 4 minutes (1400 scf divided by 350 scfm).

If possible, a fleet operator will take advantage of the cost savings of a compression/storage design. For comparison to a pure compression station design, recall the previous example which required a 350 scfm compressor to fill a vehicle in 4 minutes, and consider instead a compression/storage design that will still fill the same vehicle in 4 minutes. Let us choose a smaller compressor of 75 scfm, which if run overnight, when most fleets are probably inactive, for 14 hours can compress into storage 63,000 scf (75 scfm x 60 min/hr x 14 hr) of natural gas at 3600 psig. This total volume is most efficiently delivered to vehicles if it is divided into *banks* and operated in *cascade* fashion. For purposes of this simple example, let us divide the 63,000 scf of storage into 3 banks of equal volumes (21,000 scf per bank). (As explained later, the actual storage volume will be about 2.5 times the amount of gas deliverable from the storage to the vehicles. The amount of gas stored overnight is the amount delivered to the vehicles from storage. So, in this case the actual storage volume would be closer to 157,000 scf (2.5 x 63,000 scf).) To understand cascade operation, let us label one bank the low pressure bank, another the middle pressure bank, and the third the high pressure bank. When the cascade is fully *charged,* each bank is at maximum pressure, which is nominally 3600 psig.

The first vehicle is then filled from the low pressure bank by the equalization of pressure occurring when the two are connected. It may fill completely from that bank, but while doing so the pressure of the bank will fall below 3600 psig, while the middle and high pressure banks remain untouched and full at 3600 psig. Vehicles are filled from the first bank until the *delta pressure* (Δp), defined as the difference in pressure between the bank in use and the partially filled vehicle tank, becomes small enough that the flow rate becomes too small to fill the vehicle in the allotted time. When the cutoff Δp is reached the vehicle is automatically switched to the middle pressure bank, and the vehicle tank is topped off. Now, the middle pressure bank is partially used. The next vehicle is filled from the low pressure bank first and will be switched to the middle pressure bank when the cutoff Δp is reached. Vehicles always begin filling from the low pressure bank. When that bank can no longer provide an adequate flow, the vehicle is switched to the middle pressure bank and then, if necessary, to the high pressure bank. Finally, when the high pressure bank's Δp reaches cutoff, the fill station's storage is said to be *depleted* and can no longer fully fuel a vehicle in the allotted time. At such time, only the compressor flow rate (75 scfm in this example) is available to top off a vehicle tank. This rate is less than the 350 scfm average flow rate that was provided by the cascade storage operation. Therefore, our example vehicle with 1400 scf of on-board storage will not be fueled completely in 4 minutes.

At this point, a fleet operator must accept either longer fill times or partially filled vehicles. The fill time of the first vehicle fueled by the depleted station would be just a little greater than 4 minutes, but the times would progressively increase for each vehicle, approaching a maximum of 18.7 minutes for this example (1400 scf divided by 75 scfm). The maximum time is reached when the volume of gas in storage no longer provides a Δp sufficient to sustain an average flow rate greater than the compressor's. As neither longer fueling times nor partially filled vehicles are acceptable to most fleet operators, the storage volume selected must be large enough to continuously fill the required number of vehicles. Also, the compressor must be large enough to recharge the cascade in the station's down-time before its next usage.

Since each bank will still contain a fair amount of natural gas when the cascade is considered depleted, the total amount of gas stored in a fully charged cascade must be greater than the total amount of fuel required by all the vehicles continuously fueling in the fueling session. To quantify this, usable storage is defined as the percentage difference in the amount of gas in a fully charged cascade (100 percent) and a depleted cascade. For example, if at depletion the cascade contains 60 percent of its original fully charged gas quantity, the usable storage would be 40 percent. Also, the compressor will begin running when the cascade is partially depleted, in an attempt to replenish the cascade. The exact point at which this occurs varies for different station designs. Since the compressor flow rate (75 scfm in this example) is less than the average flow rate from the cascade (350 scfm in this example) the storage will deplete if enough vehicles are fueled continuously.

There is a relationship between usable storage, average flow rate, and initial vehicle tank pressure. If the station is designed such that the cutoff Δp's are low then more of the storage will be utilized, since more gas will be drawn from each bank before switching to the next bank, but the average flow rate will be low. If the cutoff Δp's are increased then usable storage will decrease and average flow rate will increase. Also, the pressure of the vehicles' tanks at the start of fueling (they will be partially full) is related to the usable storage. For example, if all the initial vehicle tank pressures are 2000 psig, then the low and medium pressure banks cannot be utilized below 2000 psig. On the other hand, if all the initial vehicle tank pressures are 500 psig, then the low and medium pressure banks can be utilized below 2000 psig and therefore, the usable storage will be higher. Whenever one talks of usable storage and average flow rate these relationships must be kept in mind.

4.3.1 Cost Components

The six major cost components for setting up a CNG compression/storage fueling station are:

1) compressor costs,
2) storage costs,
3) dispenser costs,
4) dryer costs
5) miscellaneous component costs, and
6) construction/installation costs.

Following set up, two other costs are incurred:

7) operating costs and
8) maintenance costs.

The compressor, storage, and dispenser costs make up a large proportion (about 80 percent) of the total set up cost and are the most dependent on station design (DOE, 1990a; EPA, 1990a). Therefore, it is important for a fleet operator to be able to judge if a proposed station design is close to optimal for his/her fleet. Both compressor and storage costs increase as the fleet's demand for natural gas increases, i.e., the greater the volume of gas to deliver, the larger the compressor flow rate and storage volume required and hence, greater costs.

Dispenser costs are related to the number of vehicles which must be fueled in the allotted amount of time and the average volume of gas required per vehicle. The minimum dispenser cost is for a one hose dispenser. If enough vehicles, with a large enough gas demand per vehicle, need to be fueled in a short enough period of time that simultaneous fueling of vehicles is necessary, then more hoses per dispenser and possibly more dispensers will be needed, thus increasing costs. A major cost component of the dispenser, itself, is the meter to measure the amount of natural gas delivered. If a fleet operation does not require metering, then significant cost savings are possible.

A dryer must be provided to remove water from the pipeline natural gas. Its cost is dependent on the size of the compressor and whether or not it is regenerative or requires periodic chemical changing. Miscellaneous components include the priority and sequencer panels, pipes, safety valves, etc. The costs of these components can be considered constant for any compression/storage station design.

Construction/installation costs include the concrete, structural, electrical, and plumbing work necessary to construct the base facility, in addition to costs for installing the compressors, storage, and dispensers in that facility. These costs are somewhat dependent on site specifics, such as location of the natural gas line and current existence of concrete and structures. For example, underground piping will be more expensive if a thick layer of concrete to break through is already present and costs increase as the distance the station is located from the gas line increases. Both the construction and installation costs increase as the size of the compressor, size of storage, and the number of dispensers increase, since more square footage of concrete base is required. Administrative overhead costs are also included in this component.

Operating costs are the costs to power the compressor. The total operating cost increases as the fleet's demand for gas increases (i.e., the more gas compressed the longer the compressor runs), but the cost per unit volume of gas compressed is fairly constant over the limited sample of compressors investigated so far. It seems that this may be the case over the total range of compressor sizes. To increase the flow rate of a compressor the motor horsepower must be increased. Therefore, a compressor with a large flow rate will deliver more gas in a certain time period than a smaller compressor, but will use more energy in doing so. Intuitively, it seems that the amount of energy needed to compress a unit volume of gas may be similar for any compressor flow rate. Further investigation is necessary to verify this theory.

According to the limited information obtained on maintenance costs, these seem to be directed mostly at the compressor and increase with compressor size (DeLuchi, Johnston & Sperling, 1988). More data is required to ascertain if other items (dispenser, sequencer and priority panels, pipes, couplings, etc.) require significant maintenance.

4.3.2 Compression/Storage Station Design Issues

A compression/storage station is designed to deliver natural gas at a high enough average flow rate to fill the required portion of a vehicle fleet in an allotted time and then recharge before the next fueling session. Cost savings are possible if the fleet operation allows for more than one daily fueling session. For example, fueling half of the vehicles in a morning session and the other half in an evening session allows the storage to recharge throughout the middle of the day in addition to overnight, thereby requiring less storage than if all vehicles requiring fueling were filled continuously in one daily session. Hereafter, this discussion will be based on fueling a certain number of vehicles continuously in a session and on the amount of time necessary to fully recharge the storage after that session. A fleet operator can apply these fueling session and recharge "chunks" to a day in any way that is best for the particular fleet operation, be it one fueling session per day, both a morning and an evening session, or any other combination of sessions. Other scenarios are possible, such as those dealing with a varying number of vehicles fueling at each session or distributing fills across time other than continuously. It should be noted that the design for continuous filling of vehicles in a fueling session with no vehicles fueling in the recharge time will handle fueling for the same number of vehicles distributed in any way across the total time period of the fueling and recharge. In fact, if fuelings are spread across the recharge time also, more vehicles can fuel than allowed in the original fueling session, but the storage will not be fully charged at the end of the original recharge time. The latter fueling scenarios are not specifically addressed in this discussion.

A fleet operator needs to determine the average amount of natural gas required by the representative fleet vehicle per fueling session. In determining this, the fleet operator may wish to use a "worst case" strategy, especially if this quantity is highly variable, to help ensure that fleet performance will not unduly suffer on those worst-case days. Designing on the high side is safer and will allow for future growth in either fleet size or miles driven on CNG. Of course, the greater the quantity of gas the station is designed to deliver, the higher the cost of the station. The fleet operator must weigh the benefits of an increased level of service from the station against higher station costs in relation to the particular fleet operation. The average amount of gas required by the representative vehicle is at a maximum equal to the aggregate amount of on-board storage of every vehicle fueled in the session divided by the number of vehicles. Of course, this maximum amount is needed only if every vehicle uses up all its CNG before the session. Vehicles will typically be fueled when their tanks are partially full.

Based on fleet operating constraints, a fleet operator determines how long a time period is available to fuel all the vehicles in a given session. A certain average flow rate from the station is necessary in order to meet this time requirement. There is a limit to the average flow rate obtainable, and this limit is determined by the gas flow impedance from the tubing, couplings, check valves, bends, etc. from storage to vehicle tank, the usable storage desired, and the initial vehicle tank pressures. Thus, the average flow rate required from the station may not be attainable with a compression/storage design. If not, a pure compression design is required. Obviously, the greater the required volume of gas and the shorter the fueling session, the greater the average flow rate required.

The major flow impedances usually exist in the dispenser, fuel probe/receptacle, and vehicle piping to the on-board storage. B.C. Gas evaluated the pressure losses throughout the piping system of a typical Canadian public fill station and found that 44 percent of the pressure losses are in the 1/4 inch pipe in the vehicle, 19 percent is due to the fuel probe/receptacle, and 15 percent percents accounted for by the dome-load regulator (Cv=0.43) in the dispenser. Their simulations show that by using 3/8 inch pipe in the vehicle and an increased capacity fuel probe/receptacle the fueling time of a test vehicle would be reduced from 130 to 100 seconds and down to 80 seconds with an additional improvement of an increased capacity dome-load regulator (Cv=1.1). This shows that significant improvement in fill times can be achieved by a fleet which plans its vehicle conversions to use larger diameter piping and high capacity fueling receptacles. They also found a negligible difference in flow rate between using 100 feet of 1 inch pipe or 100 feet of (considerably less expensive) 1/2 inch pipe from the cascade to the dispenser (B.C. Gas, 1990). Both B.C. Gas and the Institute of Gas Technology have ongoing research in identifying and eliminating fueling bottlenecks.

Since the major impedances to flow are in the dispenser and vehicle, increasing the number of dispenser hoses will effectively increase the average flow rate of the station by allowing the simultaneous fueling of several vehicles. For example, consider a single hose station with an average flow rate of 350 scfm to the vehicles. If the impedance of the dispenser and vehicle were removed (i.e., let the gas flow by direct connection from the dispenser input to the vehicle's tank) the gas might flow at, say, 700 scfm. If another dispenser hose was added, then two vehicles might fuel simultaneously with average flow rates of, say, 250 scfm per vehicle. This would give an effective average flow rate of 500 scfm for the station, which is an increase of 150 scfm from the single hose design. The numbers in this example were not scientifically derived, but are merely use to illustrate conceptually the effects of adding dispenser hoses. Additional information is required in order to provide average industry-available flow rates per dispenser hose and determine how these flow rates are related to usable storage and initial vehicle tank pressure.

If more than one dispenser hose is used, a connection should be provided from each cascade bank to each dispenser hose. This allows vehicles fueling simultaneously, but from different hoses, to draw from different banks when necessary. In this way, each vehicle benefits from the cascade filling strategy.

The fleet operator can ask a vendor to design a station which will deliver enough gas to fill the required number of vehicles in the allotted fueling session time period. The vendor's design will probably include a 3 bank cascade storage system. The industry standard is 3 banks, but there is some speculation that 4 or 5 banks may be more efficient in some operational scenarios (Blazek, 1991). The cascade should be capable of storing about 2.5 times the quantity of gas required from storage per session, since when the gas in storage drops to about 60 percent of the fully charged amount, gas can no longer be delivered in acceptable times at full vehicle pressure (Cavens, 1986; AGA, 1989b; Pearson, 1991; Slack, 1991; IANGV, 1990; Cripps, 1991; Tren Fuels, 1991). Sixty percent is a conservative estimate within the range of reported percentages and is used in the methodology discussed in Chapter Five (in the form of a usable storage of 40 percent). As discussed previously, certain station designs may sacrifice usable storage for a greater average flow rate or vice-versa. Average flow rates have seldom been reported along with the usable storage values. Therefore, it is uncertain what average flow rate is obtainable with a usable storage of 40 percent, but it is believed to be somewhere in the neighborhood of 1000 scfm for a dual-hose station (i.e., about 500 scfm per hose). It is generally acknowledged that greater volumes in the lower pressure banks will provide more efficient cascade operation (Petsinger, 1991; Slack, 1991; Blazek, 1991; Cripps, 1991). A split of around 50-30-20 percent of the total volume among the low-medium-high pressure banks, respectively, has been quoted (Slack, 1991; Cripps, 1991). Also, the compressor flow rate must be large enough to recharge the cascade in the down-time between fueling sessions.

It is difficult for a fleet operator to determine if the desired average flow rate will actually be obtained from the vendor's design. The average flow rate of the station can be computed, knowing the volumes and cutoff Δp's of each cascade bank, as well as the lengths and diameters of all piping, couplings, and bends impeding the gas flow from the storage cascade to the vehicle's tank, however this computation is rather complex. Industry-available average flow rate estimates would greatly help a fleet operator analyze a vendor's design. Also, the Institute of Gas Technology (IGT) is updating a software package they developed to handle some of the parameters that impact the average flow rate. (This update should be available in early 1992 from IGT for approximately $100.) The Version 1.2 of this package is easy to use and informative, but lacking in average flow rate impacts (IGT, 1990). One must assume an average flow rate to use this version effectively, since it will unrealistically fill any size vehicle tank in any time you allow. Depending on the updates incorporated in the next version, this package may provide a way to verify a vendor's design. B.C. Gas already has an optimization program that they will run for a consulting fee. Given compressor and cascade sizes, fleet operating parameters, piping dimensions, coupling dimensions, etc., their program will provide information as to how the station will perform (including flow rates) and optimize cutoff Δp's for cascade bank switching. Some vendors use B.C. Gas' service for their final design work. One may wish to ask the vendor if this was done for the design they provide and if so, obtain B.C. Gas' report.

Some other station design features may be desirable. One is an oil filtering system to remove compressor lubricating oil, which may find its way into the compressed gas. It is possible for this oil to plug pipes or couplings. Also, water in the natural gas may freeze in the pipes if temperatures drop below freezing. Methanol injection is sometimes used to prevent freezing (Garland ISD, 1991). Dryers can also be installed to remove the water from the gas. It looks like dryers will be required and methanol injection prohibited by the next National Fire Protection Association (NFPA) 52 standard (1992 edition) (Petsinger, 1991). (Currently, Texas has not adopted NFPA 52.) It also seems to be a break-even economic and environmentally sound investment to capture the natural gas escaping due to compressor blow-by and reuse it, instead of venting it to the atmosphere (Slack, 1991; Garland ISD, 1991). Finally, an outdoor station installation is likely to be simpler and less expensive, because gas sniffers, alarms, and specialized ventilation systems will not be necessary. A schematic of a typical compression/storage station is shown in Figure 4.1.

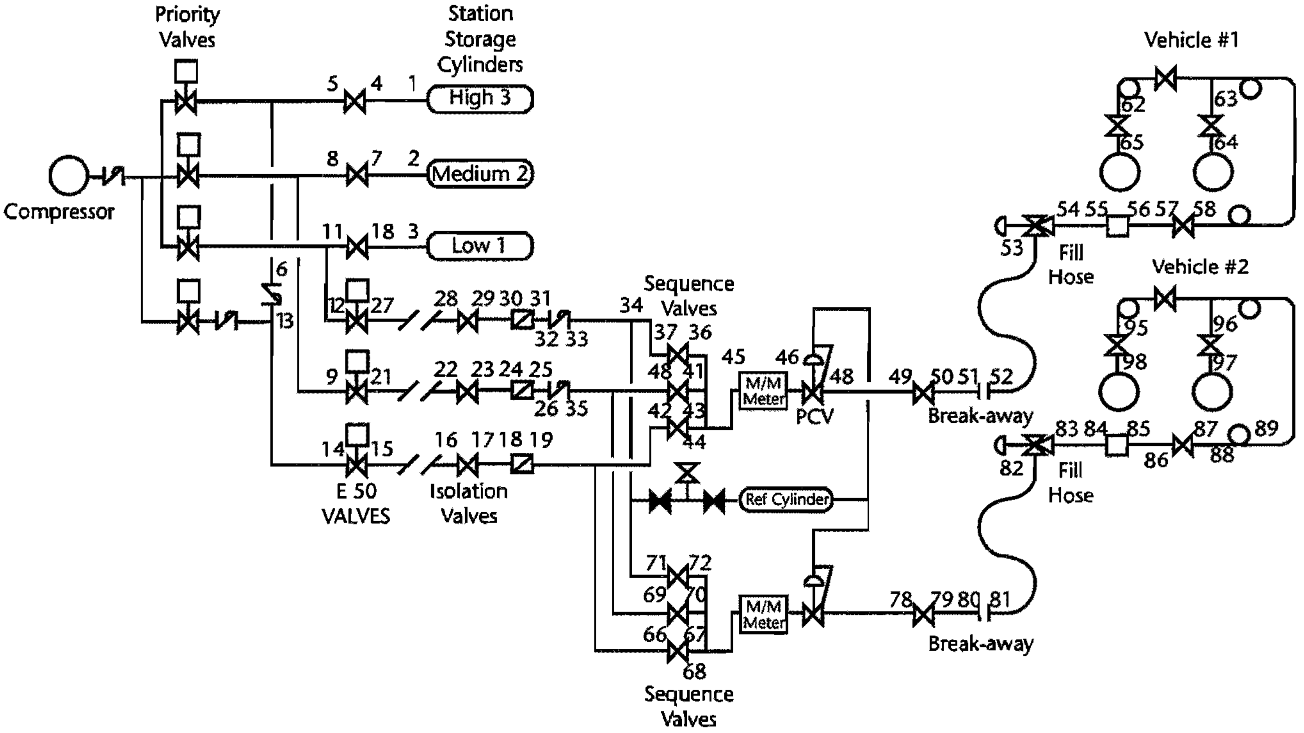


Figure 4.1 Schematic of a typical compression/storage station design (B.C. Gas, 1990)

4.3.3 Estimating Station Costs

Numerous combinations of compressor and storage sizes will satisfy a fleet's needs. The methodology discussed in the next section selects a commercially available compressor/storage combination that will meet fleet needs at minimum cost and provides the approximate cost of that combination. Also, other compressor/storage combinations which were close to the minimum cost combination, but provide better station performance, can be obtained. The fleet operator may wish to consider these other combinations for two reasons:

1) to provide for future fleet growth and/or
2) to be on the safe side in providing for the fleet's current operation.

Dispenser costs are dependent on the number of hoses required and whether the dispenser has the ability to meter the quantity of gas dispensed. The number of dispenser hoses required is determined by the methodology discussed in the next section. Dispenser costs can then be computed, given the average cost of commercially available dispensers. As discussed in Section 4.3.1, miscellaneous component costs are considered constant for any compression/storage station.

The interrelation among construction/installation costs and other factors was discussed in Section 4.3.1. The variation in these costs appears to be more dependent on site specifics (location of gas line, pre-existing structures, etc.) than on station design (square footage of concrete base required for compressor, storage, and dispensers). Data is necessary in order to quantify these relationships.

The only significant operating cost is for the energy to run the station's compressor(s). Compressor operating costs are sensitive to the input gas line pressure, sometimes referred to as *suction* pressure. The higher the input gas line pressure, the less a compressor has to work to output higher pressure gas. A compressor designed for a high (input) gas line pressure requires less energy than one designed for a lower pressure. The "normal" CNG fill station compressor is designed to operate at an input gas line pressure of about 5 psig. If one wishes to take advantage of cost savings from a "specially tailored" compressor the guaranteed minimum pressure to one's site must be found and the compressor sized for that suction pressure. We will not consider the cost savings possible with a "specially tailored" compressor, since most U.S. input gas line pressures are about 5 psig (DeLuchi, Johnston & Sperling, 1988).

CNG fill station compressors can be powered by either electricity or natural gas. Compressors driven by natural gas are not considered practical below the 100 to 200 horsepower level, which is the horsepower range necessary to drive a 4000 psig compressor at 25 psig suction pressure providing a flow rate of between approximately 220 to 400 scfm, respectively (GRI, 1990). Compressor flow rates of these magnitudes will probably not be required unless a pure compression station design is used. Therefore, the compressors considered here are electric motor driven. The kilowatt-hours (kWh) of electricity used is easily estimated by multiplying the compressor motor horsepower by the conversion factor to kilowatts (1 hp = 0.745712 kW), a duty-cycle factor, and the number of hours the compressor will run. The station operating costs can be computed by multiplying the cost of electricity per kWh by the kWh of electricity used.

The ratio of the compressor's motor horsepower to its flow rate (hp/scfm) is the horsepower minutes (hpm) to compress one cubic foot of natural gas. Multiplying this ratio by a constant, which converts hpm/scf to kWh per gasoline gallon equivalent of natural gas (kWh/gal_e), gives the energy used to compress a gasoline gallon equivalent of natural gas. (This constant is computed by: 0.745712 kW/hp x 1/60 h/m x 124 scf/gal_e = 1.541.) Therefore, the ratio, hp/scfm, is an easily computed measure of the station operating cost and is an indication of the cost savings possible with compressors designed for higher input gas line pressures. For example, the ratios for five compressors designed for a suction pressure of 7 psig is between 0.70 and 0.78. These compressor's flow rates range from 40 to 115 scfm. A linear approximation of the relationship between motor horsepower and flow rate in compressors designed for an input gas line pressure of 25 psig has a slope, which is the hp/scfm ratio, of about 0.45. These compressor flow rates range from 250 to 2000 scfm (GRI, 1990). The operating cost savings of the 25 psig suction pressure compressors is reflected in their lower hp/scfm ratio.

Station maintenance costs are mainly dependent on the compressor. Both ASME and DOT certified storage containers have a life that is usually considered indefinite. However, the Texas Railroad Commission (RRC) requires re-certification of cylinders every five years. Costs of dispenser and priority and sequencer panel maintenance is unknown. Also, piping, hoses, and couplings will require some minor maintenance, but the only maintenance which is currently considered significant is compressor maintenance. Wear to piston rings, seats, valves, etc. can cause lubrication oils to leak into the natural gas and natural gas to be wasted through piston blow-by. The motor used to drive the compressor will also require maintenance. The wear and tear on a compressor is very sensitive to the number of times it is toggled on and off (Slack, 1991). Assuming that station design and use is such that the compressor is toggled on and off just a few times a day, it is believed that an approximate maintenance cost function based on compressor size can be developed (DeLuchi, Johnston & Sperling, 1988).

4.3.4 A Compressor/Storage Selection Methodology

The compressor/storage selection methodology presented here is based on work related to the design of Canadian public gas stations and on several personal communications (Cavens & Cripps, 1986; Petsinger, 1991; Pearson, 1991; Slack, 1991; Blazek, 1991; Cripps, 1991). It is guided by the premise that when the amount of gas in storage falls below a certain level, the station can no longer fill a vehicle in the allotted time and is considered depleted. It is physically possible for another vehicle to fill from the station, but not within the allotted time, or within the allotted time after the storage has partially recharged. These options are not directly considered by this methodology. As discussed earlier, this methodology is intended for a fleet operation with continuous fueling of a certain number of vehicles in a fueling session and an associated storage recharge time before the next fueling session.

Inputs to the compressor/storage selection methodology are:

1) vehicles per session, N_{veh}
2) average CNG demand per vehicle (scf), D_{veh}
3) session time (minutes), $T_{session}$
4) downtime between sessions (minutes), T_{down}
5) between vehicle switching time (minutes), T_{switch}

The outputs are:

1) minimum compressor/storage cost
2) minimum cost compressor (scfm, hp) and storage (scf) size
3) number of dispenser hoses
4) time to recharge storage (minutes), $T_{recharge}$
5) actual session time (minutes), T_{total}
6) better performing compressor/storage combinations

Internal to the methodology, but modifiable by an informed user are the following data items:

1) compressor size, F_{comp}, and price list
2) storage size, $V_{storage}$, and price list
3) usable storage, $U_{storage}$ (%)
4) average flow rate, $F_{station}$, per number of hoses, N_{hose}

These data items can be modified to allow for changes in prices, in the estimate of usable storage, and/or the station flow rates per number of hoses.

The following are samples of the compressor and storage size/price lists based on data obtained from only one vendor. To be useful these lists should reflect industry averages.

COMPRESSORS

F_{comp} Flow rate (scfm)	Horsepower	Cost
40	30	$24,950
50	35	$29,950
75	50	$47,950
100	70	$54,950
115	90	$57,950

STORAGE

$V_{storage}$ Volume (scf)*	Cost
9000	$9,500
27000	$27,500
63000	$63,000

*(The volume of natural gas at standard temperature and pressure that is stored at 3600 psi.)

The following is a list of station average flow rates for different numbers of dispenser hoses. This list is intended only as an example. Actual industry-available average flow rates per number of hoses have not been determined at this time. It should be emphasized that these flow rates are the average rates obtained across all vehicles fueled before the station depletes. In actuality, the first vehicle filled will achieve a higher flow rate than the last, because the pressure differential between storage and vehicle tank will be greater. Also, the flow rate for each vehicle is highly variable if simultaneous fueling occurs.

STATION AVERAGE FLOW RATES

$F_{station}$ Flow Rate (scfm)	N_{hose} Hoses
300	1
500	2
600	3
650	4

The total time (T_{total}) to fill all vehicles in a session is dependent on the number of dispenser hoses available. The minimum station cost occurs when the minimum number of dispenser hoses is used. The methodology calculates the total time to fill all vehicles in the session for any number of hoses from the following equation:

$$T_{total} = (N_{veh} / N_{hose}) \times (T_{switch} + T_{fill}) \qquad (1)$$

where, the average fill time per vehicle,

$$T_{fill} = D_{veh} / F_{hose}$$

and the flow rate per hose,

$$F_{hose} = F_{station} / N_{hose}$$

(This equation slightly underestimates T_{total} when more than one hose is used and the queues at each hose are not of the same length. This slight error is not significant in comparison to the approximate nature of most of the input data.)

The methodology first calculates T_{total} for one hose and continues adding hoses and recalculating T_{total} until $T_{total} \leq T_{session}$. In other words, scenarios of filling all the vehicles in a queue from 1 hose, or in 2, 3, 4, etc. queues from 2, 3, 4, etc. hoses, respectively, are examined to find the least number of hoses required for the particular fleet fueling requirements. For example, consider a sample fleet with the following characteristics:

N_{veh} = 20
D_{veh} = 1500 scf
$T_{session}$ = 100 minutes
T_{down} = 270 minutes
T_{switch} = 2 minutes

For 1 hose,

F_{hose} = 300/1 = 300 scfm,
T_{fill} = 1500/300 = 5 minutes, and
T_{total} = (20/1) x (2 + 5) = 140 minutes.

This is not fast enough to satisfy the desired session time of 100 minutes, so 2 hoses are evaluated, and

F_{hose} = 500/2 = 250 scfm,
T_{fill} = 1500/250 = 6 minutes, and
T_{total} = (20/2) x (2 + 6) = 80 minutes.

This is fast enough to satisfy the desired session time of 100 minutes. Therefore, two or more dispenser hoses will provide for the fleet needs, but two hoses is the most economical choice.

Next, the methodology finds the subset of compressor/storage combinations that will provide the gas demand per session. The session demand ($D_{session}$) is computed by multiplying the average CNG demand per vehicle (D_{veh}) by the number of vehicles fueled per session (N_{veh}). This is shown in the following equation:

$$D_{session} = D_{veh} \times N_{veh} \qquad (2)$$

Continuing with the example, $D_{session}$ = 1500 x 20 = 30,000 scf.

The natural gas volume deliverable (V_{del}) to vehicles during the session can be viewed as coming from two places: the gas stored in the fully charged cascade and the gas compressed into the cascade by the compressor during the fueling session itself. The volume from the cascade is equal to the usable storage ($U_{storage}$), converted to a proportion, multiplied by the total volume of storage ($V_{storage}$). (As previously discussed, a usable storage of 40 percent is used.) The volume from the compressor is equal to the compressor flow rate (F_{comp}) multiplied by the time the compressor runs during the session. The time the compressor runs (T_{comp}) is given by the following equation:

$$T_{comp} = T_{total} - T_{switch} \qquad (3)$$

T_{switch} is subtracted from T_{total} to account for the time that it takes to drive in and connect the first vehicles to the hoses, since the compressor will not run until they are connected, fueling begins, and the cascade is not full anymore. This accounts for approximately one half of the subtracted time, T_{switch}. The other half is the time it takes to disconnect and drive the last vehicles away from the dispenser. Even though the compressor will be running during this time, the gas delivered is rightfully allocated to the recharge of the cascade, not to the current session. For our example, T_{total} = 80 minutes. Therefore, T_{comp} = 80 - 2 = 78 minutes.

In order to prevent compressor wear and tear due to toggling on and off, the station design will probably be such that the compressor will not turn on immediately after the first vehicles begin fueling. This can be handled by replacing T_{switch} in equation (3) with the actual time the compressor is idle during the fueling session.

The volume deliverable from any compressor/storage combination can be computed from the following equation:

$$V_{del} = (U_{storage}/100 \times V_{storage}) + (F_{comp} \times T_{comp}) \qquad (4)$$

The methodology finds the subset of compressor/storage combinations which meet the session demand through the iterative process of trying every possible combination of compressor and storage sizes. If $V_{del} \geq D_{session}$, then the combination is included. Using the sample lists presented earlier, the methodology would start by evaluating a 40 scfm compressor with 9000 scf of cascade storage. From equation (4), the volume deliverable by this combination is:

$$V_{del} = (40/100 \times 9000) + (40 \times 78) = 6720 \text{ scf.}$$

This is not enough to satisfy the example session demand of 30,000 scf. The volume deliverable by the combination of a 115 scfm compressor with 63,000 scf of storage is:

$$V_{del} = (40/100 \times 63{,}000) + (115 \times 78) = 34{,}170 \text{ scf.}$$

This is enough to satisfy the example session demand. The combinations of 100 scfm compressor/ 63,000 scf storage and 75 scfm compressor/63,000 scf storage are the only others that satisfy the example session demand.

Finally, the methodology selects, from the subset of compressor/storage combinations satisfying session demand, the cheapest combination which will recharge the storage before the next fueling session. This maximum recharge time is the down-time between sessions (T_{down}) added to the difference between the allotted session time and the actual session time ($T_{session} - T_{total}$). The time to recharge storage ($T_{recharge}$) is computed by subtracting the time the compressor ran during the session from the total time the compressor must run to satisfy the session demand, as shown in the following equation:

$$T_{recharge} = (D_{session}/F_{comp}) - T_{comp} \qquad (5)$$

The three compressors still in the running will recharge the storage in our example in the following times:

$T_{recharge}$ for 75 scfm compressor = (30,000/75) - 78 = 322 minutes,
$T_{recharge}$ for 100 scfm compressor = (30,000/100) - 78 = 222 minutes,
$T_{recharge}$ for 115 scfm compressor = (30,000/115) - 78 = 183 minutes.

Both the 100 and 115 scfm compressor will recharge the storage within the example fleet's maximum recharge time of 290 minutes (270 + 100 - 80). The cheapest of these combinations, the 100 scfm compressor and 63,000 scf storage, along with a 2 hose dispenser is chosen as the most cost effective compressor/storage/number of hoses combination that will provide for the example fleet's needs.

Since the chosen station design will probably fill the vehicles in less than the required session time and recharge storage quicker than required, the actual session time, T_{total}, and the time to recharge storage, $T_{recharge}$, are important outputs of the methodology. Even though the chosen design will probably perform better than required, information on successively better performing stations at successively higher costs are also obtainable as outputs for the fleet operator's evaluation.

It must be emphasized that, given the level of averaging and estimating that will be necessary to obtain industry-available average station flow rates per number of dispenser hoses and the error inherent in using a constant value for usable storage across all possible cascade sizes and operations, the station design chosen by this methodology will not perform exactly as portrayed. As such, this methodology is only meant to find a station design suitable to help a fleet operator evaluate various vendors' designs and to estimate the fill station cost in connection with the operation of a given fleet of vehicles on CNG. It is not meant to replace sophisticated software or a vendor's experience in tailoring a system to the fleet's needs.

The fueling station cost estimation procedure used in the cost-effectiveness analysis framework presented in Chapter Five is different from that presented in this section, although both are based on the same basic engineering principles. Although more accurate, the methodology presented in this section was considered too computationally demanding and data intensive to easily implement in a spreadsheet model, which is how the cost-effectiveness analysis framework is implemented. The cost estimation procedure used in the Chapter Five framework makes the simplifying assumption that minimizing compressor size will always be most cost-effective, even as it requires a large amount of storage. Although lacking sufficient proof of this claim to generalize for all fleets, it is assumed for three reasons:

1) if the assumption is incorrect, the resulting costs are not significantly higher than those estimated by the methodology presented in this section,
2) minimizing compressor size minimizes peak power required, which has benefits for electrical rate setting purposes, and
3) the assumption offers the computational convenience required for easy implementation in a spreadsheet.

4.4 COMBINATION SLOW/FAST-FILL

For the additional cost (relative to slow-fill) required to purchase, install, and maintain a volume of storage and a dispenser, fast-fill capability can be combined with a primarily slow-fill operation. This would allow the fleet to handle emergency fueling and other non-typical scenarios. The compressor size is derived in the same manner as for slow-fill (see Section 4.2). In this case, the compressor will also run during the shift time (in addition to the vehicle down-time) to replenish the storage whenever it falls below a certain level.

The fast-fill storage can be operated in cascade fashion, as describe previously in Section 4.3, or as a single volume, if use of fast-fill is not frequent enough to warrant the expense of sequencer and priority panels. The storage size and number of fast-fill dispenser hoses required can be estimated based on the expected frequency of fast-fills and the amount of fuel per fill, using the fast-fill approach described in Section 4.3.4.

4.5 NURSE-TRUCK

A nurse-truck CNG fueling station consists of a volume of high pressure natural gas storage and a dispenser unit at the fleet's site. Instead of filling the storage with pipeline-supplied natural gas via an on-site compressor, as in a compressor/storage fast-fill strategy, a nurse-truck is used to transport the gas from an off-site compressor facility to the on-site storage. Vendors currently provide this service. The vendor incurs the compressor purchasing, maintenance, and operating costs and passes them off to the fleet in the price of natural gas.

The fleet's on-site storage unit will probably contain a sequencer panel, so that it can be operated in cascade fashion. As discussed in Section 4.3, this decreases the volume of storage required and thereby, reduces storage costs. Estimating storage size and number of dispenser hoses can be performed utilizing the approach laid out for fast-fill in Section 4.3.4.

The cost components of this type of station are a subset of those of a compressor/storage fast-fill station, excluding those costs associated with the compressor. When contemplating a nurse-truck station design, the fleet operator must consider the trade-off between these compressor costs and increased natural gas prices, in addition to the amount of capital the fleet has available for a station purchase. The fleet operator must also realize that this type of station can be upgraded to a compressor/storage fast-fill station by adding a compressor later on.

4.6 PROPANE PUBLIC FUELING

In 1990 there were approximately 25,000 retail propane outlets in the U.S., 10,000 of which provided motor vehicle service (R.F. Webb, 1989). Of these 10,000, between 1,250 and 2,000 are located in Texas (Texas LP-Gas Association, 1989). It is uncertain how many new stations will open in the near- and mid-term. Even though there are significantly more public propane stations than CNG stations, there are still an order of magnitude more gasoline/diesel stations, and the additional labor and fuel costs required of a fleet relying on public fueling stations are significant enough for many fleets to provide their own gasoline/diesel fueling. Consequently, it is probable that the implementation of propane as an alternative fuel for fleets will require the development of on-site fill stations.

4.7 PROPANE ON-SITE FUELING

Regardless of the type of fuel, a fleet operator faces the same two principal concerns when making decisions pertaining to the feasibility of purchasing and operating its own fueling station. The first of these, that the station must meet the operational needs of the fleet, is not of particular concern for propane, because propane stations operate very similarly to traditional gasoline/diesel fueling stations. The second, that this fueling capability should be provided economically, is of obvious concern. In order to assess the extent to which a propane station can meet these two concerns, this section explains how a propane station functions, identifies the cost components incurred in setting up and operating a station, discusses some of the criteria affecting the design of a station, and presents a methodology for estimating the station costs for a particular fleet. Also, it should be noted that propane dealers will often provide and maintain a propane station at the fleet's location and recoup the associated costs in the price of propane to the fleet. However, this option is not pursued further in this discussion, which addresses only the purchase, operation, and maintenance of the station by the fleet owner/operator.

Propane fueling is very similar to gasoline/diesel fueling. Propane is stored and pumped as a liquid, with flow rates similar to those achieved by current gasoline/diesel dispensers. One difference is that propane is stored under pressures of about 100 to 200 psig to keep it liquified. Therefore, the dispenser probe must achieve an air-tight seal with the vehicle receptacle (as for CNG) during fueling. Propane storage tanks are usually above ground (like CNG storage tanks) and are filled whenever necessary by a local propane dealer via truck transport.

Two types of trucks are used for transport of propane:

1) the *highway transport* and
2) the *bobtail* truck.

Transports generally have between 7,000 and 12,000 gallon propane capacities, while the capacity of a bobtail's tank is between 1,600 and 2,400 gallons (Texas LP-Gas Association, 1989). If a fleet receives transport loads instead of bobtail loads, cost savings of between 10 and 30 cents per gallon are possible (Schmidt, 1992; Anderson, 1992; Modern Butane, 1992; Hill, 1992; Holloway, 1992). One must consider this cost difference in conjunction with the additional costs of a larger storage tank and the fuel demand of the fleet in order to choose the best storage size for that fleet.

The three major cost components for setting up a propane fueling station are:

1) storage costs,
2) dispenser costs, and
3) construction/installation costs.

Following set up, two other costs are incurred:

4) operating costs and
5) maintenance costs.

Storage costs are dependent on the fuel demand of the fleet and the price difference between transport and bobtail loads. Dispenser costs are related to the number of vehicles fueling per session and the time allowed for fueling them, as each vehicle requires a hose and fuel probe. Construction/installation costs include the concrete and structural work necessary for tank and dispenser(s) installation, labor, and administrative overhead.

Operating costs are incurred to power the fuel pump. These are considered to be the same as for a gasoline/diesel pump. They are minimal compared to the power costs of a CNG station compressor. Maintenance costs are also mostly dispenser/pump related, although minor maintenance to the tank and structures may be necessary. These are less than CNG compressor maintenance.

Because propane is available at reduced prices for transport volume purchases, it is problematic to attempt to pick one propane price suitable for all fleets. One method for estimating capital station costs that handles this problem is to consider two stations with different storage sizes. Each station would require the same number of dispensers in order to fill the required number of vehicles in the required time period. Thus, the only difference in cost is that associated with storage size. A life-cycle financial analysis for fleet operation on propane is conducted for two scenarios:

1) a small storage size, capable of receiving bobtail truck volumes at a small volume (retail) propane price, and;
2) a large storage size, capable of accepting highway transport truck volumes at a large volume (wholesale) propane price.

The most cost-effective storage size is chosen.

4.8 CLOSURE

This chapter discussed the fueling infrastructure required for operation of fleets on either CNG or propane. This discussion is of importance to the introduction and diffusion of these fuels into U.S. markets, since gasoline/diesel fueling infrastructure is significantly larger, thereby creating a barrier to CNG and propane use. Both public and on-site fueling operations were examined. On-site fueling was emphasized, because of the lack of public fueling infrastructure (especially for CNG) and the fact that many fleets have already chosen to build and operate on-site gasoline/diesel fueling stations for economic and convenience reasons.

The discussion was much more detailed for CNG, because of the various types of on-site CNG fueling stations (slow-fill, fast-fill, combination slow/fast-fill, and nurse-truck) and the fact that the technology differs greatly from current gasoline/diesel fueling stations. Fast-fill was emphasized, because it provides service that is most comparable to that currently provided by gasoline/diesel stations. This is not to say that slow-fill is inferior, merely that it would involve a more drastic departure from current fleet operations.

For propane and all types of CNG stations, this chapter explained how the station functions, identified the cost components incurred in setting up and operating the station, discussed some of the criteria affecting the design of the station, and in the case of fast-fill CNG and propane, presented methodologies for estimating the station costs for a particular fleet. This was done to aid a fleet operator in assessing whether or not the station can meet the operational needs of the fleet in an economical manner and to provide essential background material for the methodology development in Chapter Five.

CHAPTER 5. COST-EFFECTIVENESS ANALYSIS FRAMEWORK

In this chapter, the practical evaluation framework discussed in Chapter Two is operationalized through the development of a detailed cost-effectiveness analysis framework. The framework concentrates on fleet level financial costs and benefits. It also allows one to compute the value one would have to place on societal benefits in order for fleet operation on the alternative fuel to be cost effective.

The remainder of the chapter is divided into three sections. The first conceptually discusses the costs and benefits associated with operation on either CNG or propane; the principal focus is on fleet level monetary costs and benefits. The second section presents the framework for fleet level cost-effectiveness analysis of CNG operation. The final section presents the framework for propane analysis, focusing on the differences with the CNG analysis.

5.1 CONCEPTUAL COSTS AND BENEFITS

As already noted, there are a number of positive social impacts associated with the use of alternative fuels for motor vehicles, and generally these impacts are the driving force behind alternative fuel legislation. Although the focus of the cost/benefit analysis is on fleets, it is still important to consider the larger social impacts even if they are not dealt with in financial terms for the fleet analysis. In the long run, all costs and benefits must be considered in evaluating alternative fuel policies and their consistency with broader societal issues.

Societal benefits from utilization of natural gas or propane as an alternative fuel may include reductions in urban air pollution, a decrease in transportation's impact on global warming, increased national energy security, economic stimulus to gas producing areas, decreased fuel toxicity, decreases in land and water pollution, improved vehicular safety, and development of an infrastructure consistent with—and a gaseous fuel knowledge base for—a hydrogen-fueled vehicle future. (Hydrogen-fueled vehicles offer significant environmental improvements over all other vehicular fuels.) These benefits are difficult to quantify and incorporate into a fleet level cost/benefit analysis. Rather than attempt to place a monetary value on these benefits, one can determine the minimum value that the broader social benefits must assume in order to overcome costs. This value could be used as a basis for developing a tax or fee to accommodate externalities that typically are not included in economic analysis. Societal costs and benefits are addressed more completely in Chapter 7.

In evaluating the economic feasibility or implications of converting to and operating a fleet of vehicles on natural gas or propane, a life-cycle cost/benefit analysis is necessary. The main focus of this analysis is from the fleet operator's viewpoint, in particular on the cost-effectiveness of fleet operation on the alternative fuel. Therefore, the narrower monetary costs and benefits (shown collectively in Figure 5.1) to the fleet operator's budget are analyzed. This provides useful information for evaluating the economic feasibility of a natural gas or propane operation.

Benefits

A. Fuel cost savings
B. Maintance cost savings

Costs

- A. Capital infrastructure
  - 1. Compressor
  - 2. Storage
  - 3. Dispenser
  - 4. Dryer
  - 5. Setup
  - 6. Land
- B. Capital vehicle
  - 1. If converted
    - a. Conversion kit equipment
    - b. Storage tank(s)
    - c. Labor
  - 2. If OEM
    - a. Cost differential
- C. Operating
  - 1. Station maintenance
  - 2. Power
  - 3. Cylinder recertification
  - 4. Driver and mechanic training
  - 5. Labor losses from fueling
  - 6. Texas state gaseous vhicle fuel tax

Figure 5.1 Summary of principal monetary fleet costs and benefits

5.1.1 Monetary Benefits

Monetary fleet benefits are derived from:

1) the fuel price differential between the alternative fuel (natural gas or propane) and gasoline/diesel and
2) potential maintenance savings.

The former is the primary source of monetary benefits, since both natural gas and propane are currently cheaper on an energy-equivalent basis. Adjusting for possible differences in fuel efficiencies between the alternative fuels and gasoline or diesel, savings are accrued based on the differential in price between the fuels. Maintenance savings (increased oil and spark plug life are two possibilities) is the other potential monetary benefit. Documented proof of maintenance savings or of its magnitude is currently lacking, though anecdotal and theoretical evidence suggests the possibility of some savings.

It is assumed that the fleet already has gasoline and/or diesel fueling capabilities on-site. These facilities will be used less while dual-fuel converted vehicles are used and may be eliminated if dedicated original equipment manufacturer (OEM) vehicles are fully phased in, but no benefit is given in this analysis for reduced operating and maintenance costs or for possible elimination of those facilities. (One potentially large cost savings is that associated with the elimination of underground gasoline/diesel storage tank inspection, maintenance, and replacement.)

5.1.2 Monetary Costs

Monetary fleet costs can be categorized as

1) capital infrastructure costs,
2) capital vehicle costs, or
3) operating costs.

Capital infrastructure costs. These costs represent the initial investment for an on-site fueling station and future additions for increased capacity. For CNG, the station design could be slow-fill, fast-fill, combination slow/fast-fill, or nurse truck. In this framework, fast-fill is considered and as such, the station design will vary according to the particular fueling scenario for a given fleet (for instance, whether all vehicles fill daily, in one session, or several sessions, etc.). Regardless, the fast-fill station has six cost components:

1) compressor,
2) storage,
3) dispenser,
4) dryer,
5) setup, and
6) land.

Setup costs include miscellaneous component costs (such as those for priority and sequencer panels, piping, etc.) and construction/installation costs (such as those for labor and managerial overhead), as discussed in Chapter Four. They are grouped together here for convenience. Also, land is a cost component, though it was not germane to the discussion in Chapter Four and therefore, was not presented there. A propane station has four cost components:

1) storage,
2) dispenser,
3) setup, and
4) land.

Capital vehicle costs. These costs are those above what would be spent on a comparable gasoline or diesel vehicle. If the vehicle is converted from an existing gasoline or diesel vehicle, these differential costs are divided into three categories:

1) conversion kit equipment,

2) storage tank(s), and
3) labor.

The conversion kit costs include those for all "under the hood" parts such as air/fuel mixer, regulator, and piping. Storage tank costs include the cost of on-board tanks and mounting equipment. Labor costs are incurred in performing the conversion. If the vehicle is replaced with an OEM vehicle, then the capital vehicle cost is the price differential between the comparable OEM alternative fuel vehicle and gasoline (or diesel) vehicle.

Operating costs. These include:

1) station maintenance, which is performed mainly on the compressor for CNG or pump for propane;
2) power to drive the compressor (CNG) or pump (propane);
3) costs to recertify on-board cylinders (CNG only);
4) additional training for drivers and mechanics;
5) labor losses (or savings) from fueling; and
6) the Texas state gaseous vehicle fuel tax.

Station maintenance and power costs are discussed in detail in Chapter Four. High pressure on-board CNG tanks must be recertified periodically to meet Texas Railroad Commission requirements. Additional training is required for both drivers and mechanics of CNG or propane vehicles, since use of these vehicles is not commonplace.

Labor losses from fueling are normally incurred for CNG operation if the fast-fill fueling method is used. Because CNG fast-fill fueling is characterized by longer and more frequent fills (a result of current natural gas fueling and on-board storage technology) employees must spend extra time fueling vehicles, which takes away from their productivity elsewhere. Thus, additional person-hours are required to achieve the same productivity as with gasoline/diesel operation, resulting in a labor cost. If slow-fill is used, one might be able to argue for labor time savings, since the time involved in connecting and disconnecting the fuel probe is minimal compared to the time associated with filling and switching (driving the vehicle up to and away from a fueling station and getting in and out of the vehicle). With slow-fill, the only labor time associated with fueling is connecting and disconnecting the fuel probe daily. Labor time is saved on the other parts of the the fueling process, since one must park the vehicle and retrieve it anyway; moreover the fueling occurs during idle periods, so no person-hours are lost due to waiting.

Labor losses or savings are also incurred for propane fueling. Flow rates on a volumetric basis are comparable for propane, gasoline, and diesel fueling, but propane contains less energy per unit volume than gasoline or diesel. This leads to a labor loss if the on-board storage volume of propane is similar to that of gasoline/diesel. Yet, users often purchase a propane tank that is much larger than the gasoline/diesel tank. If so, the reduction in fueling frequency may compensate for the increased time to pump the larger volume of propane needed to acquire an amount of energy equivalent to gasoline or diesel.

Texas law requires all private fleets and most state fleets to pay a fuel tax on vehicular use of natural gas or propane. This tax is based on the annual mileage driven on the alternative fuel and the weight of the vehicle. Currently, most state vehicles are exempt from federal propane, gasoline, and diesel taxes, and there is not a federal tax on natural gas use for vehicles.

5.1.3 Non-Monetary Fleet Costs and Benefits

Operation on alternative fuels also generates some non-monetary fleet costs and benefits. Because of the difficulty in quantifying them, they are not included in the main economic analysis. Possible benefits include safer vehicles and improved public relations from capitalizing on the clean air aspects of natural gas or propane use. Possible costs include the risk involved in investing in a new technology (although there are over 700,000 natural gas vehicles operating world-wide, there are only about 30,000 in the U.S.) and negative impacts from perceived safety problems. The monetary costs and benefits discussed previously represent the significant factors for evaluating the economic feasibility of a CNG or propane fleet. Additional work is needed in valuing non-monetary fleet impacts.

5.2 FRAMEWORK DEVELOPMENT (CNG)

This section presents an overview of the cost-effectiveness analysis framework and discusses the underlying assumptions and required input data. The analysis applies at the fleet level. A fleet is composed of different types of vehicles, each with a given set of attributes reflecting performance characteristics and utilization, both of which influence fuel consumption. Most of the cost and benefit items are incurred at the individual vehicle level, independently of other fleet characteristics. The major exceptions are infrastructure capital costs, where some fixed costs are incurred regardless of actual fleet size.

The detailed expressions for each cost item are presented here, along with the principal conceptual relations and assumptions, the input data required, and the manner in which the various data items affect the calculations. These have been implemented in spreadsheet format and documented elsewhere in greater detail (Taylor, Euritt & Mahmassani, 1992b). Of particular interest is the approach devised in this study to estimate the fueling infrastructure requirements of the fleet under consideration; these requirements are translated into approximate sizes for the various station components on the basis of fundamental engineering principles.

The discussion in this section follows the order in which the principal cost and benefit elements are presented in the previous section. The principal input data requirements and assumptions are then discussed.

5.2.1 Benefit and Cost Calculations

The monetary cost/benefit fleet analysis uses a net present value (NPV) approach whereby all future incremental costs and benefits over the time horizon of interest are discounted to the present using a rate that reflects the opportunity cost of capital for the particular fleet operating agency. In addition, measures are computed in order to allow comparison of cost-effectiveness for different fleet sizes and to assist in identifying the level of societal benefits to achieve cost-effectiveness. One such measure is computed by annualizing the NPV of all incremental costs and benefits and dividing by the fleet size, thereby finding the additional cost (or savings) per vehicle per year. The other, increased cost (or savings) per mile, is computed by dividing the annualized NPV by the annual fleet mileage.

As explained in the previous section, monetary benefits derive primarily from fuel cost savings under CNG operation relative to gasoline and diesel. At the fleet level, then, savings depend on fleet size and composition (in terms of the different vehicle categories described in Section 5.2.2). For a given vehicle type, the annual fuel cost savings are given by:

$$\text{Savings} = \begin{bmatrix} \eta_{GAS,U}\, p_{GAS} - \alpha_{CNG}\eta_{CNG,C}\, p_{CNG} \\ -(1-\alpha_{CNG})\eta_{GAS,C}\, p_{GAS} \end{bmatrix} \times \text{miles} \qquad (1)$$

where:

α_{CNG}	is the fraction of total annual miles driven on CNG, $0 < \alpha_{CNG} < 1$.
p_{CNG}, p_{GAS}	are the respective prices of CNG and gasoline (per gasoline gallon equivalent), for the year under consideration.
$\eta_{CNG,C}$, $\eta_{GAS,C}$	are the respective CNG and gasoline fuel consumption characteristics (in gasoline gallon equivalents per mile) of the vehicle after conversion to dual-fuel operation.
$\eta_{GAS,U}$	is the gasoline fuel consumption for the vehicle prior to conversion.
"miles"	is the annual mileage of the vehicle.

The above expression is modified appropriately to consider conversions of diesel vehicles as well as OEM vehicles. It is applied to each year separately over the time horizon of interest, allowing increased reliance on CNG over time as users become more familiar with converted vehicles and as the reliability of the technology is established. This can be reflected by increasing the value of α_{CNG} over time, or simply by using a lower value for the first few years.

In developing fleet-level estimates, average values (for each vehicle type) are used for the vehicle utilization and consumption characteristics. Letting the subscript k denote a particular vehicle type, the total fuel cost savings are given by

$$\sum_{k} (\text{saving})_k N_k \qquad (2)$$

where

N_k is the number of fleet vehicles of type k.

The other source of cost savings is maintenance savings. As noted earlier, these may or may not materialize. No particular methodology has been developed here to estimate such savings, given the absence of factual evidence to support such calculations. At present, such savings can be input directly as a per-vehicle amount for each type, allowing the analyst to conduct related sensitivity studies.

Three major cost items were described in the previous section: fueling (capital) infrastructure costs, vehicle conversion (capital) costs, and operating costs. The most challenging to estimate are the fueling infrastructure costs, as the literature contains little guidance in this regard. A new cost estimation methodology, described below, was developed for this application.

This analysis assumes that fleets will provide their own fueling infrastructure. Even if this is not the case, and the fleet is assumed to fuel at a public CNG filling station, this framework can still be used. The CNG fuel prices would then be adjusted to reflect public station prices, and all capital infrastructure, station maintenance, and station power costs would be removed, since they are now incurred by the public station and passed on to the fleet in the fuel price. As previously discussed, the fleet can provide its own fueling in several ways:

1) slow-fill,
2) fast-fill,
3) combination slow/fast-fill, or
4) nurse-truck.

Lower costs to the fleet may be possible with the slow-fill option, though one would have to change the fueling operation for the fleet. Such a change may not always be detrimental, as pointed out in the earlier discussion of possible person-hour productivity gains associated with slow-fill. Though this analysis can be performed for any of the natural gas fueling options, the rest of this section deals with the option that most closely replicates the service a fleet now receives with its own on-site gasoline and/or diesel stations, namely continuous fast-fill with pipeline-supplied natural gas.

As discussed in Chapter Four, the most cost-effective fast-fill (with pipeline gas) fueling station design requires compression of natural gas into cascade storage. Vehicles are filled from the storage in cascade fashion to get the maximum amount of gas out of storage, while still retaining sufficient flow rates to fill vehicles in times comparable to those for gasoline/diesel. The size of the compressor and the size of the storage are chosen so that the storage is depleted when the last vehicle fuels. With depleted storage, another vehicle could still fuel, but would take longer than the required maximum time allowed for fueling. It has often been suggested that minimizing the compressor size and maximizing the amount of storage will always be most cost-effective. Although we have not seen sufficient proof of this claim to generalize for all fleets, we assume it here for three reasons:

1) if the assumption is incorrect, costs are not significantly higher,
2) minimizing compressor size minimizes peak power required, which has benefits for electrical rate setting purposes, and
3) the assumption offers computational convenience.

This analysis features a new cost estimation approach that relies on a fueling station design methodology based on underlying engineering relationships (see Chapter Four for background information). The fueling station design methodology breaks each fueling cycle into two distinct time periods, the time of the continuous fueling session ($T_{session}$) and the time for storage recharge ($T_{recharge}$) before the next session. The minimum compressor size (C_{min}) is then computed from:

$$C_{min} = D_{session}/(T_{session} + T_{recharge}) \qquad (3)$$

where

$D_{session}$ is the fleet demand per session.

The maximum storage size (S_{max}) is computed from:

$$S_{max} = D_{session}/[U_{storage} \times (1 + T_{session}/T_{recharge})] \qquad (4)$$

where

$U_{storage}$ is usable storage or the proportion of storage deliverable to vehicles from cascade operation.

Equation (4) is derived from equation (3) and from the fact that the amount of natural gas used from storage during the session must be replaced by the compressor during recharge, as shown here:

$$S_{max} \times U_{storage} = C_{min} \times T_{recharge} \qquad (5)$$

The underlying assumption in each of the above equations is that the compressor is running continuously in order to minimize its size and maximize its productivity. One must have values for $U_{storage}$, $T_{recharge}$, $T_{session}$, and $D_{session}$ in order to calculate compressor and storage size.

$U_{storage}$ is a function of desired flow rate and the initial vehicle tank pressures. Therefore, values for $U_{storage}$ and flow rate per dispenser hose (F_{hose}) must be assumed and entered. $T_{recharge}$ can be found by subtracting $T_{session}$ from the fleet fueling cycle time, which is normally 24 hours, since it is typical for fleets to operate on daily cycles.

$T_{session}$ is computed, as shown in equation (6), by assuming that queues of vehicles (with vehicles uniformly distributed by type) form at each available dispenser hose and that each vehicle type requires a certain total fill time ($T_{vehicle}$), which consists of a transition time between vehicles (T_{switch}) and an actual filling time (T_{fill}). The latter is simply calculated as $D_{vehicle}/F_{hose}$, where $D_{vehicle}$ is the natural gas demand per fill. It is also assumed that there is no waiting time in the queue.

$$T_{session} = \Sigma\ [(V_{session} / C_{hoses}) \times T_{vehicle}]_k \qquad (6)$$

where

$V_{session}$ is the number of vehicles fueling per session,
C_{hoses} is the number of CNG dispenser hoses, and
k denotes a particular vehicle type.

The average number of vehicles of each type fueling daily and $D_{session}$ can be derived, if one knows the on-board storage capacity and average annual miles traveled for each vehicle type. The average number of vehicles of each type fueling daily and the number of dispenser hoses then gives the number and type of vehicles in each fueling queue.

The compressor and storage sizes directly affect their costs (in dollars) through cost/size relationships (equations 7 and 8) empirically calibrated using compressor and storage cost/size data reported in the literature and received from manufacturers and vendors (Christy Park, 1991; Cherco Compressors, 1991; Tri-Fuels, 1991; EPA, 1990b).

$$\text{Compressor cost} = 15{,}791 + (482.38 \times C_{min}) + (0.16734 \times C_{min}^2) - (0.001037 \times C_{min}^3) \qquad (7)$$

$$\text{Storage cost} = -487.55 + (1.0889 \times S_{max}) \qquad (8)$$

The compressor cost/size equation (7) holds only for compressors designed to operate at input gas line (suction) pressures of 5 to 7 psig. Significant capital compressor and operating (power) costs savings are possible if the fleet has access to pipeline gas pressures higher than these. In fact, it has been reported that in Italy cost-effective natural gas filling stations require suction pressures of 150 psig (DeLuchi, Johnston & Sperling, 1988).

In addition, the calibrated equation (8) implies that storage is available in continuous increments, and this is not the case. In reality, the fleet will need to purchase an amount of storage which is commercially available. This will probably result in a slightly higher cost than predicted here. The same is true for compressors, as individual companies may offer specific compressors at a price lower than predicted here on the basis of average patterns.

Several key assumptions affect the major outputs (compressor and storage sizes) of this design methodology. The first being the assumption of continuous filling of vehicles in one session per day, which maximizes the required storage. If it were assumed instead that vehicles fueled in two or three continuous sessions, with storage recharge time in between, then the storage size and cost would be less. The minimum storage cost would be incurred if the vehicles fueled at the maximum time-permissive intervals throughout the work day. Another factor to consider is that these estimates are based on average daily fuel needs. In reality, a fleet may want to purchase a compressor and storage that are slightly larger than estimated here (and therefore more expensive) in order to handle their "worst case" days.

Dispenser and dryer costs are input directly by the analyst, and the station setup cost is considered to be equivalent to a percentage of the combined cost of the compressor, storage, and dispenser (EPA, 1990a; DOE, 1990a).

Some elements in this methodology tend to under-predict while others tend to over-predict station costs. On balance, the resulting estimate should be sufficiently close to actual costs for the purpose of this analysis. In fact, it produces predictions that are similar to other reported natural gas fueling station costs (EPA, 1990a; EPA, 1990b; DOE, 1990a). It also provides the fleet operator with an approximate station design (i.e., size of compressor and storage) and indications of how conversion to natural gas (fueling aspects only) will affect fleet operation, through comparison of fueling session times, number of vehicles fueling daily, and labor fueling losses between natural gas and gasoline/diesel fleets.

The other major capital costs, vehicle conversion costs, are computed as shown in equations (9) through (16). The various vehicle and cost items required are supplied directly by the analyst, as discussed in the input data section below.

$$\text{Kit cost} = (C_{new} \times P_{kit}) - [(C_{retired} - T_{kits}) \times S_{kit/tank}] \qquad (9)$$

where

C_{new} is the number of vehicles converted with new kits/tanks,
$C_{retired}$ is the number of converted vehicles retired,
T_{kits} is the number of kits transfered from retired vehicles to new conversions,
P_{kit} is the price of a new kit, and

$S_{kit/tank}$ is the salvage value of the conversion kit and tanks.

$$\text{Total fleet kit cost} = \Sigma\ (\text{Kit cost})_k N_k \qquad (10)$$

where

k again denotes a particular vehicle type, and
N_k is the number of fleet vehicles of type k.

$$\text{Tank cost} = C_{new} \times T_{vehicle} \times P_{tank} \qquad (11)$$

where

$T_{vehicle}$ is the number of tanks per vehicle and
P_{tank} is the price of a new tank.

$$\text{Total fleet tank cost} = \Sigma\ (\text{Tank cost})_k N_k \qquad (12)$$

$$\text{Labor cost} = (C_{new} + T_{kits}) \times P_{labor} \qquad (13)$$

where

P_{labor} is the price of labor to install the kit and tank(s).

$$\text{Total fleet labor cost} = \Sigma\ (\text{Labor cost})_k N_k \qquad (14)$$

$$\text{OEM cost} = (O_{vehicles} \times P_{differential}) - (O_{retired} \times S_{OEM}) \qquad (15)$$

where

$O_{vehicles}$	is the number of new OEM CNG vehicles purchased,
$O_{retired}$	is the number of OEM CNG vehicles retired,
$P_{differential}$	is the price differential between a new OEM CNG vehicle and a comparable gasoline or diesel vehicle, and
S_{OEM}	is the differential salvage value between a retired OEM CNG vehicle and a comparable gasoline or diesel vehicle.

$$\text{Total fleet OEM cost} = \Sigma\ (\text{OEM cost})_k N_k \qquad (16)$$

As reported in the previous section, six operating cost components are included in the analysis. Their computation is briefly discussed below.

Station maintenance costs. These are incurred primarily by the compressor and are taken to be directly proportional to the fuel consumed, as shown in equation (17) (DeLuchi, Johnston & Sperling, 1988; EPA, 1990a; IANGV, 1990; AGA, 1989b; Moran & Fiore, 1986; EPA, 1988a). The unit cost per gasoline gallon equivalent is an input to the procedure.

$$\text{Station maintenance cost} = CNG_{annual} \times M \qquad (17)$$

where

CNG_{annual}	is the annual natural gas demand of the fleet, and
M	is the maintenance cost per unit of natural gas compressed.

Power costs. This significant operating cost component is a function of the cost of electricity per kilowatt-hour (kWh) and the energy required by the compressor. The cost/kWh is an input to the procedure. The energy required by the compressor is a function of its motor horsepower (HP), its duty-cycle, and the number of hours of operation (obtained from the station design methodology). The computation of this cost proceeds as follows:

$$\text{Power cost} = C_{hp} \times D \times (CNG_{annual}/C_{min}) \times 0.745712 \times C_{elect} \qquad (18)$$

where

C_{hp}	is the compressor horsepower rating,
D	is the compressor duty-cycle,
0.745712	is the number of kilowatts per horsepower, and
C_{elect}	is the cost of electricity per kilowatt-hour.

Note that in years where tank recertification is required for a given vehicle, the annual fleet demand for natural gas (and therefore the compressor operating hours, power cost, and fuel price savings) is reduced accordingly to account for the number of days that the vehicle cannot be operated on CNG, as current methods require that the tank be removed from the vehicle and taken offsite for hydrostatic testing. The compressor HP is computed from equation (19), which was empirically calibrated from published data and data obtained directly from manufacturers and vendors (Cherco Compressors, 1991; Tri-Fuels, 1991; EPA, 1990b).

$$C_{hp} = 2.6588 + (0.54898 \times C_{min}) \qquad (19)$$

Cylinder recertification costs. This cost is incurred periodically (every 3 years for composite cylinders and every 5 years for steel). It is computed on a per-cylinder basis, as shown in equations (20) and (21), and includes costs for labor (to remove and replace the cylinder on the vehicle), for transportation (to the testing facility), and for the test itself. The total cost per cylinder is an input to the procedure. Recertification is required by the Texas Railroad Commission.

$$\text{Recertification cost} = T_{recert} \times P_{tank/recert} \qquad (20)$$

where

T_{recert}	is the number of tanks requiring recertification and
$P_{tank/recert}$	is the price to recertify one tank.

$$\text{Total fleet recertification cost} = \Sigma\ (\text{Recertification cost})_k N_k \qquad (21)$$

where

k	again denotes a particular vehicle type and
N_k	is the number of fleet vehicles of type k.

Additional training. This component, encompassing both driver and mechanic training, is directly entered by the analyst in the appropriate year it is incurred, if applicable.

Fueling labor lost time. The fast-fill CNG fueling process is more time-consuming because of its slower fuel dispensing rate and lower onboard fuel capacity which requires these vehicles to fuel more frequently (and thus incur the switching time between vehicles more often) than gasoline and diesel vehicles. The additional CNG fueling time relative to gasoline is multiplied by an hourly labor rate to obtain the corresponding labor costs. Computation of this cost is as follows:

$$\text{Labor fuel cost} = [(C_{hoses} \times T_{session}) - (G_{hoses} \times G_{session}) - (D_{hoses} \times DE_{session})] \times D_{year} \times C_{labor} \qquad (22)$$

where

G_{hoses} and D_{hoses}	are the number of gasoline and diesel dispenser hoses,
$G_{session}$ and $DE_{session}$	are the fueling session times required to fuel dedicated gasoline and diesel vehicles with enough fuel to offset the natural gas used by these vehicles were they replaced (see equations (23) and (24) and equation (6) for $T_{session}$),
D_{year}	is the number of days the fleet is operational per year, and
C_{labor}	is the cost of labor to fuel vehicles.

$$G_{session} = \Sigma\ [(V_{session} / G_{hoses}) \times T_{vehicle}]_k \qquad (23)$$

$$DE_{session} = \Sigma\ [(V_{session} / D_{hoses}) \times T_{vehicle}]_k \qquad (24)$$

Texas state natural gas vehicle fuel tax. This is a tax required for many fleets by Texas law. The tax is based on the annual mileage driven on natural gas and the weight of the vehicle, as shown in Table 5.1.

The above calculations require fleet data and several assumed values that must be supplied by the analyst. These are discussed next.

Table 5.1 Texas natural gas (and propane) fuel tax per vehicle (1991)

	Annual Mileage			
Vehicle Type	**0 – 5,000**	**5,001 – 10,000**	**10,001 – 15,000**	**>15,000**
Automobile	$30	$60	$90	$120
Light truck	$30	$60	$90	$120
Heavy Gasoline	$48	$96	$144	$192
Heavy Diesel	$48	$96	$144	$192

5.2.2 Input Data Requirements

The input data can be broken into five categories:

1) vehicle data,
2) fuel prices,
3) fueling station data,
4) fueling labor loss data, and
5) miscellaneous factors.

Vehicle data. Four vehicle types are considered in this framework:

1) automobile,
2) light truck (pickups and vans),
3) heavy-duty gasoline, and
4) heavy-duty diesel.

Each type is characterized by different attributes that affect the costs and benefits of CNG conversion and operation. The data required characterize the specific fleet being analyzed by fleet composition (number of vehicles, year they are converted or an OEM natural gas vehicle replacement is purchased, and current gasoline fuel efficiency) and vehicle utilization (average annual miles travelled and percentage of this mileage travelled using natural gas). Factors to adjust fuel efficiency for comparable converted and OEM natural gas vehicles are also included here, as are the costs of conversion kit equipment, tanks, and labor for conversion and an OEM price differential. Other vehicle data include: on-board gasoline storage capacity, maintenance cost differential, tank recertification cost, number of CNG tanks per vehicle, and salvage value differentials.

Fuel prices. These are used to calculate the major monetary fleet benefit. The pipeline price of natural gas to the fleet in dollars per thousand cubic feet (mcf) is used along with the natural gas-to-gasoline and natural gas-to-diesel energy conversion factors (in the miscellaneous factors section) to compute the price of natural gas per gasoline and diesel gallon equivalents. These prices are for an amount of natural gas with the energy equivalence of a gallon of gasoline or diesel. Also needed are the gasoline and diesel prices per gallon.

Because of the uncertainty involved in predicting natural gas, gasoline, and diesel prices over the next year, much less over the next 30 years, this analysis does not present any elaborate future predictions. Since natural gas price trends have tracked gasoline price trends fairly closely over the last 20 years (see Figure 5.2), it is not unreasonable to assume that they will continue to do so in the future. This assumption might be incorrect if natural gas vehicles take over a significant share of the gasoline and/or diesel vehicle market. In this case, the past trends, which were for a non-vehicular-based natural gas market, may not continue. For flexibility and sensitivity analysis purposes, the analysis framework permits the consideration of any forecast profile and the comparison of different macroeconomic scenario forecasts, thereby allowing an assessment of the robustness of a particular fleet conversion decision.

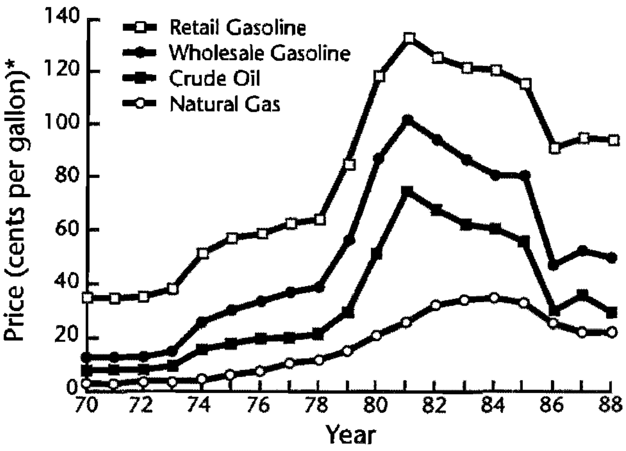


Figure 5.2 ***Comparison of oil, gasoline, and natural gas prices (*natural gas prices are in gallon equivalents)***

Fueling station data. The principal parameters introduced in the station cost estimation procedure must be supplied by the analyst. In particular, values for the dispenser cost, dryer cost, switch time between vehicles, cycle time (i.e., session plus recharge time), number of dispenser hoses, station setup cost factor, usable storage, and average flow rate per dispenser hose over the whole session must be provided.

Fueling labor losses. These data are very similar to those necessary to calculate the fueling session time for natural gas. In particular, values for gasoline and diesel flow rates, number of gasoline and diesel hoses, the gasoline/diesel switch time between vehicles, and the average hourly labor rate must be provided.

Miscellaneous factors. Included here are the number of fleet work days per year and the percentage of natural gas stored in a vehicle tank at 3,000 psig after the tank temperature stabilizes to around 70°F. During a fast-fill, increased tank temperatures temporarily reduce the natural gas capacity of the tank (IANGV, 1990). Compression factors allowing the calculation of the amount of natural gas remaining in the vehicle when it is ready to be filled, from the amount of gas stored in the tank when it is full are also given, as are the volumes of natural gas in cubic feet at standard pressure and temperature (standard cubic feet, or scf) that have the energy equivalence of a gallon of gasoline and a gallon of diesel. The cost of station maintenance (mainly compressor) per gasoline gallon equivalent is input here.

The cost of electricity per kilowatt-hour is the price to the fleet under analysis. Also input here is the number of days that tanks will be off a converted vehicle for DOT recertification. It is assumed that by the time OEM natural gas vehicles are widely available, tank recertification will be a part of ordinary state vehicle inspection and maintenance programs. Costs for this additional testing during inspection will be spread out over all vehicle types, gasoline, diesel, natural gas, and others, so at this time there will be no incremental difference in cost for recertification. Finally, the discount rate or opportunity cost of capital, used to compute the present values of future monetary costs and benefits, also needs to be provided by the analyst.

5.3 FRAMEWORK DEVELOPMENT (PROPANE)

This section presents an overview of the cost-effectiveness analysis framework for propane and discusses the underlying assumptions and required input data. The propane framework is conceptually the same as the CNG framework discussed in the previous section. Therefore, only the elements that differ will be discussed in detail.

The discussion in this section follows the order in which the principal cost and benefit items are presented in the first section. The principal input data requirements and assumptions are then discussed.

5.3.1 Benefit and Cost Calculations

The propane monetary cost/benefit fleet analysis uses the same net present value (NPV) approach as for CNG, in addition to finding the incremental cost (or savings) per vehicle per year and the increased cost (or savings) per mile in the same manner. Fuel cost and maintenance savings computations are also handled identically.

The three major cost items described in the first section of this chapter also apply to propane. They are: fueling (capital) infrastructure costs, vehicle conversion (capital) costs, and operating costs. Estimating fueling infrastructure costs for propane is much simpler than for CNG (see Chapter Four for background information).

This analysis assumes that fleets will provide their own fueling infrastructure. However, the framework can still be used even if the fleet is assumed to either fuel at a public propane filling station or at an on-site fueling station provided by the propane supplier. The propane fuel prices would then be adjusted to reflect either public station or supplier prices, and all capital infrastructure and station maintenance costs would be removed, since they are now incurred by the public station or supplier and passed on to the fleet in the fuel price.

As discussed in Chapter Four, the fleet can purchase propane in either large or small volumes. A lower cost per gallon is available for large volume purchases, but a larger storage tank is required, meaning a greater capital cost. This framework allows the analyst to consider both a small and large storage volume, each with different capital costs, maintenance costs, and associated propane prices. The NPV of all costs and benefits over the analysis period is computed for both station sizes, and the most cost-effective size is chosen.

The station setup cost is considered to be equivalent to a percentage of the combined cost of the storage and dispenser. This percentage is less than that for CNG, since installation of a propane station requires far fewer miscellaneous components, less structural work, and less labor.

The other major capital costs are vehicle conversion costs. Computation of these costs is the same as for CNG. As reported in the first section, six operating cost components are included in the analysis. Their computation is briefly discussed below.

Station maintenance costs. These are incurred primarily by the fuel pump and are input directly by the analyst on an annual basis.

Power costs. This operating cost component is a function of the cost of electricity (cost/kWh) and the energy required by the fuel pump. This cost is considered to be the same as that for the gasoline/diesel fuel pump. The differential cost is therefore zero and is not included in the framework.

Cylinder recertification costs. This cost is not applicable to propane.

Additional training. This component, encompassing both driver and mechanic training, is directly entered by the analyst in the appropriate year it is incurred, if applicable.

Fueling labor lost time. As discussed previously, propane fueling may take more or less time than gasoline/diesel fueling. As for CNG, the differential fueling time relative to gasoline/diesel is multiplied by an hourly labor rate to obtain the corresponding labor costs or savings.

Texas state propane vehicle fuel tax. This is a tax required for many fleets by Texas law. As for

CNG, the tax is based on the annual mileage driven on propane and the weight of the vehicle (see Table 5.1).

The above calculations require fleet data and several assumed values that must be supplied by the analyst. These are discussed next.

5.3.2 Input Data Requirements

As for CNG, the input data can be broken into five categories:

1) vehicle data,
2) fuel prices,
3) fueling station data,
4) fueling labor loss data, and
5) miscellaneous factors.

Vehicle data. This data is identical to the data required for CNG, excluding tank recertification data.

Fuel prices. These are used to calculate the major monetary fleet benefit. Propane price to the fleet for both small and large volume purchases is computed by summing the following: propane refinery cost, transportation cost, federal tax, and the supplier markup for either small or large volume purchases. Also needed are the gasoline and diesel prices per gallon.

This analysis does not present any elaborate future predictions for propane, gasoline, or diesel price trends. As for CNG, it is not unreasonable to assume that propane prices will track gasoline/diesel prices in the future, as they have in the past, unless propane vehicles take over a significant share of the gasoline and/or diesel vehicle market. In this case, the past trends, which were for a non-vehicular-based propane market, may not continue. Therefore, the analysis framework permits the consideration of any fuel price forecast profile.

Fueling station data. Values for the cost of both the small and large storage vessels, dispenser(s), and station setup cost factor must be provided.

Fueling labor losses. These data are very similar to those necessary to calculate the fueling session time for natural gas. In particular, values for propane, gasoline, and diesel flow rates, number of propane, gasoline, and diesel hoses, both the propane and gasoline/diesel switch times between vehicles, and the average hourly labor rate must be provided.

Miscellaneous factors. Included here are the number of fleet work days per year, the percentage of propane that can be safely stored in a vehicle or fueling station tank, the fuel remaining in a vehicle's tank when it is fueled, the volume of propane that has the same amount of energy as a gallon of gasoline and a gallon of diesel, and the discount rate or opportunity cost of capital, used to compute the present values of future monetary costs and benefits.

5.4 CLOSURE

This chapter presented a cost-effectiveness analysis framework for use in analyzing fleet operation on either CNG or propane. The elements of the framework which differ significantly between CNG and propane are: the estimation of fueling infrastructure costs, lack of recertification costs for propane, lack of a power cost differential for propane relative to gasoline/diesel, and the estimation of station maintenance costs. This framework has been implemented in spreadsheet format and will be used in the analyses in the next two chapters.

CHAPTER 6. FLEET ANALYSIS

In this chapter, the cost-effectiveness analysis framework discussed in Chapter Five (implemented in spreadsheet format) is used, along with scenario and sensitivity analyses, to investigate the economic feasibility of operating Texas Department of Transportation (TxDOT) fleets on either CNG or propane. This analysis proceeds in the following manner. Report 983-2, Volumes 1 and 2, Cost Effectiveness Analysis of TxDOT CNG Fleet Conversion and Report 983-4, Volumes 1 and 2, Cost Effectiveness Analysis of TxDOT LPG Fleet Conversion contain detailed analyses of all 314 TxDOT fleet fueling locations. The purpose of this chapter is to illustrate the use of the model and how it effects, generally, fleets of different sizes. The first two sections use "favorable" and representative TxDOT fleets in order to draw conclusions on a fleet-wide basis. (Favorable meaning that the fleet has characteristics favorable to cost-effective operation on the alternative fuel (either CNG or propane).) The first section analyzes CNG operation and the second analyzes propane. The next two sections use actual TxDOT locations of three different sizes (small, medium, and large), in order to analyze some of the variability in locations not captured by the favorable and representative fleets in the first two sections and draw conclusions on an individual location basis. The first of these sections analyzes CNG operation and the second analyzes propane.

6.1 FAVORABLE AND REPRESENTATIVE CNG FLEET ANALYSES

This section uses the cost-effectiveness analysis framework described in Chapter Five, along with scenario and sensitivity analyses, to analyze "favorable" and representative Texas Department of Transportation (TxDOT) fleets. First, a hypothetical fleet with characteristics favorable to cost-effective conversion and operation on CNG is analyzed, as an illustration of the type of fleets that may be cost-effective. Such favorable characteristics include:

1) a large number of vehicles to share in the fixed fueling infrastructure costs and
2) high average annual mileage, generating greater fuel price savings per year.

Next, fleets more representative of TxDOT are analyzed and compared with the "favorable" fleet.

6.1.1 Assumptions

To facilitate comparison, characteristics of the "favorable" fleet are based on representative TxDOT vehicles, with the differences being higher average annual mileage and larger-than-average fleet size. The characteristics of this fleet are shown in Table 6.1.

Table 6.1 Characteristics of "favorable" fleet

Vehicle Type	Number of Vehicles	Average Fuel Efficiency (mpg)	Average Annual Mileage
Automobile	10	19.0	22,500
Light Truck	120	14.0	22,500
Heavy-Duty Gasoline	10	5.5	22,500

Heavy-duty diesel vehicles are not considered, because their conversion is much less cost-effective than gasoline vehicles. This is due to higher vehicle costs, both conversion and OEM; reductions in fuel efficiencies for CNG over diesel (for dedicated CNG vehicles); the greater energy density of diesel relative to gasoline; and the lower price of diesel to TxDOT fleets relative to the price of gasoline (4 cents per gallon less).

Vehicles are assumed to be used for 90,000 miles (i.e., 4 years for this fleet). For the first 10 years, OEM gasoline vehicles are purchased and converted to dual-fuel CNG operation. In year 11, OEM-dedicated CNG vehicles are assumed available for all vehicle types.

Other important input variables are fuel prices, conversion costs, and OEM vehicle price differentials. Fuel prices are obviously highly uncertain, and conversion and OEM costs are somewhat negotiable and subject to change owing to technological advances and economies available with mass production and market competition, among other things. In this example, constant fuel prices (1991 dollars) are used over the entire 30-year analysis period. A gasoline price of 89 cents/gallon (including tax) is assumed, based on the prices paid by TxDOT in 1991. Conversion costs and OEM cost differentials are drawn from several sources (EPA, 1990a; EPA, 1990b; GRI, 1989a; Natural Gas Resources, 1991), and shown in Figure 6.1, along with all other major input data assumptions. (Note that these analysis assumptions are identical to those used in another analysis of the same fleet (Taylor, Euritt & Mahmassani, 1992C), except for the average flow rate per hose (500 scfm versus 300 scfm) and the number of days off for tank recertification (5 versus 20). The increased flow rate greatly reduces labor fueling losses and slightly increases fueling station storage (and therefore, setup) costs. Decreasing the number of days off for recertification slightly increases power and station maintenance costs, along with increasing fuel savings. Therefore, this analysis is more optimistic for CNG cost-effectiveness than the other.)

6.1.2 Favorable Fleet Analysis

Figure 6.2 shows a summary of the analysis for the "favorable" fleet with a natural gas price of \$1.95/mcf. The complete analysis spreadsheet is shown in Appendix A. Under the base assumptions of the model, this price (\$1.95/mcf) is required for conversion and operation of this fleet to be cost-effective (i.e., for the 30-year NPV of Savings minus Costs to be non-negative). Since actual natural gas prices are quite variable for different fleet locations, the break-even price of natural gas (i.e., the price required for cost-effectiveness) is found by performing a sensitivity analysis. One can then compare the break-even price with the price to any particular location or—as done in these analyses—compare the break-even price with plausible natural gas prices. Herein, \$2.50/mcf is considered to be the lowest plausible pipeline delivered natural gas cost to TxDOT fleets (AGA, 1989a; EIA, 1984-1990). Thus, conversion of this hypothetical fleet is not cost-effective under the base model assumptions.

Conversion costs	
Automobile	\$1,950
Light Truck	\$2,200
Heavy-Duty Gasoline	\$3,300
OEM vehicle cost differential	\$900
Gasoline fuel price (cents/gallon) (constant over entire analysis period)	89.0
Diesel fuel price (cents/gallon) (constant over entire analysis period)	85.0
Station maintenance cost (cents/gallon)[a]	4.5
Electricity cost (cents/kWh)	6.3
Vehicle life (miles)	90,000
CNG in a gallon of gasoline (scf)	122.7
Vehicle tank pressure before fill (psig)	100
Year OEM vehicles available	11
Cylinder recertification cycle (years)	3
Analysis period (years)	30
Days off for tank recertification	5
Discount rate	10%
Fuel efficiency decrease for conversions	5%
Fuel efficiency increase for OEM	15%
Usable cascade storage	40%
Percentage of mileage on CNG	100%
Station setup cost factor	25%
Average flow rate per hose (scfm)	500
Number of dispenser hoses	2
Vehicle maintenance cost savings	\$0
Land cost for fueling station	\$0
Additional training cost	\$0
Labor rate per hour	\$15

[a] Values of this factor ranging from 3 to 10 cents have been reported (Deluchi, Johnston & Sperling, 1988; EPA, 1990a; IANGV, 1990; AGA, 1989b; Moran & Fiore, 1986; EPA, 1988a).

Figure 6.1 Base input data assumptions

Savings	30 year NPV
Gasoline Price Difference	$1,500,403
Automobiles	$72,343
Light Trucks	$1,178,150
Heavy-Duty Trucks	$249,911
Diesel Price Difference	$0
Maintenance	$0
Total Savings	$1,500,403
Costs	
Infrastructure	
Land	$0
Station setup	($89,845)
Compressor	($65,829)
Storage Vessels	($258,625)
Dispenser	($24,857)
Dryer	($9,943)
Subtotal	($449,099)
Vehicle	
Conversion Kit	($89,889)
Tanks	($132,500)
Labor	($175,872)
OEM	($82,748)
Subtotal	($481,009)
Operating	
Station Maintenance	($104,032)
Cylinder Recertification	($25,228)
Power	($129,171)
Labor - fuel time loss	($144,493)
Natural Gas Fuel Tax	($165,160)
Additional training	$0
Subtotal	($568,084)
Total Costs	($1,498,191)
Savings - Cost	$2,212

Figure 6.2 "Favorable" fleet analysis summary ($1.95/mcf natural gas)

It is interesting to note the relative magnitudes of the cost items. The 30-year NPV of fueling station infrastructure costs ($449,099) and vehicle costs ($481,009) are of the highest magnitude, followed by the Texas state natural gas vehicle fuel tax ($165,160), labor-fuel time losses ($144,493), power ($129,171), and station maintenance ($104,032). It should be noted that power and station maintenance costs accumulate on a per-gallon basis, and as such directly reduce the savings from the fuel price differential. There are no economies of scale for these costs, as more fuel is consumed through either annual mileage increases or changes in fuel economy. The sensitivity of the results to the assumptions used in computing the four highest cost items is examined next.

For the "favorable" sample fleet described above, sensitivity to the following three relaxations of the base model assumptions are analyzed first:

Relaxation 1 - Eliminate Texas state natural gas vehicle fuel tax;
Relaxation 2 - Ignore labor-fuel time losses; and
Relaxation 3 - Reduce fueling station infrastructure costs by one third.

Relaxation 1 is a potential policy instrument for encouraging greater natural gas use. Relaxation 2 is important in order to highlight the value of both fueling station and on-board storage technology improvements. Finally, relaxation 3 is used as an approximation of the maximum potential cost reductions associated with other fueling scenarios and technologies. The results are shown in Table 6.2 for the "favorable fleet". Under any of the relaxation combinations, this fleet's conversion becomes cost-effective at low—but plausible—natural gas prices.

Table 6.2 Sensitivity analysis, "favorable" fleet

Relaxations	Break-Even NG Price (per mcf)
None	$1.95
1	$2.54
1 and 2	$3.04
1,2, and 3	$3.57

Sensitivity to the price of natural gas can be examined by considering the base case above, where cost-effectiveness occurred at a price of $1.95/mcf (24 cents per gasoline gallon equivalent). As natural gas price increases to $7.25/mcf (equivalent to the gasoline price of 89 cents per gallon on an energy basis), fuel price savings approach zero (and become slightly negative owing to fuel efficiency losses with CNG conversions), resulting in a very high cumulative NPV (about the same as total costs, -$1,498,191). Thus, cost-effectiveness is very sensitive to fuel price, and natural gas prices in the middle of and at the high end of this range are quite possible, depending on fleet location, volume of natural gas purchased, and the supplier (AGA, 1989a; EIA, 1984-1990).

6.1.3 Representative Fleet Analysis

Vehicles in TxDOT fleets are driven closer to 15,000 miles annually, rather than the 22,500 miles of the "favorable" fleet. So, under the 90,000 mile vehicle life assumption used in this analysis, they are kept for 6 years. Since there are approximately 300 TxDOT locations where vehicles fuel, and since they have about 6,000 gasoline vehicles statewide (mostly light trucks), the average fleet size is only about 20 gasoline vehicles, as opposed to 140 in the fleet analyzed above. Yet fleet size variability is such that there are a few locations with fleets as large as 140 vehicles. Therefore, sensitivity analyses to average annual miles per vehicle and fleet size are performed. Fleet size is adjusted by changing the number of light trucks and keeping both the number of automobiles and the number of heavy-duty gasoline vehicles at 10. Three fleet sizes are analyzed, consisting of 10, 60, and 120 light trucks, respectively, in addition to the 10 automobiles and 10 heavy-duty gasoline vehicles. The results are shown in Table 6.3.

Table 6.3 Sensitivity analysis, 15,000 mile fleet

	Break-Even NG Price (per mcf) for		
Relaxations	10 Light Trucks	60 Light Trucks	120 Light Trucks
None	$0.36	$0.73	$0.91
1	$1.12	$1.58	$1.79
1 and 2	$1.58	$2.08	$2.30
1, 2, and 3	$2.51	$2.77	$2.89

The case with 120 light trucks differs from the one previously analyzed only in that the average annual mileage per vehicle is assumed to be 15,000 instead of 22,500 miles. The results are quite sensitive to this change. The break-even natural gas price is reduced by an amount ranging from 68 to 104 cents per mcf and all three relaxations are necessary for the 15,000 miles per vehicle fleets to become cost-effective for a low—but plausible—natural gas price.

Results are also fairly sensitive to fleet size. The break-even price increases as the fleet size increases, mainly because of economies of scale in the fueling infrastructure costs. This price is about 20 cents less for the 60 light truck fleet than for the 120 light truck fleet, and drops by about another 40 cents for the 10 light truck fleet. Since most of the TxDOT locations are best represented by the 10 light truck fleet, even relaxation of all three assumptions barely yields a plausibly low break-even price for natural gas. Any other combination of relaxations yields implausibly low break-even prices. One can therefore conclude that it will not be cost-effective to convert most TxDOT locations to CNG, unless many of the base assumptions can be relaxed or natural gas is available at prices less than $2.50/mcf.

A discount rate of 10 percent has been adopted by TxDOT, based on recommendations from the State Purchasing and General Services Commission. Sensitivity to this rate is reported in Table 6.4 for the 10 light truck fleet with 15,000 average annual miles per vehicle, assuming no other relaxations of the base assumptions. The appropriate discount rate would have to be very low (below 4 percent) for the majority of TxDOT fleets to be cost-effective, and then only with fairly low natural gas prices.

Table 6.4 Sensitivity to discount rate, fleet with 10 light trucks and annual mileage of 15,000 miles

Discount Rate (%)	Break-Even NG Price (per mcf)
10	$0.36
8	$1.05
6	$1.74
4	$2.40
2	$3.04
0	$3.65

The final sensitivity analysis reported here is for conversion costs. The conversion costs assumed up to this point are: automobiles - $1,950; light trucks - $2,200; and heavy-duty gasoline vehicles - $3,300. These include kit, tank, and installation labor costs. These costs are about 30 percent less than TxDOT is currently paying for conversions, as our analysis assumes a more mature natural gas vehicle market in Texas. Nevertheless, because of claims that conversions can and will be performed even cheaper, the limiting case of immediate availability of OEM-dedicated CNG vehicles was analyzed for the three fleet sizes for 15,000 annual miles per vehicle. It is assumed that an OEM-dedicated CNG vehicle costs $900 more than a comparable gasoline vehicle. This is the best case possible, because no conversions or tank recertifications are necessary, and greater benefits accrue from the increased fuel efficiencies of OEM-dedicated CNG vehicles. The results of this analysis are reported in Table 6.5. As expected, the break-even natural gas prices are much higher than those when conversions are utilized for the first 10 years. Even though this analysis assumes immediate replacement of all fleet vehicles, without accounting for losses due to scrappage, it still confirms that the introduction of OEM-dedicated CNG vehicles is very important to the cost-effectiveness of fleet conversion, as is the reduction of conversion costs until that time.

Table 6.5 Analysis for immediate availability of OEM vehicles, 15,000 mile fleet

Fleet Size (Light Trucks)	Break-Even NG Price (per mcf)
10	$2.17
60	$2.68
120	$2.90

Sensitivity to other factors (e.g., maintenance savings, vehicle fuel efficiencies, labor costs, electricity costs, power costs, station maintenance costs and cylinder recertification costs) can also be investigated using this model and are discussed in an earlier report (Euritt, Taylor, Mahmassani, 1992a).

6.1.4 Conclusions

The analysis in this section:

1) highlights the primary significance of fuel price differential, conversion cost, and fueling infrastructure cost in the trade-offs underlying CNG fleet conversion and operation decisions.
2) confirms that the actions of the natural gas industry and others to push for OEM vehicles (with lower cost differentials and better fuel efficiencies relative to conversions), improved and lower-cost on-board storage technologies, and improved and lower-cost fueling infrastructure represent a good near-term strategy for achieving greater market penetration of natural gas vehicles.
3) illustrates that large fleet sizes are more cost-effective, because of economies of scale in fueling infrastructure costs.
4) illustrates that the greater the annual vehicle mileage the more cost-effective operation on CNG will be (all other things being equal), due to greater fuel cost savings.
5) verifies that other lower-cost fueling station designs (such as slow-fill) should be considered, because a continuous fast-fill design is a significant cost item. In addition, trade-offs in station design and labor fueling losses should be investigated, because of the significance of the latter's cost.
6) shows that the Texas state natural gas fuel tax is a significant cost item for fleet conversion to natural gas operation.
7) illustrates how the cost-effectiveness analysis model can be used as a decision support tool that allows one to deal with uncertain energy and technological futures through alternative scenarios and sensitivity analyses.
8) indicates that it will not be cost-effective for most TxDOT fleets to convert to compressed natural gas operation under the assumptions stated herein.

6.2 FAVORABLE AND REPRESENTATIVE PROPANE FLEET ANALYSES

This section uses the cost-effectiveness analysis framework described in Chapter Five, along with scenario and sensitivity analyses, to analyze "favorable" and representative Texas Department of Transportation (TxDOT) propane fleets. The propane analysis in this section proceeds in a manner similar to the CNG analysis in Section 6.1, performing very similar sensitivity analyses, while using the same "favorable" (see Table 6.1) and representative fleets. First, the hypothetical fleet with characteristics favorable to cost-effective conversion and operation on propane is analyzed. Next, fleets more representative of TxDOT are analyzed and compared with the "favorable" fleet. To facilitate comparison, characteristics of the "favorable" fleet are based on representative TxDOT vehicles, with the main differences being higher average annual mileage and larger-than-average fleet size.

6.2.1 Assumptions

As in the CNG analysis in Section 6.1, heavy-duty diesel vehicles are not considered, because their conversion is much less cost-effective than gasoline vehicles. Vehicles are assumed to be used for 90,000 miles (i.e., 4 years for this fleet). For the first 10 years, OEM gasoline vehicles are purchased and converted to dual-fuel propane operation. In year 11, OEM-dedicated propane vehicles are assumed available for all vehicle types.

Other important input variables are fuel prices, conversion costs, and OEM vehicle price differentials. As for the CNG analysis, constant fuel prices (1991 dollars) are used over the entire 30-year analysis period. Conversion costs and OEM cost differentials are drawn from several sources (CEC, 1989; Phillips 66, 1991a; Manchester Tank, 1991; Phillips 66, 1991b), and shown in Figure 6.3, along with all other major input data assumptions.

Conversion costs	
Automobile	$1,600
Light Truck	$1,190
Heavy-Duty Gasoline	$1,200
OEM vehicle cost differential	
Automobile	$400
Light Truck	$400
Heavy-Duty Gasoline	$450
Gasoline fuel price (cents/gallon) (constant over entire analysis period)	89
Diesel fuel price (cents/gallon) (constant over entire analysis period)	85
Propane transportation cost (cents/gallon)	3
Propane gallons in a gallon of gasoline	1.35
Small station/volume	
Storage/pispenser cost	$10,000
Maintenance cost ($/year)	$500
Supplier propane markup (cents/gallon)	21
Large station/volume	
Storage/pispenser cost	$57,000
Maintenance cost ($/year)	$1,500
Supplier propane markup (cents/gallon)	4
Vehicle life (miles)	90,000
Year OEM vehicles available	11
Analysis period (years)	30
Discount rate	10%
Fuel efficiency decrease for conversions	0%
Fuel efficiency increase for OEM	10%
Percentage of mileage on propane	100%
Station setup cost factor	15%
Average propane fill rate (gallon/minute)	7
Average gasoline fill rate (gallon/minute)	7
Vehicle maintenance cost savings	$0
Land cost for fueling station	$0
Additional training cost	$0
Labor rate per hour	$15

Figure 6.3 Base input data assumptions

6.2.2 Favorable Fleet Analysis

Figure 6.4 shows a summary of the analysis for the "favorable" fleet with a refinery propane price of 43 cents/gallon.The cost of propane to the fleet is the sum of the refinery price, the transportation cost, and the supplier markup. For a 43 cent/gallon refinery price, this would be 50 and 67 cents/gallon to the fleet for large and small volume propane purchases, respectively. The complete analysis spreadsheet is shown in Appendix B. Under the base assumptions of the model, this refinery price (43 cents/gallon) is required for conversion and operation of this fleet to be cost-effective. Herein, 36 cents/gallon is considered to be a plausible refinery propane price for TxDOT fleets, given that the yearly average refinery propane price at Mount Belvieu, Texas was 35.9 cents in 1991 and 37.7 cents in 1990 (Butane/Propane News, 1990-1991). Thus, conversion of this hypothetical fleet is cost-effective under the base assumptions.

Savings	30 year NPV
Gasoline Price Difference	$534,613
Automobiles	$25,777
Light Trucks	$419,790
Heavy-Duty Trucks	$89,046
Diesel Price Difference	$0
Maintenance	$0
Total Savings	$534,613
Costs	
Infrastructure	
Land	$0
Station setup	($8,746)
Storage/Dispenser	($56,672)
Subtotal	($65,418)
Vehicle	
Conversion Kit	($75,017)
Tanks	($39,800)
Labor	($102,046)
OEM	($36,317)
Subtotal	($253,180)
Operating	
Station Maintenance	($14,140)
Labor - fuel time loss	($18,767)
Propane Fuel Tax	($165,160)
Additional training	$0
Subtotal	($198,067)
Total Costs	($516,666)
Savings - Cost	$17,948

Figure 6.4 "Favorable" fleet analysis summary (43 cents/gallon refinery price).

It is interesting to note the relative magnitudes of the cost items and compare them to the costs of CNG operation in Figure 6.2. The 30-year NPV of vehicle costs ($253,180) and the Texas state propane vehicle fuel tax ($165,160) are of the highest magnitude for propane, followed by fueling station infrastructure costs ($65,418), labor-fuel time losses ($18,767), and station maintenance ($14,140). For this fleet, only the state tax is the same for both fuels; all other costs are much less for propane. Fueling station infrastructure costs are 85 percent less, vehicle costs 47 percent less, labor-fuel time losses 87 percent less, station maintenance costs 86 percent less, and both power and tank recertification costs are eliminated for propane operation relative to CNG.

It should also be noted that in the model, station maintenance costs do not accumulate on a per-gallon basis, as they do for CNG. In actuality, propane station maintenance costs are probably somewhat dependent on use, though this relationship has not been quantified. It is probable that the more the station is used the more maintenance is required, especially for the fuel pump. In the model, these costs exhibit economies of scale, as more fuel is consumed through either annual mileage increases or changes in fuel economy. Consequently, the model may over- or under-estimate these costs, depending on the fuel usage of the fleet under analysis.

The lower costs for fleet operation on propane compared to CNG are accompanied by smaller fuel savings. Yet, the net result for this fleet is that propane would be cost-effective, because the break-even refinery propane price of 43 cents/gallon is quite plausible, while for CNG the break-even natural gas price of $1.95/mcf is not plausible.

The sensitivity of the results to the state fuel tax and propane price are examined next. Sensitivity to fueling infrastructure costs is not examined, as it was for CNG, because fueling infrastructure costs for propane are not as uncertain as those for CNG. Only one fairly mature propane fueling technology dominates the market. Sensitivity to labor-fuel time losses is not examined either, since these losses are fairly insignificant for propane.

Even though the "favorable" fleet is cost-effective under the base assumptions, it is interesting to find the break-even propane refinery price if the Texas state propane fuel tax is removed. This allows one to analyze scenarios of refinery propane prices higher than 36 cents/gallon. Without the tax, operation of the "favorable" fleet on propane would be cost-effective at the break-even propane price of 49 cents/gallon.

Sensitivity to the refinery price of propane can be examined by considering the base case above, where cost-effectiveness occurred at a refinery price of 43 cents/gallon. As this price increases to 59 cents/gallon (this is 66 cents/gallon to the fleet, which is equivalent to the gasoline price of 89 cents per gallon on an energy basis), fuel price savings approach zero (actually they are slightly positive owing to fuel efficiency gains with OEM propane vehicles) and the cumulative NPV approaches total costs ($516,666, in this case). Thus, cost-effectiveness is fairly sensitive to fuel price.

6.2.3 Representative Fleet Analysis

Sensitivity analyses to average annual miles per vehicle and fleet size are performed in the same manner as for CNG in Section 6.1.3. The same three fleet sizes, with annual mileage of 15,000 per vehicle, are used here. The results are shown in Table 6.6.

Table 6.6 ***Sensitivity analysis, 15,000 mile fleet (price in cents/gallon).***

	Break-Even Refinery Propane Price (per mcf) for		
Relaxations	**10 Light Trucks**	**60 Light Trucks**	**120 Light Trucks**
None	29	35	37
No fuel tax	36	43	45

To investigate sensitivity to annual mileage, the case with 120 light trucks in Table 6.6 differs from the one previously analyzed only in that the average annual mileage per vehicle is assumed to be 15,000 instead of 22,500 miles. The results are quite sensitive to this change. The break-even refinery propane price is reduced by 4 to 6 cents/gallon, but the 15,000 miles per vehicle fleet is still cost-effective at a 36 cent/gallon refinery propane price.

Results are also fairly sensitive to fleet size. The break-even refinery propane price increases as the fleet size increases, mainly because of economies of scale in both fueling infrastructure and station maintenance costs. The break-even refinery propane price is about 2 cents less for the 60 light truck fleet than for the 120 light truck fleet, and drops by another 6 to 7 cents for the 10 light truck fleet. Since most of the TxDOT locations are best represented by the 10 light truck fleet, even elimination of the fuel tax barely yields a plausible (36 cents/gallon) break-even refinery price for propane. This indicates that most TxDOT locations will not be cost-effective for propane, unless some of the base assumptions of this analysis can be relaxed or propane is available at refinery prices less than 36 cents/gallon.

Sensitivity to the discount rate is reported in Table 6.7 for the 10 light truck fleet with 15,000 average annual miles per vehicle, assuming no other relaxations of the base assumptions. The appropriate discount rate would have to be fairly low (6 percent or less) for the majority of TxDOT fleets to be cost-effective. Obviously, if assumptions were relaxed along with a discount rate reduction, conversion would be cost-effective at higher propane prices.

Table 6.7 Sensitivity to discount rate, fleet with 10 light trucks and annual mileage of 15,000 miles

Discount Rate (%)	Break-Even Refinery Propane Price (cents/gallon)
10	29
8	33
6	36
4	39
2	42
0	45

The final sensitivity analysis reported here is for conversion costs. The conversion costs assumed up to this point are: automobiles - $1,600; light trucks - $1,190; and heavy-duty gasoline vehicles - $1,200. These include kit, tank, and installation labor costs. Because of claims that conversions can and will be performed at an even lower cost, the limiting case of immediate availability of dedicated propane OEM vehicles was analyzed for the three fleet sizes, with 15,000 average annual miles per vehicle. As discussed previously, it is assumed that an OEM-dedicated propane automobile or light truck costs $400 ($450 for heavy-duty gasoline) more than a comparable gasoline vehicle. This is the best case possible for vehicle costs, and greater benefits accrue from the increased fuel efficiencies of OEM-dedicated vehicles. The results of this analysis are reported in Table 6.8.

Table 6.8 Analysis for immediate availability of propane OEM vehicles, 15,000 mile fleet

Fleet Size (Light Trucks)	Break-Even Refinery Propane Price (cents/gallon)
10	38
60	44
120	47

As expected, the break-even refinery propane prices are much higher (about 10 cents/gallon) than those when conversions are utilized for the first 10 years. In fact, all fleets would be cost-effective at plausible refinery prices (36 cents/gallon). Even though this analysis assumes immediate replacement of all fleet vehicles, without accounting for losses due to scrappage, it still confirms that the introduction of OEM-dedicated propane vehicles would contribute much to the cost-effectiveness of fleet conversion, as would the reduction of conversion costs until that time.

It should be noted that for all the propane analyses in this section the most cost-effective operation occurred for a large propane fueling station with large volume propane purchases. One can compute the minimum annual volume of propane that a fleet must consume in order for the savings generated by the lower fuel price associated with large volume purchases to compensate for the additional costs of a large fueling station (necessary to support large volume purchases). Given a fuel price difference of 17 cents/gallon (as assumed herein) between large and small volume purchases, the fleet must consume about 40,000 gallons of propane annually for a large fueling station to be more cost-effective than a small one. Even the fleet with the smallest fuel demand, the 10 light truck fleet at 15,000 miles per vehicle, uses about 62,000 gallons annually.

6.2.4 Conclusions

The propane analysis in this section:

1) highlights the primary significance of fuel price differential, conversion cost, and fueling infrastructure cost in the trade-offs underlying propane fleet conversion and operation decisions.
2) confirms that OEM vehicles (with lower cost differentials and better fuel efficiencies relative to conversions) represent a good near-term strategy for achieving greater market penetration of propane vehicles.
3) illustrates that large fleet sizes are more cost-effective (within the two categories defined by whether a small or a large fueling station is most cost-effective), because of economies of scale in both fueling infrastructure and station maintenance costs.
4) illustrates that the greater the annual vehicle mileage the more cost-effective operation on propane will be (all other things being equal), because of greater fuel cost savings.
5) shows that fueling infrastructure and labor-fueling costs are not as significant for propane as they are for CNG.
6) shows that the Texas state propane fuel tax is a significant cost item for fleet conversion to propane operation.
7) illustrates the use of the cost-effectiveness analysis model as a decision support tool that allows one to deal with uncertain energy and technological futures through alternative scenarios and sensitivity analyses.
8) indicates that it will not be cost-effective for most TxDOT fleets (i.e. small fleets) to convert

to propane operation, under the assumptions herein, although medium and large fleets will be marginally cost-effective.

9) shows that propane is in general more cost-effective than CNG.
10) computes a rule-of-thumb stating that a fleet must consume over 40,000 gallons of propane annually in order to justify a large fueling station on an economic basis.

6.3 ANALYSIS OF ACTUAL FLEET OPERATION ON CNG

This section analyzes three actual TxDOT fleets, shown in Tables 6.9, 6.10, and 6.11, for operation on CNG (see Euritt, Taylor, Mahmassani, 1992c,d for a detailed analysis of all TxDOT locations). These fleets were chosen because their sizes are representative of small, medium, and large TxDOT fleets. It is interesting to compare these actual TxDOT fleets with the "favorable" and representative fleets analyzed in Section 6.1. The total numbers of vehicles are similar to those for the representative small, medium, and large fleets, which were 30, 80, and 140, respectively. The average annual mileage is similar to, but usually even less than that of the representative fleets (15,000 miles per vehicle). This is not conducive to cost-effective operation on CNG. Both the small and medium sized fleets have fuel efficiencies slightly less than that of the representative and "favorable" fleets, and lower fuel efficiencies are favorable for CNG cost-effectiveness. Yet, the large fleet, which is most likely to be cost-effective, has fuel efficiencies slightly greater than those of the representative and "favorable" fleets. Since even operation of the "favorable" fleet on CNG was not cost-effective, it is easy to see that none of these fleets will be cost-effective either, as they most closely resemble the representative fleets.

Table 6.9 Characteristics of small fleet; District 1, Clarksville location

Vehicle Type	Number of Vehicles	Average Fuel Efficiency (mpg)	Annual Mileage	Average Annual Repair Costs
Automobile	1	17.35	26,031	$879
Light Truck	7	12.02	16,325	$770
Heavy-Duty Gasoline	6	5.40	11,040	$694
Heavy-Duty Diesel	5	9.00	15,100	$634

Table 6.10 Characteristics of medium fleet; District 18, Dallas District Office

Vehicle Type	Number of Vehicles	Average Fuel Efficiency (mpg)	Annual Mileage	Average Annual Repair Costs
Automobile	22	18.87	12,067	$531
Light Truck	42	13.06	12,606	$784
Heavy-Duty Gasoline	3	4.70	2,098	$1,169
Heavy-Duty Diesel	3	5.00	14,597	$2,546

Table 6.11 Characteristics of large fleet; District 15, San Antonio District Office

Vehicle Type	Number of Vehicles	Average Fuel Efficiency (mpg)	Annual Mileage	Average Annual Repair Costs
Automobile	43	22.02	11,394	$581
Light Truck	101	14.07	14,281	$549
Heavy-Duty Gasoline	11	5.52	9,649	$1,223
Heavy-Duty Diesel	10	6.00	15,530	$2,991

The analysis in this section proceeds in a systematic matter. Sensitivity to several assumptions is investigated for each fleet size. These assumptions are as follows (including the figure(s) showing the results of that analysis):

1) Natural gas fuel price (Figure 6.5 and 6.6)
2) Diesel vehicle operation on CNG (Figure 6.7)
3) Removal of both one-third of the fueling infrastructure costs and all labor fueling losses (This could be considered a rough approximation of utilizing a slow-fill fueling station design.) (Figure 6.8)
4) Removal of the Texas state natural gas vehicular fuels tax (Figure 6.9)
5) Removal of the fuels tax, one-third of the fueling infrastructure costs, and all labor fueling losses (Figure 6.10)
6) Reduction in maintenance of 30 percent per year (which is probably more than can be expected) (Figure 6.11)

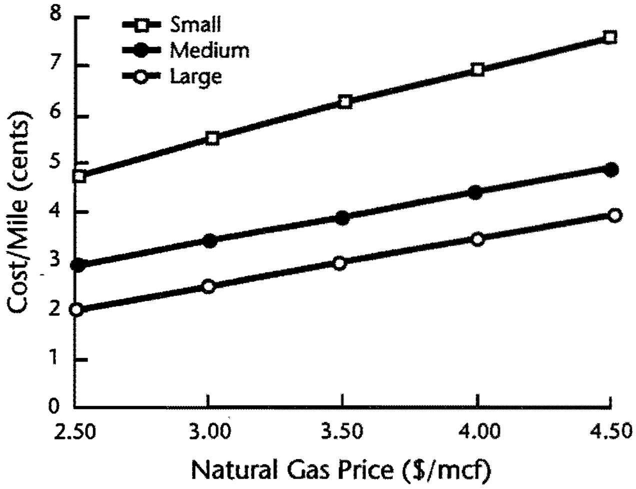


Figure 6.5 *Sensitivity to natural gas price (cost per mile)*

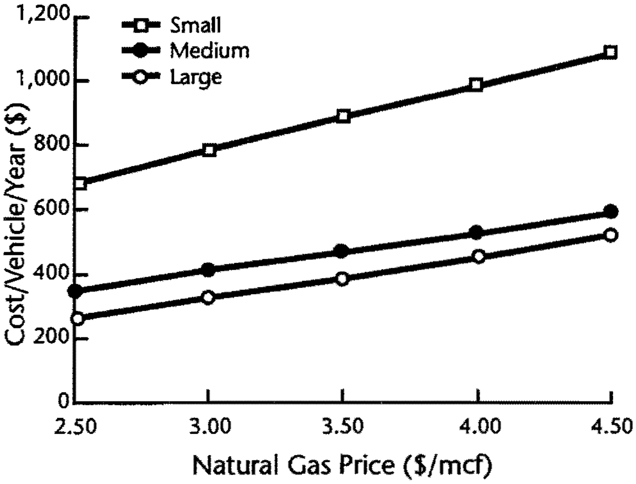


Figure 6.6 *Sensitivity to natural gas price (cost per vehicle per year)*

The analysis results are presented using either the cost per mile (in cents) or cost per vehicle per year (in dollars) above that required for operation on gasoline/diesel. (Cost (or benefit) per mile is computed by annualizing the cumulative net present value of all costs and benefits and dividing by the total annual mileage of the fleet. Annual diesel mileage is approximated by taking five-sixths of the average annual mileage driven by diesel vehicles, since diesel vehicles are only operated on CNG in years 6 thru 30. Cost per vehicle per year is computed similarly, except the annualized net present value is divided by the total number of vehicles (including diesels). No attempt is made to adjust for the fact that diesel vehicles are operated on CNG for only 25 of the 30 years. This adjustment is made in the earlier reports (Euritt, Taylor, Mahmassani, 1992a).) For all analyses, except that where sensitivity to natural gas fuel price is examined, the natural gas fuel price is $2.50/mcf, considered in this study to be the lowest feasible natural gas price available to fleets in Texas. All other input data assumptions for these analyses are as shown in Figure 6.1, except where sensitivity to one of these parameters is being examined.

Figure 6.7 *Sensitivity to diesel vehicle operation on CNG*

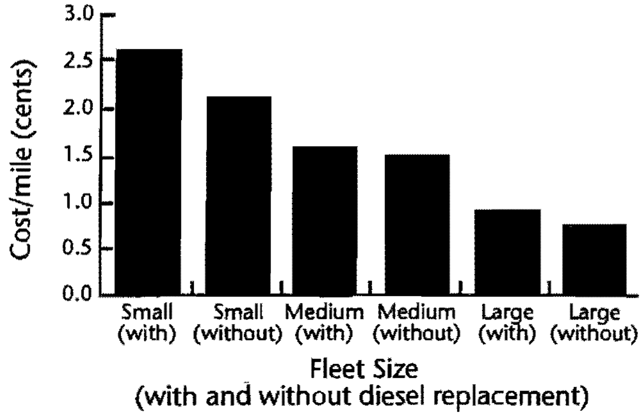


Figure 6.8 ***Analysis of removal of one-third of the fueling infrastructure costs and all labor fueling losses***

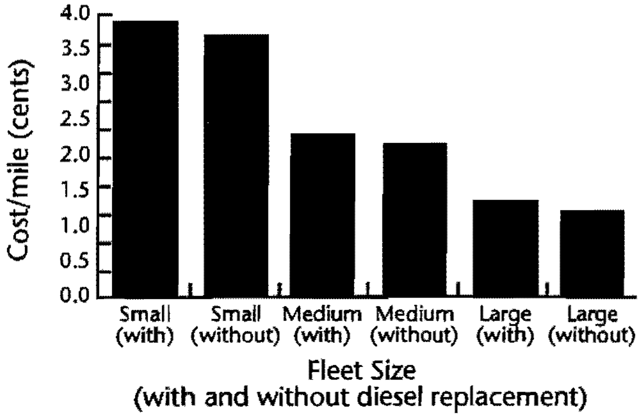


Figure 6.9 ***Analysis of removal of Texas state fuels tax***

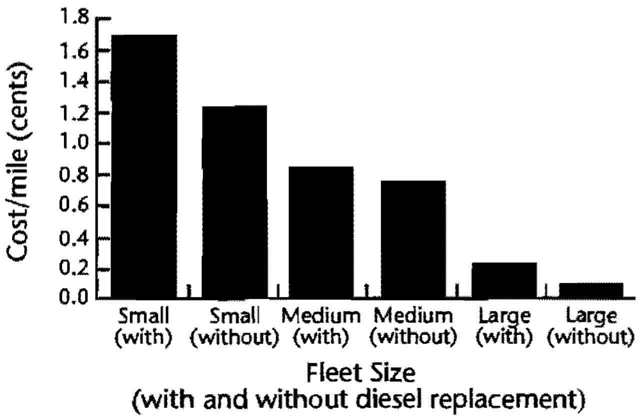


Figure 6.10 ***Analysis of removal of the fuels tax, one-third of the fueling infrastructure costs, and all labor fueling losses***

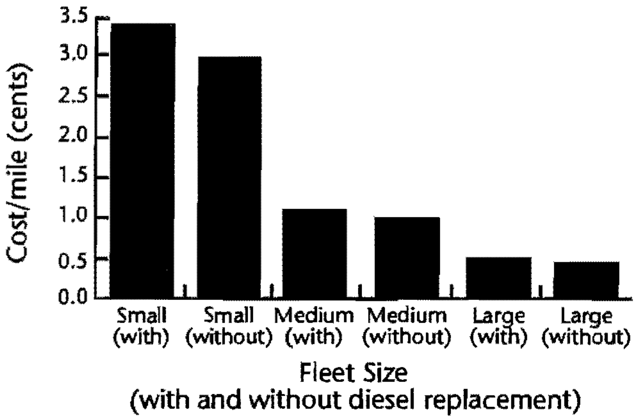


Figure 6.11 ***Analysis of maintenance savings of 30 percent per year***

These analyses show that none of these locations would be cost-effective operating on CNG, even if natural gas were available at $2.50/mcf and many of the most costly input data assumptions (i.e. fueling infrastructure, labor fueling losses, and the Texas fuels tax) are relaxed in tandem. The figures also clearly illustrate that the larger the fleet size (everything else being equal) the more cost-effective operation on CNG will be and that operating diesel vehicles on CNG is less cost-effective than operating gasoline vehicles on CNG.

By presenting the analysis results in terms of cost/mile, another useful perspective is provided. The additional cost of operating a CNG fleet ranges from 7.59 cents/mile for the small fleet at a natural gas price of $4.50/mcf to 0.09 cents/mile for the large fleet (gasoline vehicles only) at a natural gas price of $2.50/mcf, when one-third of the fueling infrastructure costs, all labor fueling losses, and the state fuels tax are removed. Consider that the cost of purchasing and operating gasoline vehicles is often reported to be in the range of 25 to 50 cents/mile, depending on vehicle type, usage, and what costs are included. If TxDOT current vehicle costs are at the high end of this range and the large fleet could be operated on CNG at an additional cost of only 0.09 cents/mile, then the cost increase for CNG operation would only be about 2 tenths of one percent. Even if current TxDOT vehicle costs are only 25 cents/mile, operation of the least cost effective fleet scenario, the small fleet on CNG priced at $4.50/mcf, would increase fleet costs by 30 percent.

6.4 ANALYSIS OF ACTUAL FLEET OPERATION ON PROPANE

This section analyzes the same three actual TxDOT fleets analyzed in the previous section (see

Tables 6.9, 6.10, and 6.11) for operation on propane (see Euritt, Taylor, Mahmassani 1992c,d for a detailed analysis of all TxDOT locations). Since these fleets operate fewer miles than the representative fleet analyzed in Section 6.2, they will be less cost-effective than the representative fleet. Since operation of the large representative fleet on propane was just barely cost-effective, it is expected that none of these fleets will be cost-effective, though the large fleet will be close and will probably become cost-effective with the relaxation of some assumptions.

Sensitivity to several assumptions is investigated for each fleet size. Fewer assumptions are analyzed than for CNG, because there are fewer cost items for propane, and these costs are more stable. These assumptions are as follows (including the figure(s) showing the results of that analysis):

1) Propane refinery price (Figure 6.12 and 6.13)
2) Diesel vehicle operation on propane (Figure 6.14)
3) Removal of the Texas state propane vehicular fuels tax (Figure 6.15)
4) Reduction in maintenance of 10 percent per year (which may be a reasonable approximation of what can be expected) (Figure 6.16)

As for CNG, the analysis results are presented using either the cost per mile (in cents) or cost per vehicle per year (in dollars) above that required for operation on gasoline/diesel. For all analyses, except that where sensitivity to propane refinery price is examined, the propane refinery price is 36 cents/gallon, (a 36 cents per gallon refinery price results in prices to the fleet of 43 cents/gallon and 60 cents/gallon for large and small volume purchases, respectfully), considered in this study to be the expected propane refinery price available to fleets in Texas. On the other hand, the reference natural gas price used in the previous section ($2.50/mcf) is deemed to be the lowest plausible price that might be available to fleets in Texas. One should also note that the maintenance savings sensitivity examined for propane is more realistic than that for CNG (10 percent versus 30 percent). This is done because propane fleets may very well become cost-effective with rather small maintenance savings, whereas CNG fleets are farther from being cost-effective, and the use of less reasonable assumptions further serves to illustrate this fact. All other input data assumptions for these analyses are as shown in Figure 6.3, except where sensitivity to one of these parameters is being examined.

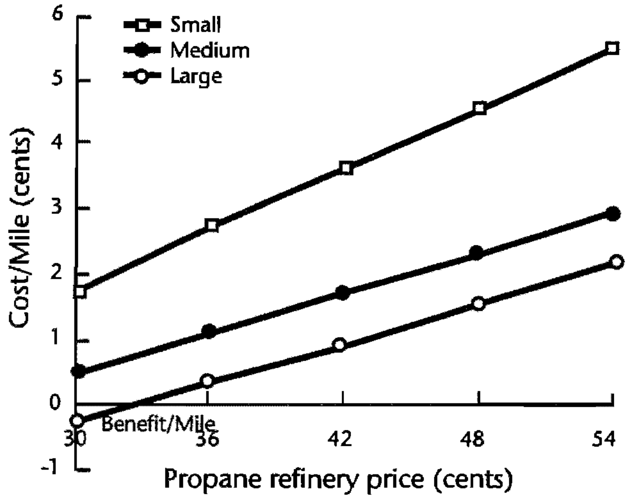


Figure 6.12 Sensitivity to propane refinery price (cost per mile)

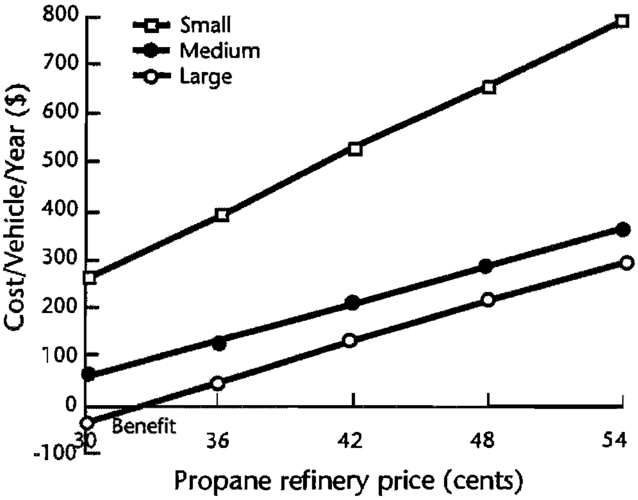


Figure 6.13 Sensitivity to propane refinery price (cost per vehicle per year)

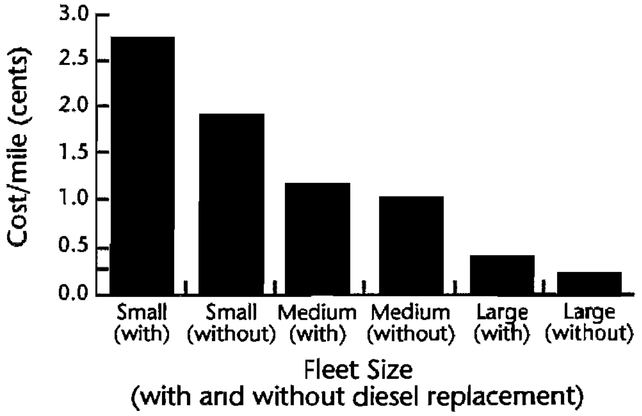


Figure 6.14 Sensitivity to diesel vehicle operation on propane

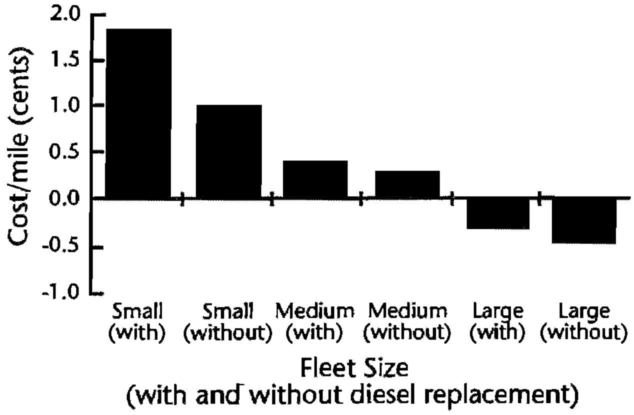


Figure 6.15 Analysis of removal of the Texas state fuels tax

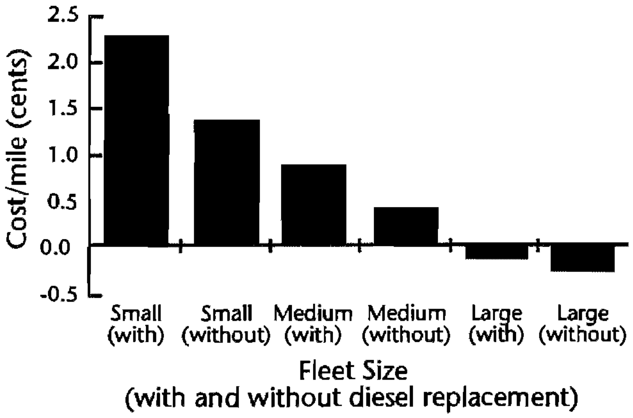


Figure 6.16 Analysis of maintenance savings of 10 percent per year

These analyses show that none of these locations would be cost-effective operating on propane, if the propane refinery price is as expected (36 cents/gallon) and the basic assumptions are accurate. Even with relaxations of the basic assumptions, only the large fleet becomes cost-effective. The large fleet becomes cost-effective if one of the following is true:

1) propane is available from the refinery at an average price below 32.5 cents/gallon,
2) the propane fuel tax is removed, or
3) maintenance savings of 10 percent occur with propane operation (actually only about 5 percent is required, since at 10 percent, benefits accrue with propane use).

As for CNG, the figures clearly illustrate that the larger the fleet size (everything else being equal) the more cost-effective operation on propane will be and that operating diesel vehicles on propane is less cost-effective than operating gasoline vehicles on propane.

The differential between operating a fleet on propane relative to gasoline/diesel ranges from an additional cost of 5.48 cents/mile for the small fleet at a propane refinery price of 54 cents/gallon to a benefit of 0.52 cents/mile for the large fleet (gasoline vehicles only) at a propane refinery price of 36 cents/gallon, when the state fuels tax is removed. These results further verify that operation on propane is more cost-effective than operation on CNG.

It is also interesting to report that a large propane fueling station was most cost-effective for every fleet, except the small fleet without diesel vehicles. The latter fleet has a propane demand of 31,473 gallons per year, which is under the 40,000 gallon requirement for large station usage. All the other fleets use over 40,000 gallons annually. Also of interest is that for all three fleets, diesel vehicle operation on propane actually results in fuel price costs, not savings, when the propane refinery price is 36 cents/gallon.

6.5 CLOSURE

This chapter illustrated the use of the cost-effectiveness analysis framework discussed in Chapter Five as a decision support tool that allows one to deal with uncertain energy and technological futures. Utilizing this framework, along with scenario and sensitivity analyses, it was shown that it will not be cost-effective to operate most Texas Department of Transportation fleets on CNG. On the other hand, medium and large TxDOT fleets may be marginally cost-effective on propane, though small fleets will not. This analysis highlighted the significance of the major benefit and cost items for operation of fleets on either CNG or propane, specifically fuel price differential, vehicle costs (conversion and OEM differential), fueling infrastructure, labor for fueling, and the Texas gaseous vehicle fuel tax. In addition, the effects of fleet size and annual mileage are illustrated through sensitivity analysis.

CHAPTER 7. SOCIETAL IMPACTS OF CNG AND PROPANE VEHICLES

The preceding chapters have analyzed in some detail the economics of fleet operation on CNG and propane. However, alternative fuels contribute to the solution of broader societal problems, which must also be considered. Societal impacts are more difficult to analyze than fleet economics because, as noted in Chapter Two,

1) the measures of effectiveness corresponding to the different decision criteria (both societal and fleet) are generally non-commensurable and
2) some of the societal criteria may be difficult to quantify.

This chapter attempts to alleviate some of the problems inherent in the analysis of societal impacts of fleet operation on CNG and propane. Less information is available on propane, so it is discussed in much less detail than CNG and only where applicable.

The CNG analysis identifies the principal impacts and provides background information on each, pertaining to the extent, severity, and location of the effect of gasoline/diesel vehicles in each area, in addition to guidance on how much alternative fuels may help. Though propane is not discussed in as much depth, and other fuels are not directly addressed, the CNG analyses provide guiding frameworks for the future analysis of these other alternative fuels.

To help a decision maker evaluate these societal impacts, this chapter discusses the impacts of natural gas (and propane, where applicable) vehicles relative to gasoline/diesel vehicles on:

1) urban air pollution,
2) global warming,
3) acid rain,
4) land and water pollution,
5) energy security,
6) regional economic development in the state of Texas,
7) CNG as lead in to a hydrogen vehicle future,
8) natural gas supply, and
9) safety.

Discussions of each of these societal impacts are presented in the first nine sections, respectively. This information allows decision makers to make relative comparisons between the fuels for each impact. They can then use these comparisons along with fleet economic analysis to make decisions between fuels.

The final section presents an approach for evaluating societal impacts in combination with fleet economic analysis. It uses a fleet economic analysis to determine the value one would have to place on certain societal benefits in order for fleet operation on CNG to be cost-effective. This value can be compared to the cost of achieving this societal benefit by other means, or it can simply convey a different perspective on the societal benefit.

7.1 URBAN AIR POLLUTION

Over half the U.S. population lives in areas that fail to meet the National Ambient Air Quality Standards (NAAQS) established by the Environmental Protection Agency (EPA) to protect human health. In 1988, nearly 100 areas containing over 130 million Americans violated ozone (here, ozone refers to ground level (tropospheric) ozone, not to the upper atmospheric (stratospheric) ozone, which absorbs solar ultraviolet radiation and is being depleted by compounds such as chloroflourocarbons) standards and 59 areas were in violation of carbon monoxide standards (Beckham, Reilly & Becker, 1990). In addition, motor vehicles emit particulate matter and toxic compounds such as benzene and formaldehyde. The potential impact of alternative fuels, primarily CNG, on the emission of each of these pollutants is discussed hereafter.

7.1.1 Ozone

Ozone (O_3), the major component of smog, is formed through a complex interrelated set of photochemical reactions in the atmosphere, driven by the energy of the sun. Two of the principal compounds in these reactions are hydrocarbons (as many as 200 distinct hydrocarbon molecules are found in automobile exhaust), normally referred to as a group as HC, and nitrogen oxides, such as nitric oxide (NO) and nitrogen dioxide (NO_2), normally referred to as NO_x (Patterson & Henein, 1972). Gasoline and diesel vehicles account for about half of U.S. ground level ozone production, through their HC and NO_x emissions (Beckham, Reilly & Becker, 1990). Of the six air pollutants with EPA established standards, ozone is the most persistent and widespread problem, both nationally and in Texas (TACB, 1990). In 1989 the following Texas counties were designated as non-attainment areas for ozone: Brazoria, Dallas, El Paso, Galveston, Gregg, Harris, Jefferson, Orange, Tarrant, and Victoria. In addition, EPA proposed that Fort Bend, Waller, Montgomery, Liberty, Chambers, Collin, Denton, Rockwall, Ellis, Johnson, Kaufman, and Parker counties also be designated as non-attainment areas for ozone (TACB, 1989). Basically, these are the counties around Dallas/Ft. Worth, Houston, Beaumont/Port Arthur, Corpus Christi, and El Paso.

Ozone is a pungent smelling gas that irritates the mucous membrane which helps filter air entering the lungs, causes choking and coughing, reduces resistance to colds and other respiratory diseases, irritates eyes, can worsen asthma, bronchitis, and emphysema, and causes damage to plants (TACB, 1989). EPA reports that even healthy people who exercise in ozone levels at or slightly above the standard can experience a variety of the above mentioned ailments, in addition to chest pain, sore throat, congestion, and increased respiratory rates. Studies have demonstrated that permanent lung damage can result from repeated prolonged exposure to ozone (Beckham, Reilly & Becker, 1990). In addition, ozone contributes to global warming, forest damage, and damage to U.S. agriculture estimated at $5 billion per year (Harvey & Keepin, 1990).

Almost all of the hydrocarbon molecules (65 to 95 percent) emitted from gasoline vehicles react in ozone formation and are as such termed *reactive hydrocarbons.* On the other hand, between 75 and 95 percent of the hydrocarbons emitted from natural gas vehicles are methane, which is *nonreactive* in ozone formation (EPA, 1988a; EPA, 1988b; EPA, 1990a). This percentage is usually just slightly lower than the percentage of methane in the natural gas itself, the difference probably consisting of burned lubricating oil in the exhaust gas (EPA, 1990a). Until now, EPA's strategy for ozone reduction has targeted the reduction of reactive hydrocarbons; as such, natural gas vehicles would contribute to solving the ozone problem (Radian, 1989). However, NO_x emissions are also reactive in ozone formation, and natural gas vehicles currently have a problem with NO_x emissions. They will probably emit as much as or more NO_x than a comparable gasoline vehicle. Because of the complicated system of at least 13 simultaneous reactions involved in ozone formation, it is difficult to predict the exact effect that increases or decreases in NO_x and HC will have in different airsheds (Patterson & Henein, 1972). There is still some uncertainty regarding the overall role of NO_x in ozone formation. In fact, in some airsheds a decrease in NO_x may actually increase ozone levels (DeLuchi, Johnston & Sperling, 1988; Roth, 1990).

The ozone formation process depends on the ratio of reactive hydrocarbons to oxides of nitrogen in the atmosphere, which varies greatly among urban areas. Because of this and the overall complexity of the ozone formation process, even the most sophisticated airshed models have error margins of 30 percent or more in predicting ozone concentrations. Only in the Los Angeles area have enough meteorological and pollutant concentration data been collected to operate multi-day airshed models (National Research Council, 1990). The ozone benefits of natural gas vehicles have not been quantified by any studies, but are likely to be greater than those of methanol, because of significantly less reactive hydrocarbon emissions, even considering slightly higher NO_x emissions. The ozone benefits of methanol are still in doubt. In a synthesis of various studies of methanol ozone reduction, DeLuchi et al (1988) found that if all vehicles were replaced with advanced technology methanol vehicles, the ozone reduction in most U.S. cities would be from 10 to 70 percent of the reduction that could be achieved by eliminating all vehicular emissions.

Evaporative emissions of hydrocarbons from the fuel tank and fuel metering system are projected by EPA (1990a) to be zero for dedicated natural gas vehicles while the vehicle is:

1) hot and running *(running loss),*
2) hot and stopped *(hot soak),*
3) subjected to daily temperature fluctuations *(diurnal)* and
4) fueling.

Considering that about 45 percent of the total reactive hydrocarbon emissions of a 1993 gasoline vehicle will be evaporative and that in the hot (80 to 95 degrees Fahrenheit) summer months, when ozone problems are at their worst, 57% of reactive HC emissions from 1981-1989 vehicles are evaporative, the fact that CNG emits no evaporative hydrocarbons is very significant (AGA, 1990a; Radian, 1989).

Reducing carbon monoxide (CO) emissions also reduces ozone formation, but the amount of reduction has not been quantified (EPA, 1988b). Natural gas vehicles should emit significantly less CO than gasoline vehicles and as such, will further assist in ozone reduction.

Based on current research, it appears that natural gas vehicles can be designed to emit no evaporative hydrocarbons and between 70 and 90 percent less reactive hydrocarbons than comparable gasoline vehicles, though they might emit slightly more NO_x. Depending on the number of gasoline/diesel vehicle miles travelled replaced by natural gas and the composition of the atmosphere in the urban airshed, natural gas does offer possibilities for reducing urban ozone levels, though the magnitude of this reduction will vary in different airsheds. Additionally, this reduction comes at the expense of higher emissions of methane, a powerful greenhouse gas, and possibly greater amounts of nitrogen dioxide emissions, which can irritate eyes, nose, throat, skin, and lungs (especially in asthmatics) and is an atmospheric acid precursor, contributing to acid rain (TACB, 1990).

7.1.2 Carbon Monoxide

Carbon monoxide is formed from the incomplete combustion of the carbon in the fuel. Ideally, all the carbon would oxidize to CO_2. Almost all urban, and about 80 percent of total U.S. CO emissions are from motor vehicles (Beckham, Reilly & Becker, 1990; AGA, 1989c; Sperling, 1988a; Radian, 1989). In Texas, only a portion of El Paso County was designated a non-attainment area for carbon monoxide in 1989 (TACB, 1989). Topographical and meteorological (wintertime temperature inversion) conditions along with the influence of pollution sources from neighboring Juarez, Mexico contribute to this non-attainment. Nationally, the problem is much more serious and most violations occur during cold temperature winter months. Areas around Los Angeles and Denver, for example, have not been able to attain CO standards.

Carbon monoxide reduces the blood's ability to absorb oxygen and thereby transfer it to the tissues of the body. This causes fatigue and headaches, impairs vision and judgement, slows reflexes, and can cause unconsciousness. Extended exposure can worsen heart and lung diseases (TACB, 1990). Although all people are affected, children, pregnant woman and their fetuses, and people with cardiovascular disease are especially endangered (Beckham, Reilly & Becker, 1990). Natural gas vehicles offer significant reductions in CO over gasoline vehicles. In fact, this is one emission for which the reductions predicted by theory have been confirmed in actual emission tests (see Chapter Three). Since natural gas engines require significantly less enrichment than gasoline for cold starts and low temperature operation, their contribution to reducing CO in the problematic winter months should be even greater. Whether natural gas can bring an area into CO attainment is dependent on the gasoline/diesel vehicle miles replaced by natural gas as well as other sources of CO in the airshed (such as those in El Paso, which blow over from Juarez, Mexico).

7.1.3 Particulates

Particulate matter, including that less than 10 microns in diameter (PM_{10}), comes from vehicular emissions in addition to factories, power plants, refuse incinerators, fires, construction activity, and natural windblown dust. Motor vehicles account for about 20 percent of the total U.S. PM_{10} emissions. Even though diesel vehicles account for a very small percentage of total vehicle miles travelled, heavy-duty diesel vehicles account for 89 percent of vehicular particulate matter emissions. EPA has recently changed its standards to address only PM_{10}, since most environmental and health effects are associated with particles smaller than 10 microns. Studies have shown that it is possible that 60 percent or more of urban PM_{10} emissions may be generated by motor vehicles (Radian, 1989).

El Paso is the only area in Texas that consistently exceeds the standard. As for carbon monoxide, unique conditions such as the influence of pollution sources from Juaraz, Mexico contribute to this non-attainment. Occasionally the NAAQS for PM_{10} is exceeded in Lubbock due to windblown dust. Particulates can cause coughing, throat irritation, carry carcinogenic compounds and heavy metals into the lungs, make heart and respiratory diseases worse, and worsen the symptoms of children's respiratory problems (TACB, 1990).

Vehicles operating solely on natural gas emit no significant particulate matter compared to their diesel counterparts (National Research Council, 1990; Sierra Research, 1989). Vehicles running on a mixture that uses diesel to ignite the natural gas emit less particulate matter than their pure diesel counterparts. Whether an urban area can eliminate its particulate non-attainment by replacing diesel vehicles with either dedicated natural gas vehicles or dual-fuel diesel/natural gas vehicles, depends on the diesel vehicle miles replaced by natural gas and the emission of particulate matter from other sources.

7.1.4 Benzene

Benzene and other volatile aromatic hydrocarbons are blended in gasoline to increase fuel octane levels. There are concerns about long-term effects of exposure to these emissions from both tailpipe and evaporative emissions (National Research Council, 1990). Natural gas contains no benzene, so the benzene normally emitted from evaporative gasoline fueling and running losses is eliminated and natural gas vehicle exhaust benzene levels should be much lower (though few tests have been performed) (Radian, 1989). Natural gas vehicles seem to offer significant benefits over gasoline vehicles in this area.

In addition to exhaust benzene, the only toxic emissions of concern from natural gas vehicles are 1,3-butadiene and direct and indirect formaldehyde emissions. If one considers both the type and potency of these emissions together, the emissions from natural gas vehicles can be more than 90 percent lower in toxicity than gasoline vehicle emissions (EPA, 1990a; Radian, 1990b). In addition, natural gas tank leaks or fueling losses are not of great concern as far as toxicity is concerned, since methane is non-toxic and non-carcinogenic (DeLuchi, Johnston & Sperling, 1988).

7.1.5 Formaldehyde

Since formaldehyde (HCHO) is very reactive in ozone formation and is carcinogenic, its emission from vehicles is important. In fact, one of the problems with methanol as an alternative fuel is that it has shown tendencies toward high emissions of formaldehyde. Although not totally conclusive, an EPA test of five vehicles on both CNG and gasoline shows that CNG formaldehyde emissions are fairly low and quite comparable to gasoline (EPA, 1988a). Another test of one dedicated (but not optimized) CNG vehicle shows a similar result (Gabele, Knapp & Ray, 1990), as does a prediction in a recent Radian (1989) study. Based on this, it seems that CNG as a replacement for gasoline will neither help nor hinder formaldehyde emissions.

7.1.6 CNG Summary

One must keep in mind that emissions projections for natural gas vehicles are based on theory and limited experimental data gathered primarily on low mileage vehicles. Virtually no data exists on the performance of natural gas vehicles' emission control systems at high mileage or under regular use by typical motorists. In addition, catalytic conversion systems to reduce engine emissions before they reach the atmosphere have not yet been designed specifically for natural gas vehicles. There may be little incentive to produce vehicles that emit less than the EPA emission standards require, unless standards such as California's (California requires a certain percentage of vehicles to meet standards that are more stringent than EPA's) are adopted elsewhere. Even if natural gas provides the opportunity to design vehicles that emit less than emission standards require, lower emissions may be traded off for improved performance in the design of the vehicle. Since it is projected that gasoline/diesel vehicles can be designed to meet the newer EPA (not California) standards, both natural gas vehicles and gasoline/diesel vehicles may be designed for similar HC, NO_x, and CO emissions.

Also to be considered are the emissions from the production and transmission of the fuel. The production of natural gas generates no pollutants other than the minor quantities of gas escaping during handling and through valves. It is considered far superior to all other fuel production processes, except hydrogen produced from solar powered electrolysis, as far as emissions during production are concerned (Sperling, 1988a).

Finally, one must consider the fact that less polluting vehicles are only part of the answer to the urban air pollution problem. In fact, this strategy has been in effect for over 20 years and urban air pollution has increased. As shown in Table 7.1, automobile emission standards have been reduced significantly in the last 20 years, as have evaporative and crankcase blow-by emissions. However, total passenger car vehicle miles traveled (VMT) have increased from about 0.85 trillion in 1968 to around 1.3 trillion in 1988, old vehicles are not immediately replaced, and new cars built to certain standards may not perform as well in real world conditions (tampered pollution control systems, dirty oil, and poor tuning all increase emissions) (Beckham, Reilly & Becker, 1990). With VMT projected to continue increasing, other factors such as improved transportation systems (to lessen congestion and improve mass transit) and altered driving habits (increased use of walking, bicycling, carpooling, and mass transit) will also be necessary to improve urban air quality.

Table 7.1 ***U.S. Exhaust Emissions Standards for new automobiles (grams/mile) (Sperling, 1988a)***

	Precontrol	1968	1981 +
HC	6 - 10	5.9	0.41
CO	60 - 90	51.0	3.4
NO_X	4 - 8	No Standard	1.0

7.1.7 Propane

As noted in Chapter Three, propane vehicles should be able to achieve reactive hydrocarbon and carbon monoxide tailpipe emissions improvements over gasoline or diesel vehicles, but not as great as the improvements possible with CNG vehicles. In addition, propane vehicles will have some evaporative hydrocarbon emissions, because their fuel systems have venting capabilities (Wyman, 1988). No information was found on the propane emissions of NO_X, particulates, benzene, or formaldehyde, relative to gasoline/diesel.

7.2 GLOBAL WARMING

Global warming is the warming of the Earth's atmosphere caused by the trapping of heat by what are commonly referred to as *greenhouse gases.* Motor vehicle emissions contribute toward the following greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Global warming could lead to world-wide changes in rainfall patterns, disruptions in crop growing regions, and coastal flooding in seaboard cities world-wide from melting mountain glaciers and polar ice caps. Various studies have shown that if current trends continue, temperatures could increase by 2 to 10 degrees Fahrenheit in the next 50 to 100 years, though no consensus exists on this matter (Sperling, 1988a).

Scientists have warned that lack of concerted action towards preventing global warming could lead to dire consequences (Sperling, 1988a; Gray, 1989). One reason for lack of action to date is that positive proof of global warming does not exist, but alas it cannot exist. Given that, among other things, atmospheric CO_2 levels have risen 20 percent in less than two centuries, the average global temperature should have risen about 0.9 degrees Fahrenheit in the last 100 years. The average global temperature has risen about this much, but 0.9 degrees is also in the range of natural temperature variability. Therefore, there can be no direct evidence of global warming (Gray, 1989). Yet, the fact that increases in greenhouse gases have been directly observed coupled with present understanding of the processes involved make "eventual significant warming a virtual certainty" (Gray, 1989).

Up until now the warming effect has been delayed by the oceans' absorption of heat. Because the ocean's buffering of the warming effect will slowly warm the atmosphere and because most greenhouse gases have long lives, the warming effect would continue for several decades, even if all greenhouse gas production were immediately stopped. For example, CO_2 is removed by two processes: plant photosynthesis and absorption in oceans, where it is eventually deposited as limestone on the ocean floor. Absorption in the ocean is dominant, but takes on the order of 1,000 years (Patterson & Henein, 1972). Paaswell (1990) reports that many researchers feel that the level of greenhouse gases in the atmosphere must be stabilized at or near current levels in order to avoid major catastrophes.

CO_2 accounts for about half of this warming effect, with motor vehicles contributing about 17 percent of the world's output of this gas and 27 percent of the U.S. output (Lowe, 1990; Sperling, 1988b; J.E. Sinor, 1990a). Combustion of a carbon based fuel will result in CO_2 emissions. Gasoline and diesel fuel combustion emits more CO_2 than natural gas combustion for the same energy output, while natural gas combustion emits more H_2O (see Chapter Three). Natural gas has a carbon to hydrogen ratio of approximately 1:4 and gasoline and diesel have ratios of about 1:2. Substituting natural gas for gasoline and/or diesel in the transportation sector will reduce CO_2 levels, but will also probably increase the levels of methane in the atmosphere. Increased methane will be emitted from natural gas vehicles' tailpipes and from wellheads, transmission infrastructure, venting of storage tanks, and vehicle fueling stations.

Methane contributes between 5 and 30 times more to the warming effect than carbon dioxide, on a per mass basis (Sperling, 1988b). So, the overall effect on global warming of substituting natural gas vehicles for gasoline and/or diesel vehicles depends on the relative amounts of warming increase contributed by greater methane emissions and of warming decrease from reduced CO_2 emissions. The American Gas Association (AGA, 1989b; AGA, 1989c) reports that natural gas vehicles, as a replacement for gasoline vehicles, will reduce CO_2 emissions by 30 percent. Factoring in methane emissions, the global warming effect (i.e. CO_2 equivalent emissions) would be reduced by 25 percent. In a worst case analysis, giving the natural gas vehicle no credit except for reduced CO_2 emissions and charging it with all the methane losses in natural gas extraction and delivery, AGA still projects a net greenhouse benefit for the natural gas vehicle.

Sperling's (1988b) analysis, which assumes methane has 11.6 times the warming effect of carbon dioxide, is not quite as optimistic as the AGA's. Sperling included CO_2 emissions from the natural gas vehicle and from the energy used in compression, distribution, and production of the natural gas and CH_4 emissions from the natural gas vehicle, pipeline compressors, field recovery equipment, and leaks. The results showed that using CNG would reduce the greenhouse effect of motor vehicles by 19 percent over gasoline and diesel vehicles. Liquified natural gas (LNG) would reduce the effect by 15 percent. Employing sensitivity analysis for the range of plausible methane to carbon dioxide conversion factors (5 to 30), Sperling found that the global warming benefit of CNG vehicles would be between 4 and 25 percent (0 to 21 percent for LNG).

Another analysis, by Okken of the Netherlands Research Foundation (J.E. Sinor, 1990b), of just CO_2 emissions for the full cycle (production to use) shows a 20 percent reduction in CO_2 from the use of CNG vehicles. It does not appear that this analysis considered the additional methane emissions. Therefore, the actual global warming benefit would probably be less than 20 percent. Although, the AGA contends that using methane that is currently wasted may actually decrease global methane emissions.

Nitrous oxide, a greenhouse gas with a much greater warming effect per unit of mass than either carbon dioxide or methane, was not considered in any of the above studies. Although it is theoretically plausible that N_2O emissions are similar in both gasoline and natural gas vehicles, EPA recommends that they be measured to obtain a more definitive answer (EPA, 1990a). A study by Radian, that did use rough estimates for N_2O emissions and considered emissions from production, transport, and use of natural gas as a vehicle fuel, showed a reduction in greenhouse gases of between 7 and 22 percent by replacing all vehicles with natural gas vehicles (Radian, 1989).

Ozone was not considered in any of the studies, because available data and models do not allow the estimation of the greenhouse effect from ozone precursors (such as hydrocarbons and NO_x) (National Research Council, 1990). Though ozone savings cannot yet be easily quantified, the preceding section (7.1) concluded that ozone reductions are probable with CNG relative to gasoline/diesel.

Although it appears that CNG is less of a contributor to global warming than gasoline/diesel, one must keep in mind that any release of carbon from the earth into the atmosphere contributes to global warming, except carbon from biomass, which will be recaptured by the Earth's vegetation through photosynthesis. The principal ways to significantly reduce the long-term global warming effects of motor vehicle transportation are to greatly improve fuel efficiency, reduce VMT, use biomass (No fossil fuels used in growing, harvesting, or manufacturing the fuel) for the production of methane and/or methanol, or non-fossil fuel generated electricity for hydrogen and electric vehicles. However, none of these alternative fuel options are being vigorously pursued, because of economic and technical performance drawbacks. Of the options which are being actively pursued, natural gas vehicles are promising in that they

1) offer global warming benefits in and of themselves and
2) would require both the implementation of a gaseous fueling infrastructure and the study of gaseous engine technologies, thereby increasing the likelihood of a hydrogen vehicle future.

If solar, hydro, or geothermal electric power could be used to split hydrogen out of water by electrolysis, then a zero global warming effect would result. Zero global warming could also be achieved by using biomass to create synthetic natural gas, though its supply will probably limit its use to fueling only a subset of the current world-wide vehicle fleet (Sperling, 1988b; National Research Council, 1990).

The lower carbon to hydrogen ratio of propane relative to gasoline and diesel points to lower CO_2 emissions and possible global warming benefits, depending on the warming effects of the other emissions. In addition, propane is oxidized much more readily than methane (in natural gas) and therefore, causes little warming effect. The only study found on the warming impacts of propane use, predicts that CO_2 equivalent emissions will be reduced by about 24 percent over gasoline for light duty vehicles (Webb & Delmas, 1991). This is slightly better than predicted for CNG.

7.3 ACID RAIN

According to the National Acid Precipitation Assessment Program, acid rain is responsible for most of the acidification in sensitive lakes and streams in the Eastern U.S. Nitric acid formed from atmospheric NO_x is a component of acid rain, and 43.1 percent of NO_x emissions are from transportation sources. Also, acidic deposition of nitrogen in coastal waters, like the Chesapeake Bay, has been shown to cause "red tides", because nitrogen fertilizes excess algae growth (Harvey & Keepin, 1990). As stated in Chapter Three, natural gas vehicles will probably emit the same as or slightly more NO_x than gasoline vehicles.

Sulfur dioxide (SO_2) is a precursor to sulfuric acid found in acid rain. In addition, it blocks breathing passages, irritates eyes, skin, and the lungs of asthmatics, and can cause lung disease (TACB, 1990). There is no sulfur in natural gas, so compared to both gasoline and diesel, sulfur dioxide and sulfate particle levels would be reduced (National Research Council, 1990; Sierra, 1989). Yet, the combustion of fossil fuels for transportation accounts for only 4.4 percent of the total sulfur emissions, so reducing these emissions from vehicles will not have a meaningful overall impact (Harvey & Keepin, 1990).

No definitive conclusion can be drawn from the above regarding whether CNG vehicles are better or worse than gasoline/diesel vehicles as far as acid rain is concerned. However, it appears that substitution of gasoline by CNG as a motor vehicle fuel is not likely to make a significant difference on acid rain. No specific information was found on the effects of propane on acid rain.

7.4 LAND AND WATER POLLUTION

Land, ocean, river, and/or ground-water pollution from transportation fuels can occur from:

1) production/processing effluent,
2) accidental spills or leaks during fuel transport and storage, and/or
3) vehicle spills or leaks during usage.

If natural gas is used in vehicles in compressed form and supplied solely by pipeline (as it could be from Canada, Mexico, or domestically), then the fuel will always be gaseous and any leak or spill in transport or usage will not pollute land or water, only the atmosphere. In this case, the only possible source of land or water pollution would come from production/processing effluent.

It is possible that natural gas could be stored and transported as a liquid, but used in vehicles as CNG. If this is the case, or if natural gas is stored on vehicles as LNG, then its land and water pollution effect is determined by its evaporative properties when a spill or leak occurs, and its reaction with any land or water it comes in contact with. The chances of liquid natural gas contacting a ground-water supply is probably very small, since evaporation is likely to occur quickly (natural gas is only a liquid at temperatures below 260 degrees Fahrenheit). No information on the damage to an ocean or river in case of an LNG tanker spill is available to the author at this time; however, it has been reported that the biggest fear associated with LNG shipping terminals is of a huge spill at sea (DeLuchi, Johnston & Sperling, 1988). If LNG were produced domestically, it would have the same pollution effects for production/processing as CNG, since the production/processing phase entails only extracting the natural gas from the ground and processing it to pipeline standards. Natural gas would be transported by pipeline if LNG were produced on-site, thereby eliminating dangers of spills due to fuel transport. If natural gas was liquified centrally and then transported by truck, a spill would probably be less damaging than a similar gasoline/diesel spill, because of faster evaporation. Even though some of the lighter hydrocarbons of gasoline evaporate very quickly, the heavy ones take a long time.

The only plant and animal damage from LNG will probably come from the cold temperatures. LNG leaks and spills from small vehicular containers will probably evaporate so quickly that no damage will occur (DeLuchi, Johnston & Sperling, 1988).

One should also consider the land and ground-water pollution effects of fuel storage. According to the EPA there are about 676,000 underground fuel storage tanks in retail motor fuel stations, of which 30,000 to 35,000 are being replaced annually, because they were found to be leaking when inspected according to environmental regulations (DOE, 1990a). The effects of this pollution would be eliminated if gasoline and diesel were replaced by CNG or LNG. (This assumes LNG leaks are small enough that evaporation would occur very quickly.)

In summary, if domestic, Mexican, or Canadian natural gas is used for either CNG or LNG, the only significant source of land and/or water pollution would come from production and processing. While the amount and impact of this pollution are not analyzed here, they appear to be much less than that caused by petroleum through spills in the oceans, spills during highway transport, leaks during storage, etc. Even if petroleum is not spilled or leaked, it still pollutes during processing to gasoline and diesel fuels and when tankers are flushed with sea water. Information is lacking on the comprehensive impacts of an LNG tanker spill (in case of overseas natural gas supplies), but the fact that LNG evaporates much quicker than petroleum is a major advantage for natural gas.

A Radian (1989) study rates the impact of dedicated CNG vehicles on ground-water and soil contamination to be of no risk, whereas gasoline presents significant risk. On a scale from 0 to 3 (0 being no concern and 3 high concern), a study by Wyman (1988) rates the ground-water pollution effects of CNG as 0 and gasoline as 2. Both of these studies also came to the conclusion that CNG vehicles contribute much less to land and water pollution than do gasoline and diesel vehicles.

Although propane is stored as a liquid on vehicles, in fueling stations, and on transport trucks, leaks or spills will quickly evaporate to a gas, since propane is a gas at atmospheric pressure down to a temperature of minus 40 degrees centigrade. Therefore, propane is not a major concern for ground-water or land pollution. Wyman (1988) rates the ground-water pollution impact of propane to be of some concern (1 on a scale of 0 to 3) and gasoline to be of moderate concern (2) and Radian (1989) rates propane to be of slight risk, while gasoline presents significant risk. On the basis of these results, propane is not as good as CNG, but better than gasoline.

7.5 ENERGY SECURITY

U.S. energy security is usually thought of in terms of the continued availability of energy supplies at prices that allow the U.S. society to maintain its current lifestyle. Examples of supply disruptions occurred in both 1973-1974 and in 1979-1980, when petroleum prices increased by several hundred percent because of both intentional market manipulation and revolution, sabotage, and war in several countries. There is a distinction between U.S. energy security and overall energy supply. The latter is discussed in Section 7.8.

Considerable debate surrounds the costs and volumes that would provide energy security. Some advocate a minimum price on a barrel of oil, usually around $20, that would sustain greater U.S. production and thereby reduce reliance on foreign supply (Texas Governor's Office, 1991). The quantity of fuel necessary to run an effective U.S. society is also debatable. For instance, does the U.S. society need to use as much fuel as it does for transportation? Since 1960, U.S. population has increased about 36 percent, but VMT has increased by 193 percent (ITE, 1991). Vehicle efficiency gains over the same period have saved much of the fuel that would have been needed for those extra miles, but the basic question remains: "Does the U.S. society need to drive this much to be effective?". This section does not attempt to answer this question, but poses it to show that other options are available for increasing U.S. energy security. These are similar to the options presented in Sections 7.1 and 7.2 to help urban air pollution and global warming problems.

One option is to increase the average fuel efficiency of the nation's motor vehicle fleet and at least maintain current VMT. A second option is to reduce VMT by increased use of transit, carpooling, bicycling, and/or walking. Another option is use of the U.S. Strategic Petroleum Reserve (SPR), which consisted of 500 million barrels of petroleum stored in underground salt domes in 1987, and has a capacity of 750 million barrels (Sperling, 1988a). In 1988, a full SPR would have lasted 114 days if all foreign petroleum imports had been stopped. The rest of this discussion will focus on another option: fuel substitution. Specifically, replacing less reliable supplies of petroleum with reliable supplies of natural gas in the automobile and truck transportation sector.

It seems that all U.S. sectors, except transportation, have weaned themselves off petroleum almost to the extent possible. Petroleum's share of the energy consumed by the industrial sector dropped from 32.4 percent in 1979 to 28.5 percent in 1985; in the residential and commercial sector, it dropped from 16.6 to 9.7 percent, and in the electrical generation sector from 17.2 to 4.1 percent. On the other hand, about 97 percent of all transportation energy is still provided by petroleum and this percentage is even higher for highway vehicles (Sperling, 1988a). Consequently, it would seem that the fuel substitution option in the U.S. transportation sector holds considerable potential to increase energy security.

U.S. petroleum production was about 11 million barrels per day (mbd) in 1986 and its petroleum imports were 5.2 mbd. In 1988 imports grew to 6.6 mbd and by 1989, 45.2 percent of U.S. petroleum was imported. The U.S. Energy Information Administration (EIA) projects that in 1995 U.S. production will decrease to between 8 and 9 mbd and imports will increase to between 8 and 10 mbd. In 1985, the U.S. used 7.5 mbd of this petroleum for gasoline and diesel transportation fuels and is projected by EIA to use about the same amount through 2000. Even if natural gas vehicles fueled solely from domestic sources replaced all gasoline and diesel vehicles by 1995, between 3 and 14 percent of U.S. petroleum would still come from foreign sources (Sperling, 1988a; DOE, 1988a; GRI, 1989b; Oak Ridge, 1991). It should also be noted that one could argue that imports improve U.S. energy security, by increasing the time before domestic reserves deplete.

Can the U.S. feasibly replace enough petroleum with reliable natural gas (either domestic or foreign) to improve its energy security? DOE calculates that if the U.S. converted all feasible fleet vehicles to natural gas (3.1 million cars, 2.2 million light duty trucks, and 2.5 million heavy duty trucks), 0.49 mbd of petroleum would be displaced. If, in addition to those fleets, 23.4 million personal cars and light trucks were converted, a total of 1 mbd of petroleum would be displaced. This would require about 18,000 CNG fill stations and an additional 1.9 trillion cubic feet (tcf) of natural gas per year, which is about 11 percent of U.S. annual demand and well within the 25 percent excess capacity of the transmission infrastructure (DOE, 1990a).

Even though natural gas in other countries is available in large quantities at very low costs (less than $1 per million Btu compared to $2 to $3 in the U.S.), the cost of liquefying and transporting it to the U.S. makes it more expensive than domestic or Canadian gas (Sperling, 1991). Thus, natural gas for vehicles will come from reliable sources in the foreseeable future.

With low oil prices from Middle Eastern and other OPEC suppliers, who have the largest supplies and lowest production costs in the world, oil imports have increased the last few years and domestic production has decreased. From this, one must conclude that the possibility exists for natural gas vehicles to cause a reduction in U.S. production (as current wells dry up, the expense of exploration and development would preclude their replacement) and not foreign imports. In this case, the energy security benefits would be more limited. Some benefit would still accrue, since the U.S. society would be less dependent on one type and source of fuel.

Finally, even if the U.S. could convert the 31.2 million vehicles (about 1/5 of the total 1985 U.S. highway vehicle stock) necessary to displace 1 mbd of insecure petroleum imports, how much would decreasing imports in 1995 from 9 mbd to 8 mbd help energy security? Taken by itself, such decrease would have limited impact on energy security; however, used along with other replacement fuels and other measures, the impact could be significant.

No specific information was found on the magnitude of the impact propane vehicles might have on U.S. energy security. However, as the previous discussion points out, any diversification of the fuels used in the U.S. highway transportation sector would seem to increase energy security.

7.6 REGIONAL ECONOMIC DEVELOPMENT IN TEXAS

Many areas are looking towards economic development to enhance quality of life. Macroeconomic conditions in the oil market over the past decade have imposed particular economic hardships on many areas of Texas. Since Texas has large supplies of natural gas, many (Texas Governors Office, 1991; Texas General Land Office, 1989) are advocating use of this resource as one way to help the State's economy. Recent Texas legislation (SB 740 and 769), requiring operation of state motor vehicle fleets on either natural gas, propane, or electricity, is one attempt to achieve this goal.

According to the Texas General Land Office (1990), the new alternative fuels laws could create more than 8,000 new jobs and increase personal income by $500 million per year. If additional CNG vehicle markets increase natural gas demand by 1 trillion cubic feet (tcf), Texas is predicted to see 110,000 new jobs, an increase in personal income of $3 billion, and an additional $1.8 billion in incremental output value by 1992 (Texas General Land Office, 1989).

These would be significant economic benefits for Texas. The main concern is the same as that discussed in section 7.5 for national energy security: the petroleum displaced by these CNG vehicles must not be from Texas sources. Since Texas is also a large petroleum supplier, if the increase in natural gas use was at the expense of decreasing Texas petroleum use, then petroleum economic losses may offset the gains from natural gas.

No specific estimates were found for the economic benefits to Texas of increased propane vehicle use. Yet, surely benefits would accrue, since Texas is also a large supplier of propane.

7.7 TRANSITION TO A HYDROGEN VEHICLE FUTURE

This section discusses the societal benefits of CNG vehicle use as a lead in to a virtually emission-free hydrogen vehicle future. CNG can also be considered a lead in to vehicles fueled by methane created from biomass, which would have zero global warming impacts, but would still have impacts similar to CNG on urban air pollution. The methane from biomass scenario is not considered further here, since biomass supply will probably limit its use (National Research Council, 1990).

If solar, hydro, or geothermal electric power is used to split hydrogen out of water by electrolysis, then a zero global warming effect would result. Produced in this manner, hydrogen is almost a perfect fuel. It is renewable, has an abundant supply, and emits virtually no particulates, carbon monoxide, carbon dioxide, smog-forming hydrocarbons, or toxins when used in an internal combustion engine, though it will still emit nitrogen oxides.

Though hydrogen has been proven feasible in experimental vehicles, it still has significant technical barriers to overcome, such as the economics of solar energy, storage technology, and safety concerns. These will probably delay its introduction until well into the future (mid- to late 21st century), unless environmental concerns speed up the process.

Many have discussed the possible benefits of CNG vehicle use as a lead in to a hydrogen vehicle future (Sperling, 1988a; DeLuchi, Johnston & Sperling, 1988; Taylor, Euritt & Walton, 1991; Webb & Delmas, 1991). The theory behind these hard to quantify benefits is that by using CNG vehicles knowledge is gained in gaseous fueled engine technology and fuel storage, which will be applicable to hydrogen. Also, a gaseous fuel distribution system that could later be used for hydrogen would be put in place.

The magnitude of the benefits of CNG as a lead in to hydrogen are obviously debatable and depend on the decision maker's own valuation of the global warming, urban air pollution, and fuel supply problems. Yet, the current gasoline/diesel (from petroleum) scenario and the two other most probable future transportation fuel paths are much worse as far as the environment and renewability (supply) are concerned. The two other most probable future paths are:

1) synthetic fuels (closely resembling petroleum) from coal, oil shale, and oil sands and
2) methanol (from natural gas) leading to either methanol (from coal) or alcohols (from biomass) (Sperling, 1988a; DeLuchi, Johnston & Sperling, 1988).

So, there are clear benefits to using CNG as a lead in to hydrogen, even though the magnitude of these benefits is uncertain.

Current and past vehicular use of propane has already provided a lead in to CNG vehicle use, and its expanded use would encourage additional study of gaseous fueled engine technologies, thereby aiding in a transition to a hydrogen vehicle future. However, unlike CNG, propane would not aid in developing the gaseous fueling infrastructure required for hydrogen.

7.8 SUPPLY

The long term supply of natural gas is of obvious concern when considering operation of vehicles on CNG. Supply of natural gas (and petroleum) is linked to its price. The higher the price the more incentive for exploration (finding new supplies) and for the use of advanced technologies for extraction. One estimate of remaining economically producible U.S. natural gas resources for two price levels and different levels of technologies is given in Table 7.2.

Table 7.2 ***Estimated remaining economically producible U.S. natural gas resources for two price levels and current versus advanced extraction technology (National Research Council, 1990)***

	Current Technology		Advanced Technology	
Wellhead price ($/mcf)	$3	$5	$3	$5
Tcf[a] natural gas (billion barrel oil equivalent)	595 (107)	770 (140)	880 (160)	1,420 (256)
Ratio of resource base to current production	33	43	50	80

[a] Trillion cubic feet

For comparison, an estimate of the remaining economically producible U.S. petroleum resources are given in Table 7.3, indicating that known U.S. reserves of natural gas are larger than known U.S. reserves of petroleum. In addition, the ratio of resource base to current production is higher for natural gas. This means natural gas would be available over a longer time period than petroleum, at current production levels. In addition, over 90 percent of natural gas used in the U.S. is domestically produced versus about 58 percent for petroleum (Bush Administration, 1991). If one also considers unconventional gas supplies (such as gas shales, tight gas sands, and gas hydrates), U.S. supply might be as large as 3600 tcf (or a 200 year supply at current consumption levels) (DOE, 1987).

World supplies of natural gas, both proven (based on drilling information) and recoverable, are shown in Table 7.4. The proven global reserve of 3,955 trillion cubic feet (tcf) is equivalent in energy to about 740 billion barrels of petroleum. This is about 17 percent less than the proven global reserve of petroleum (896 billion barrels). Yet, annual production of natural gas is only about half that of petroleum, meaning that petroleum supplies will deplete before natural gas, if production of each remains at current levels. The global reserve to production ratio is about 60:1 for natural gas and about 40:1 for petroleum (Dreyfus, 1990). Substitution of natural gas for petroleum could balance this, both globally and in the U.S.

Table 7.3 Estimated remaining economically producible U.S. petroleum resources for two price ranges and current versus advanced extraction technology (National Research Council, 1990)

	Current Technology		Advanced Technology	
Oil price ($/barrel)	$24 - $25	$40 - $50	$24 - $25	$40 - $50
Billion barrels of oil	75 - 76	95 - 140	105 - 129	140 - 247
Ration of resource base to current production	25	32 - 47	35 - 43	47 - 82

Table 7.4 Estimate of global natural gas resources (trillion cubic feet) (Dreyfus, 1990)

Global Regions	Proven Reserves	Recoverable Resources
The Americas (North, Central, and South)	518	1,498
Western Europe	200	423
Middle East	1,182	2,126
Africa	253	570
Asia Pacific	240	630
Eastern Europe and former Soviet Union	1,561	2,807
World Total	3,955	8,107

Total 1985 U.S. gasoline and diesel fuel consumption by highway vehicles was about 2.7 billion barrels of oil, which is equivalent to about 14 tcf of natural gas (Sierra, 1989). Annual U.S. consumption of natural gas is about 18 tcf (Bush Administration, 1991). Under the current technology/low price estimates in Tables 7.2 and 7.3, 41.4 percent of the U.S. highway vehicle fleet's usage of gasoline/diesel would need to be replaced by natural gas in order to equalize the ratios of resource base to current production for each at 25 (assuming all displaced petroleum is from foreign sources). This is an additional 5.8 tcf of U.S. natural gas production per year.

In conclusion, if one feels that current petroleum supplies are sufficient for current U.S. vehicular use, then it appears that there are sufficient supplies of natural gas to support fairly widespread CNG vehicle use. Both U.S. and world supplies of natural gas are quite comparable to petroleum. Yet, with 39 percent of the world's supply in OPEC countries (OPEC holds 75 percent of the world's proven petroleum reserves) and 38 percent in the former Soviet Union, whether supplies will be secure and competitive or subject to a cartel like petroleum is still up in the air (Interagency Commission, 1990). In addition, some substitution of petroleum with natural gas may be desirable in order to make each resource last the same amount of time.

Propane comes mainly from stripping the liquids from natural gas (60 to 80 percent). The rest is produced during petroleum refining. Suppliers rarely set out to explore for propane. Therefore, propane supply is mainly tied to the supply of natural gas (Wyman, 1988). Because of these reasons, it has been generally reported that propane supply would severely limit its use as a motor vehicle fuel. However, Webb and Delmas' (1991) assessment is that the potential propane supply could fuel 12.5 percent of the United State's 150 million vehicles by 2005.

7.9 SAFETY

Safety of a vehicular fuel can be analyzed according to the following criteria:

1) risk of combustion or detonation,
2) risk during fueling and distribution,
3) risk during an accident, and
4) the health risk of exposure to the fuel.

Radian (1989) summarized the findings of several other studies for all these criteria. Their summary for the first safety criterion is shown in Table 7.5. For this criterion, CNG dominates gasoline. Diesel dominates CNG for those physical and chemical properties relating to the probability of combustion or detonation. For this reason, diesel may be better than CNG, even though the hazard of a diesel fire, if it does occur, is more severe than that for a natural gas fire. Propane is only slightly better than gasoline. Its ratings are the same for all criteria, except combustion of vapors in tank, where it is rated as no concern versus slight concern for gasoline.

Analysis of the second criterion, risk during fueling and distribution, can proceed from Table 7.6. For this criterion diesel dominates both gasoline, CNG, and propane. Gasoline appears slightly better than CNG, though it does not dominate it, and gasoline dominates propane.

Table 7.5 Concern for risks of combustion or detonation (Radian, 1989)

Physical/Chemical Properties	Gasoline	Diesel	Compressed Natural Gas	Propane
Potential damage (detonation)	High concern	No concern	Slight concern	High concern
Combustion of vapors in tank	Slight concern	No concern	No concern	No concern
Combustion (open spaces)	High concern	Slight concern	Slight concern	High concern
Combustion (restricted spaces)	High concern	Slight concern	High concern	High concern
Hazard if a fire occurs				
Flame luminosity	No concern	No concern	No concern	No concern
Severity	High concern	Extreme concern	Moderate concern	High concern
Ease of extinguishing	Very difficult	Very difficult	Moderately difficult	Very difficult

Table 7.6 Risk during fueling and distribution (Radian, 1989)

Safety Risk	Gasoline	Diesel	Compressed Natural Gas	Propane
Risk during fueling	Low concern	Lowest concern	High concern	High concern
Risk during distribution	Moderate concern	Low concern	Low concern	?

Risk during an accident can be analyzed via Table 7.7. Diesel is again dominant, and CNG dominates gasoline. Radian (1989) also comments that gasoline vehicles have accident rates similar to CNG vehicles, but much greater incidences of injury and death. No deaths have been attributed to CNG fuel system failures. Propane is dominated by diesel and has safety risks similar to gasoline.

The final criterion, the health risk of fuel exposure, can be analyzed by looking at three ways in which people can be exposed to the fuel: inhalation, skin contact, and ingestion. This is done in Table 7.8. CNG dominates both gasoline and diesel for this criterion. Radian (1989) did not rate propane for this criterion; however, Wyman (1988) rated propane better than gasoline, but worse than CNG for toxicity.

Table 7.7 Risk during accidents (1 = lowest, 5 = highest) (Radian, 1989)

Safety Risk	Gasoline	Diesel	Compressed Natural Gas	Propane
Fire	5	1	5	5
Physiological damage	4	1	2	5
Explosion	5	1	2	4
Overall	5	1	2	4

Table 7.8 Health risks of fuel exposure (Radian, 1989)

	Assessment of Concerns		
Health Risk	**Gasoline**	**Diesel**	**Compressed Natural Gas**
Inhalation			
Low concentration			
Toxicity	High	Minor	No concern
Ease of occurrence	High	Minor	High
High concentration			
Toxicity	High	Moderate	No concern
Ease of occurrence	Moderate	Minor	?
Skin contact			
Toxicity	High	Moderate	No concern
Ease of occurrence	Minor	Minor	No concern
Ingestion			
Toxicity	High	High	No concern
Ease of occurrence	Minor	Minor	No concern

Since no fuel is dominant for all four criteria, tradeoffs are necessary among the various criteria. Note Radian's (1989) conclusion that, in general, the lowest combined safety risk for the first three criteria is associated with diesel, with CNG safer than gasoline. Combining this conclusion with CNG's dominance over gasoline and diesel for the fourth criterion, allows one to conclude that CNG is safer than gasoline, and may or may not be safer than diesel. It also appears that propane is very similar to gasoline, as far as safety is concerned.

7.10 FLEET ANALYSIS

This section presents a method of considering societal benefits in connection with economic factors. It uses the cost-effectiveness analysis framework developed in Chapter Five (and applied in Chapter Six) to compute the value one would have to place on certain societal benefits in order for fleet operation on the alternative fuel to be cost-effective. In the situation where alternative fuel operation is not financially cost-effective, this allows the computation of the value that should be placed on some other criterion to compensate for the cost differential. In addition to providing the decision maker with a new perspective, this value can be used as a basis for determining financial incentives to encourage fleet operation on CNG or propane.

This method is applied here to both national energy security and urban air pollution societal benefits for CNG, though it can also be applied for other societal impacts and other fuels, such as propane. Operation of the fleet analyzed here is financially cost-effective on propane, so there is no reason to apply this method of costing societal benefits.

For national energy security analysis, it is assumed that every gallon of gasoline displaced by CNG would lessen unreliable foreign petroleum imports, not domestic production. Consider the "favorable" fleet from Chapter Six (Table 6.1) and the more representative TxDOT fleet with the same number of vehicles (and same fuel efficiencies), but with annual mileage per vehicle of 15,000 versus 22,500 miles for the "favorable" fleet. These fleets use 245,608 and 163,739 gallons of gasoline per year, respectively.

The cost-effectiveness analysis framework computes the net present value of all monetary costs and benefits of operation of the fleet on CNG relative to gasoline. Annualizing the net present value and dividing by the fleet's annual gasoline consumption gives the value (for national energy security benefits) one would have to place on displacing one gallon of gasoline from unreliable foreign sources in order for operation of the fleet on CNG to be cost-effective. Under the assumptions shown in Figure 6.1, the value of displacing one gallon of gasoline (required for cost-effectiveness) was computed for both fleets for various natural gas prices. The results are shown in Figure 7.1.

Fleets of this composition (see Table 6.1) with vehicles that operate 22,500 miles per year and can purchase natural gas at about $2.75 per thousand cubic feet (mcf) would become cost-effective if the societal benefit of displacing a gallon of gasoline made from imported petroleum were about 10 cents per gallon. It seems as if 10 cents per gallon is within the feasible range for this societal benefit, since this is only about one-tenth the price of a gallon of gasoline to U.S. consumers, and $2.75/mcf is a feasible natural gas price for fleets in the state of Texas (AGA 1989a; EIA, 1984-1990). Yet, proposals to raise gasoline taxes by similar magnitudes have not been well received in the U.S. In fact, for either fleet at natural gas costs up to $4.50/mcf, the cost of displacing a gallon of gasoline is below 44 cents, which also cannot be automatically dismissed as unreasonable.

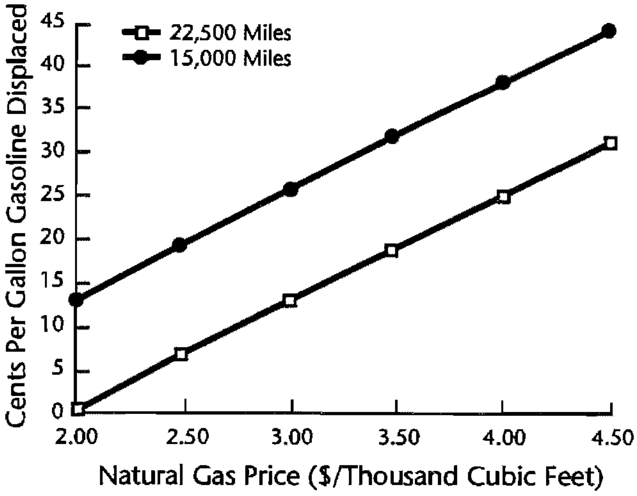


Figure 7.1 ***Value for the displacement of one gallon of foreign gasoline required for cost-effective fleet operation on CNG, for two fleets (15,000 and 22,500 miles per vehicle)***

We have not found any published costs for reducing reliance on imported petroleum by other means, such as improved auto fuel efficiency standards. If these costs were known, they could be compared to those found by the above method to determine the most cost-effective way of achieving energy security benefits. In doing so, one must also consider that increasing fuel efficiencies would generate financial benefits to the fleet by reducing the fuel cost for the same amount of travel.

For urban air pollution analysis, one can estimate the amount of the reduction of a selected pollutant if CNG vehicles replace gasoline vehicles. In this example, reactive hydrocarbon (RHC) emissions are chosen, because of their role in ozone formation. It is reasonable to estimate that 80 percent of total gasoline hydrocarbon emissions are reactive, compared to only 20 percent of CNG emissions (see Section 7.1.1). The present EPA standards for total HC emissions (0.41 grams/mile for autos and 0.80 grams/mile for light and heavy-duty gasoline trucks) can be used to estimate actual on-road total hydrocarbon emissions. This results in a 0.246 gram/mile reduction for automobiles and a 0.48 gram/mile reduction for both classes of trucks.

Since most on-road vehicles emit more than the EPA standard, due to age, insufficient maintenance, catalyst degradation, etc., more realistic estimates are also used. The first comes from an estimate of typical on-road automobile total HC emissions of 2.0 grams/mile (GRI, 1989b). Multiplying this by two is an estimate of typical gasoline truck (both light and heavy) HC emissions, since the EPA standard for these is approximately twice as high as that for automobiles. Applying the previous proportions of RHC to total HC, yields a 1.2 gram/mile reduction for automobiles and a 2.4 gram/mile reduction for both classes of trucks.

Finally, Radian (1990a) used the MOBILE4 model to estimate gasoline RHC emissions and data from EPA and the Gas Research Institute to estimate CNG RHC emissions, for the Chicago area. (These estimates will vary for other geographic areas based on ambient temperature, inspection/maintenance programs, etc.) These estimates yield RHC reductions of 1.16, 1.46, and 2.41 grams/mile for automobiles, light trucks, and heavy trucks, respectively.

An estimate of the cost per ton of RHC reduction for the "favorable" (i.e. 22,500 miles per vehicle) fleet (under the model assumptions in Figure 6.1, with varying natural gas prices) using each of the three RHC reduction estimates is shown in Figure 7.2.

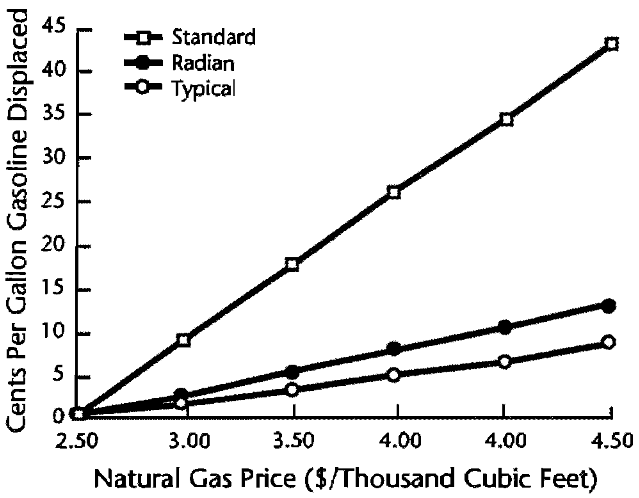


Figure 7.2 **Value for the reduction of one ton of reactive hydrocarbons (RHC) required for cost-effective fleet (22,500 miles/vehicle) operation on CNG, for three different emission estimates**

The values for cost per ton of RHC removed cannot be analyzed as intuitively as those for a gallon of gasoline displaced from foreign sources, but some insights can be drawn from the above analysis. The cost is three to five times less if one uses the more realistic estimates in the "Typical" and "Radian" cases. With natural gas prices at $2.00/mcf, all estimates are below $800, which seems relatively inexpensive. Even with natural gas prices at $3.00, all estimates are below $20,000, which may or may not be inexpensive. If the more realistic on-road estimates are used, even at a natural gas price of $4.50, both estimates are below $15,000. As for energy security, values for cost of RHC removal by other means could be compared to these in order to determine the most cost-effective method for ozone reduction.

With natural gas prices of $3.00/mcf, the additional cost per mile of operating this "favorable" fleet on CNG relative to gasoline is one cent. For this additional cost of one cent/mile, RHC reductions of 1.6, 5.2, and 8.0 tons per year are realized, for the standard, Radian, and typical estimates, respectively.

It should be pointed out that CNG reduces other vehicular emissions (and possibly raises NO_x), in addition to providing the other societal benefits (or costs) discussed in this chapter. Analyzing each impact in isolation, as done in the previous analyses, provides an interesting perspective for the decision maker. Yet, one should jointly cost many or all the societal impacts to provide both the most comprehensive and most accurate information. This is an ideal area for future use of the methods described in this section. One could allow the decision maker to allocate a portion of fleet costs to each societal impact, depending on the importance of each impact, and then compute the cost per unit of societal benefit for each societal impact included in the analysis.

7.11 CLOSURE

This chapter discussed most of the societal impacts of replacing gasoline/diesel vehicles with CNG or propane vehicles. Even though these impacts are difficult to quantify and assess at this time, the author feels that the discussion herein shows that both fuels offer enough possibilities for societal benefits to merit strong consideration for fleet usage. The information herein can be used in combination with fleet economic analysis in order to make fleet fuel decisions and support policy making in this arena.

A useful perspective is obtained using the fleet cost-effectiveness analysis framework developed in Chapter Five to compute the value one would have to place on a societal benefit in order for fleet operation on an alternative fuel to become cost-effective. This value can also be used for comparison with other methods of achieving the same benefit or to determine the magnitude of alternative fuel vehicle incentives required to achieve societal goals.

Example analyses of the cost of providing national energy security benefits through CNG fleet vehicle usage yield values that may well be within a socially and politically acceptable range. Example analyses for reactive hydrocarbon reduction did not yield results that are intuitively analyzable by this author. It would be of value to compare both values with other costs for achieving the same benefits or with estimates of the associated social cost. In addition, the various societal impacts should be considered jointly rather than in isolation. Thus, only a portion of the cost to operate the fleet on a specific alternative fuel versus gasoline/diesel would have to be offset by each benefit. A proportion of the net fleet cost could be allocated to each societal impact based on their relative importance. Future work in this area could prove very useful.

CHAPTER 8. CONCLUDING COMMENTS

This chapter presents concluding comments on the research presented in the previous chapters. In the first section a summary of the key contributions of this study are presented. The next section explores possible avenues for further research in the alternative fuels area, based on the work begun herein.

8.1 SUMMARY

This study makes several contributions to the timely topic of alternative fueled vehicles. Because of the increasing attention accorded to the environment and U.S. dependence on foreign oil (among other issues), alternative vehicular fuels are being contemplated. There are many barriers as well as advantages to alternative fuel use, presenting decision makers with difficult choices between the various alternative fuels and the traditional gasoline and diesel fuels. Further complications arise from the varying objectives of the different decision makers in this arena. For instance, fleet operators are primarily concerned with the financial impacts of operation on alternative fuels, while some government officials are more concerned with the broader social and economic impacts, such as those on the environment.

This study contributes an evaluation framework that can assist decision makers, regardless of their objectives (see Chapter Two). The criteria for vehicular fuel decisions are identified and explained. Noting that the joint consideration of all criteria is problematic, since some societal criteria are difficult to quantify and the measures of effectiveness for some criteria are non-commensurable, an operational analysis framework is developed. This framework separates those criteria for which monetary analysis is possible and proposes a financial cost/benefit analysis approach for them, while allowing those interested in societal impacts to compute the value one would have to place on specific societal benefits in order for fleet operation on the alternative fuel to become cost-effective. This framework is used throughout the rest of the study. Though this framework accommodates any fuel decision, it is applied only to CNG and propane, relative to gasoline/diesel, in this study.

Any alternative fuel presents technological challenges. This study examined the two major technical challenges for CNG and propane vehicles: engine design and fueling infrastructure. Engine design technology was reviewed in order to provide insight into the issues and trade-offs involved in designing automobiles based on several important criteria: emissions, fuel efficiency, and performance. In addition, the review provided the background necessary for several parts of the cost-effectiveness analysis used in Chapters Six and Seven, particularly those assumptions dealing with fuel efficiencies and emissions. Based on literature review and chemical analysis, natural gas and propane are shown to offer several theoretical advantages over gasoline and are, therefore, viable and desirable alternative vehicular fuels. The major problem appears to be that significant engineering work and practical use experience have resulted in gasoline vehicles optimized to consumer tastes and behavior, while propane and CNG vehicles lack both in engineering work and practical use experience.

The second major technical challenge, fueling infrastructure, is of great significance to CNG and propane. In the United States, the fueling infrastructure for these fuels is significantly smaller than for gasoline/diesel. This smaller fueling infrastructure is a major barrier to either's widespread use. Fueling technology is of particular significance to CNG, because of

1) the fairly immature state of current CNG fueling technology and
2) its differences relative to conventional gasoline/diesel fueling technology.

Propane fueling technology is well developed and similar to gasoline/diesel, and thus, presents no major barrier to propane use. However, lack of public fueling stations for propane and for CNG, along with the fact that on-site fueling stations may be more cost-effective and convenient for fleets, places particular importance on the study of the technology, operational characteristics, and cost structures of both propane and CNG on-site fleet fueling stations.

There are four possible types of CNG on-site fueling stations: slow-fill, fast-fill, combination slow/fast-fill, and nurse-truck. Chapter Four discusses the operation of the four station types, the cost components incurred in setting up and operating each station, and some of the criteria affecting the design of each type. Because fast-fill provides service that is most comparable to that currently available with gasoline/diesel, it is examined in more depth. A detailed methodology is developed (based on engineering principles) for estimating the minimum fast-fill CNG station cost for a particular fleet. The procedure provides an approximate station design based on fleet characteristics and estimates the cost of that station.

Though propane fueling is more comparable to gasoline/diesel, since propane is pumped as a liquid, it still requires a sealed pressurized system like that for CNG. The operation of a propane station, its cost components, and its design criteria are discussed, and a methodology for estimating station costs is developed. The station cost estimation methodology is based on the fact that propane is available to the fleet in either small or large volume purchases, at a different price for each. As for CNG, this discussion can aid fleet operators in choosing a station design for their fleet, while also providing the background for the station cost estimation procedure in the cost-effectiveness analysis framework of Chapter Five. No other reference appears to be as comprehensive in its discussion of CNG and propane fueling technologies. The station design and cost estimation procedures are an original contribution that could prove very useful for fleets or public fueling stations considering CNG or propane.

It was found (under the assumptions in Figure 6.3) that a fleet must consume about 40,000 gallons of propane annually to justify a large fueling station rather than a small one. This value provides a useful rule-of-thumb, though it differs from other such reported rules. For instance, Holloway (1992) estimates that a fleet needs to consume about 100,000 gallons per year and Ferrellgas (1988) says 120,000. It is possible that the discrepancy could be partly due to a longer analysis period used in this study (30 years).

Perhaps the most important contribution of this study is the development of a cost-effectiveness analysis framework to analyze operation of specific fleets on either CNG or propane, relative to gasoline/diesel. The framework has been operationalized in a spreadsheet model. The framework incorporates all known cost components and allows varying of input assumptions for both sensitivity analysis and updates due to new technological improvements, while also providing for the input of fleet characteristics, thereby allowing analysis of a particular fleet or sensitivity to various fleet characteristics.

Endogenous cost estimation for continuous fast-fill fueling infrastructure, based on fleet characteristics, and the inclusion of fueling labor losses (or gains) as a cost component are both important features of this framework. Differences in on-board storage volumes and dispenser flow rates can result in significant fueling labor time differences between fast-fill CNG and gasoline/diesel, and this appears to be the first published analysis that includes this cost component.

The model uses a net present value (NPV) approach, whereby all future incremental costs and benefits over the time horizon of interest are discounted to the present using a rate that reflects the opportunity cost of capital for the particular fleet operating agency. In addition, a measure is computed in order to allow comparison of cost-effectiveness for different fleet sizes. This measure is computed by annualizing the NPV of all costs and benefits and dividing by the fleet size, thereby finding the increased cost (or savings) per vehicle per year.

The model is used in Chapter Six to analyze several fleets, both hypothetical and actual. Under the base CNG model assumptions (see Figure 6.1), vehicle and fueling station costs are found to be of the highest magnitude, followed by the Texas state natural gas vehicle fuel tax, fueling labor losses, power, and station maintenance. This confirms that the actions of the natural gas industry and others to push for original equipment manufacturer (OEM) vehicles (with lower costs and better performance) and to improve both CNG fueling technology and on-board storage technology are good short- and mid-term strategies for increasing CNG vehicle usage.

The analysis in Chapter Six also shows that the Texas natural gas vehicle fuel tax is a significant cost item for both propane and CNG. It also illustrates the effects on cost-effectiveness of the fleet size and annual mileage. All other things being equal, larger fleets are more cost-effective due to the spreading of fixed fueling infrastructure costs over more vehicles, and fleets with higher annual mileage are more cost-effective because of increased annual fuel savings. It also shows that diesel vehicle replacement is not as cost-effective as replacing gasoline vehicles, due to

1) higher diesel vehicle costs (both conversion and OEM),
2) fuel efficiency reductions for CNG relative to diesel (for dedicated CNG vehicles),
3) the greater energy density of diesel relative to gasoline, and
4) the lower price of diesel (relative to gasoline) per unit volume.

The analysis also shows that (under the assumptions explained in Chapter Six) it will not be cost-effective to operate most Texas Department of Transportation (TxDOT) fleets on CNG. The same is true for propane, though propane is more cost-effective than CNG.

Finally, Chapter Seven provides a thorough discussion of the societal impacts of replacing gasoline/diesel vehicles with either CNG or propane vehicles. Combining this information with the economic analysis presented in Chapters Five and Six can assist policy makers in making value judgements for decisions pertaining to fuel choice. In addition, a method for computing the cost one would have to place on a certain societal benefit in order for fleet operation on CNG to become cost-effective is presented. This method utilizes the fleet cost-effectiveness analysis framework and model of Chapters Five and Six, in addition to estimates of the societal benefit of CNG, relative to gasoline. The resultant break-even cost of the societal benefit provides a useful perspective on the tradeoffs involved. For example, analysis of large TxDOT fleets in Chapter Seven shows that if one considers the cost to U.S. national security of importing one gallon of gasoline to be anything greater than 44 cents, then operation of large TxDOT fleets on CNG becomes cost-effective. It would then be reasonable for government to subsidize fleet conversion for this reason. The cost of 44 cents per gallon cannot be immediately dismissed as unreasonable, since the cost of gasoline per gallon in the U.S. is currently about 100 cents, and 44 cents is well under the tax many nations place on gasoline.

Besides this perspective, this value could be used to compare with the costs of other methods of achieving this same goal. For example, if auto manufacturers estimated their cost to deliver more fuel efficient gasoline vehicles, their estimates could be compared to 44 cents per gallon in order to choose the most cost-effective way of reaching the U.S. energy security goal.

8.2 RESEARCH NEEDS

Many areas in connection with this research are in need of further study. These research needs can be divided into the following four areas:

1) further applications of the fleet cost-effectiveness analysis framework/model,
2) additional societal impact analysis,
3) CNG fueling station design research, and
4) modifications of the fleet cost-effectiveness analysis framework/model for different applications.

There are many possible further applications of the fleet cost-effectiveness analysis framework/model. For instance, break-even points for both fleet size and annual mileage could be determined while holding the other constant. To be of practical use, these should be developed using average fuel efficiencies and a typical vehicle type distribution for the fleets in question. These break-even points would provide fleet operators and government decision makers with rules-of-thumb for cost-effective fleet operation.

The model can also be used to perform a more systematic comparison of propane and CNG to one another as well as to other alternative fuels, such as methanol, ethanol, and electricity. This would help in deciding the fuel split the U.S. or various areas within the nation should strive to achieve.

In addition, further verification is needed of the conclusion that a 40,000 gallon annual propane demand is the breakpoint between a small and large propane fueling station. Such verification would further validate the propane model, in addition to validating a useful rule-of-thumb. As discussed in Section 8.1, others have reported different values for this break-even point. The procedures used to derive these other estimates should be investigated and compared to that used here.

With regard to societal impacts, additional analysis of several of the impacts presented in the qualitative discussions in Sections 7.1 through 7.9 would be helpful. Such analysis would also involve computing the value one would have to place on the benefits in order for fleet conversion to be cost-effective. The only impacts analyzed in this study are national energy security and hydrocarbon emissions. There are numerous other important emissions, in addition to other societal impact categories.

Joint valuations of the costs of societal impacts is very important, since all societal benefits (or costs) will be incurred, not just a single one. Weightings provided by the analyst, reflecting the importance placed on each impact, could be used to divide the cumulative net present value of all fleet costs and benefits, in order to compute the cost one would have to place on each benefit in order to achieve cost-effective alternative fuel operation.

Costs of attaining societal goals by other means should be found and compared to the costs associated with CNG or propane fleet operation. This would aid in achieving environmental and energy security goals in the most economic manner. Finally, in the area of societal impact analysis, propane should be analyzed in a similar manner as CNG.

The third area of research needs is CNG fueling station design. Much work in this area is currently being done at BC Gas, the Gas Research Institute, and the Institute of Gas Technology. Only additional research that is germane to the fleet cost-effectiveness analysis framework/model is discussed here. First, Chapter Three discussed the relationship between usable storage, average flow rate per dispenser hose, and initial vehicle tank pressure (before filling). This relationship has not been sufficiently quantified. Assumptions for this relationship were used to develop the usable storage and average flow rate per hose input data for the fleet cost-effectiveness analysis in Chapter Six. These assumptions are based mostly on engineering judgement coupled with very limited actual data. A more accurate relationship would improve the overall quality of the model solution. This is especially important due to the significant impact of average flow rate per hose on labor fueling costs and the impact of usable storage on storage size and cost.

The analysis performed in this study assumed input natural gas line (suction) pressures of about 5 to 7 psig. Input line pressures greater than these may be available to many fleets. Higher input line pressures lead to reduced compressor costs, both capital and operating (power). These cost reductions should be investigated. Finally, compressor power costs are currently estimated by the CNG model at a maximum value. Investigation of load factors for CNG fueling station compressors would result in more accurate power cost estimates.

Several modifications of the fleet cost-effectiveness analysis model would be useful. Some of the input data assumptions (such as those for fuel efficiency conversion factors) are based mostly on theory and engineering judgement and very little on actual CNG vehicle data (especially for diesel), since there has been very little CNG use to date. The use of CNG vehicles in demonstration fleets should be monitored and analyzed, and the conclusions drawn should be used to update applicable model input assumptions.

Since significant cost reductions may be achievable with slow-fill relative to fast-fill, it would be useful to allow the slow-fill fueling option in the model. In addition, it would be of use to allow

1) other fast-fill scenarios, besides that implemented herein, where all vehicles fuel continuously,
2) combination slow/fast fill,
3) nurse truck, and
4) public fueling.

The discussions of these CNG fueling station types in Chapter Four should prove useful for this addition. This addition will also allow one to analyze the effect that different fleet fueling strategies would have on fueling infrastructure costs, in addition to allowing analysis of the cost and performance tradeoffs between the various fueling station types.

Since transit fleets are viewed as a very likely near-term application for CNG, it would be useful to add enough transit vehicle types to facilitate analysis of transit fleet operation on CNG. Although widespread individual CNG vehicle use is not envisioned in the near- or mid-term, it still may be useful to allow this analysis in the model. Finally, providing for liquified natural gas (LNG) vehicle analysis should also prove useful, since LNG vehicles solve several of the problems inherent in CNG vehicle use, such as limited vehicle range, while potentially causing other problems. Analysis of CNG versus LNG would be a valuable future contribution.

APPENDIX A.

SPREADSHEET ANALYSIS FOR "FAVORABLE" CNG FLEET

Summary of sample analysis for "favorable" CNG fleet
Complete Analysis on next 10 pages

SAVINGS	**30 year NPV**	**% of Savings**	**Incremental Savings/Mile**
Gasoline Price Diff.	$1,500,403	100.0%	$0.0505
Automobiles	$72,343	4.8%	$0.0341
Light Trucks	$1,178,150	78.5%	$0.0463
Heavy Duty Trucks	$249,911	16.7%	$0.1178
Diesel Price Diff.	$0	0.0%	$0.0000
Maintenance	$0	0.0%	$0.0000
Total Savings	$1,500,403	100.0%	$0.0505
COSTS		**% of Costs**	**Incremental Cost/Mile**
Infrastructure			
Land	$0	0.0%	$0.0000
Station setup	($89,845)	6.0%	($0.0030)
Compressor	($65,829)	4.4%	($0.0022)
Storage Vessels	($258,625)	17.3%	($0.0087)
Dispenser	($24,857)	1.7%	($0.0008)
Dryer	($9,943)	0.7%	($0.0003)
Subtotal	($449,099)	30.0%	($0.0151)
Vehicle			
Conversion Kit	($89,889)	6.0%	($0.0030)
Tanks	($132,500)	8.8%	($0.0045)
Labor	($175,872)	11.7%	($0.0059)
OEM	($82,748)	5.5%	($0.0028)
Subtotal	($481,009)	32.1%	($0.0162)
Operating			
Station Maint.	($104,032)	6.9%	($0.0035)
Cylinder Recert.	($25,228)	1.7%	($0.0008)
Power	($129,171)	8.6%	($0.0043)
Labor - fuel time loss	($144,493)	9.6%	($0.0049)
NG Fuel Tax	($165,160)	11.0%	($0.0056)
Additional training	$0	0.0%	$0.0000
Subtotal	($568,084)	37.9%	($0.0191)
Total Costs	($1,498,191)	100.0%	($0.0505)
Savings - Cost	$2,212	N/A	$0.0001

VEHICLE DATA	# Vehicles	MPG	Annual Miles per vehicle	CNG Conversion Cost per vehicle	OEM Cost Differential per vehicle
Automobiles	10	19.0	22,500	$1,950	$900
Light Trucks	120	14.0	22,500	$2,200	$900
Heavy Duty Gasoline	10	5.5	22,500	$3,300	$900
Heavy Duty Diesel	0	1.0	1	--	--
Dedicated	--	--	--	$6,350	$2,800
Dual-fuel	--	--	--	$5,500	N/A
Total	140				

FUEL PRICES	
Natural Gas Price/mcf	$1.95
Gasoline Price/gallon	$0.89
Diesel Price/gallon	$0.85
Natural Gas Price Equivalents:	
NG price per gasoline gallon equivalent	$0.24
NG price per diesel gallon equivalent	$0.27

DISCOUNT RATE	10.0%

OTHER FACTORS	
Electricity Cost ($/kWh)	$0.063
Labor Cost ($/hr)	$15.00

STATION DESIGN	
Year 1: Compressor Size (scfm)	85
Year 1: Storage Size (scf)	244,965

MAJOR ASSUMPTIONS

1. Fueling station is designed for continuous fast-filling in one session per day.
2. OEM vehicles are available at the beginning of year 11.
3. Diesel conversions are assumed available at the beginning of year 6.
4. Vehicles are sold off at the end of the year when they reach the following mileage totals:

Automobiles	90,000
Light Trucks	90,000
Heavy Duty Gasoline	90,000
Heavy Duty Diesel	150,000

Benefit/vehicle/year	$1.68

Incremental Benefit/mile	$0.0001

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SAVINGS																
Gasoline Price Diff.		156,722	156,722	156,722	153,487	156,722	156,722	153,487	156,722	156,722	153,487	156,722	156,722	167,482	167,482	167,482
Automobiles		7,556	7,556	7,556	7,400	7,556	7,556	7,400	7,556	7,556	7,400	7,556	7,556	8,075	8,075	8,075
Light Trucks		123,061	123,061	123,061	120,521	123,061	123,061	120,521	123,061	123,061	120,521	123,061	123,061	131,510	131,510	131,510
Heavy Duty Trucks		26,104	26,104	26,104	25,565	26,104	26,104	25,565	26,104	26,104	25,565	26,104	26,104	27,896	27,896	27,896
Diesel Price Diff.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	0	156,722	156,722	156,722	153,487	156,722	156,722	153,487	156,722	156,722	153,487	156,722	156,722	167,482	167,482	167,482
COSTS																
Infrastructure																
Land																
Station setup	87,124	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compressor	57,240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Storage Vessels	266,254	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dispenser	25,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryer	10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	445,618	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle																
Conversion Kit	98,000	0	0	0	0	0	0	0	0	0	0	0	0	-28,000	0	0
Tanks	132,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor	86,000	0	0	0	0	86,000	0	0	0	86,000	0	0	0	0	0	0
OEM	0	0	0	0	0	0	0	0	0	0	0	0	0	126,000	0	0
Subtotal	316,500	0	0	0	0	86,000	0	0	0	86,000	0	0	0	98,000	0	0
Operating																
Station Maint.		11,634	11,634	11,634	11,410	11,634	11,634	11,410	11,634	11,634	11,410	11,634	11,634	9,611	9,611	9,611
Cylinder Recert.		0	0	0	15,950	0	0	15,950	0	0	15,950	0	0	0	0	0
Power		14,418	14,418	14,418	14,140	14,418	14,418	14,140	14,418	14,418	14,140	14,418	14,418	11,910	11,910	11,910
Labor - fueling time loss		17,106	17,106	17,106	17,106	17,106	17,106	17,106	17,106	17,106	17,106	17,106	17,106	10,691	10,691	10,691
NG Fuel Tax		17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520
Additional Training																
Subtotal	0	60,678	60,678	60,678	76,127	60,678	60,678	76,127	60,678	60,678	76,127	60,678	60,678	49,732	49,732	49,732
Total Costs	762,118	60,678	60,678	60,678	76,127	146,678	60,678	76,127	60,678	146,678	76,127	60,678	60,678	147,732	49,732	49,732
Savings - Cost	-762,118	96,044	96,044	96,044	77,360	10,044	96,044	77,360	96,044	10,044	77,360	96,044	96,044	19,750	117,750	117,750
NPV	-762,118	87,313	79,375	72,159	52,838	6,236	54,214	39,698	44,805	4,260	29,825	33,663	30,603	5,721	31,007	28,188
NPV-cumulative	-762,118	-674,806	-595,431	-523,272	-470,434	-464,198	-409,984	-370,286	-325,481	-321,221	-291,396	-257,733	-227,130	-221,410	-190,402	-162,214
Discount Factor	1.000	1.100	1.210	1.331	1.464	1.611	1.772	1.949	2.144	2.358	2.594	2.853	3.138	3.452	3.797	4.177
Benefit per vehicle per year	1.68															

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Automobiles:																
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number New Conversions	10															
Number Kits Transferred						10				10						
Number Conversions Retired						10				10				10		
Number OEM														10		
Number OEM Retired																
Number Vehicle Needing Recert.					10			10			10					
Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
CNG MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	1.15	1.15	1.15
CNG MPG	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	21.9	21.9	21.9
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Dual-Fuel Gasoline MPG	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual NG consump (scf)		1,529,783	1,529,783	1,529,783	1,500,364	1,529,783	1,529,783	1,500,364	1,529,783	1,529,783	1,500,364	1,529,783	1,529,783	1,263,734	1,263,734	1,263,734
Annual gasoline consump (gal)		0	0	0	240	0	0	240	0	0	240	0	0	0	0	0
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Conv. labor cost	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800
Tank cost	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Fuel Capacity/tank (scf)	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual NG Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120
On-board gasoline capacity	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Light Trucks:																
Number of Vehicles	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Number New Conversions	120															
Number Kits Transferred						120				120						
Number Conversions Retired						120				120				120		
Number OEM														120		
Number OEM Retired																
Number Vehicle Needing Recert.					120			120			120					
Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
CNG MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	1.15	1.15	1.15
CNG MPG	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	16.1	16.1	16.1
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Dual-Fuel Gasoline MPG	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual NG consump (scf)		24,913,607	24,913,607	24,913,607	24,434,499	24,913,607	24,913,607	24,434,499	24,913,607	24,913,607	24,434,499	24,913,607	24,913,607	20,580,805	20,580,805	20,580,805
Annual gasoline consump (gal)		0	0	0	3,904	0	0	3,904	0	0	3,904	0	0	0	0	0
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Conv. labor cost	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600
Tank cost	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Fuel Capacity/tank (scf)	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Number tanks/veh.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual NG Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120
On-board gasoline capacity	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Heavy Duty Gasoline:																
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number New Conversions	10															
Number Kits Transferred						10				10						
Number Conversions Retired						10				10				10		
Number OEM														10		
Number OEM Retired																
Number Vehicle Needing Recert.					10			10			10					
Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
CNG MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	1.15	1.15	1.15
CNG MPG	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	6.3	6.3	6.3
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Dual-Fuel Gasoline MPG	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual NG consump (scf)		5,284,704	5,284,704	5,284,704	5,183,075	5,284,704	5,284,704	5,183,075	5,284,704	5,284,704	5,183,075	5,284,704	5,284,704	4,365,625	4,365,625	4,365,625
Annual gasoline consump (gal)		0	0	0	828	0	0	828	0	0	828	0	0	0	0	0
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Conv. labor cost	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600
Tank cost	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
Fuel Capacity/tank (scf)	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
Number tanks/veh.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual NG Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192
On-board gasoline capacity	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Heavy Duty Diesel:																
Number of Ded. CNG Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Dual-Fuel Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number New Ded. Conversions							0									
Number Ded. Kits Transferred																
Number Ded Conversions Retired																
Number New Dual Conversions							0									
Number Dual Kits Transferred																
Number Dual Conversions Retired																
Number OEM (Ded.)																
Number OEM Retired (Ded.)																
Number Ded. Veh. Needing Recert.										0			0			0
Number Dual Veh. Needing Recert.										0			0			0
Diesel MPG	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Ded. CNG MPG Adjust. Factor	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Ded. CNG MPG	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Dual-Fuel MPG Adjust. Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Dual-Fuel MPG	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Annual miles traveled per vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Annual NG consump (scf)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual diesel consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ded. Conversion Kit Cost	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Ded. Conv. Kit Salvage Value	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500
Ded. Conv. labor cost	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350
Dual Conversion Kit Cost	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500
Dual Conv. Kit Salvage Value	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500
Dual Conv. labor cost	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Tank cost	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference (Ded.)	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800
OEM Salvage Value Difference	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500
Fuel Capacity/tank (scf)	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
Number Tanks/Ded. vehicle	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Number Tanks/Dual vehicle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
% NG of fuel consumed (dual-fuel)	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%
Maint. Cost Difference/year (Ded.)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maint. Cost Difference/year (Dual)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual NG Fuel Tax per vehicle	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48
On-board diesel capacity	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FUEL PRICES																
Natural Gas Price/mcf	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950
Gasoline Price/gallon	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890
Diesel Price/gallon	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850
NG price/gallon gasoline equivalent	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239
NG price/gallon diesel equivalent	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271
Annual Fuel Price Adjustment	0.0%															
Total NG consump (scf)	0	31,728,094	31,728,094	31,728,094	31,117,938	31,728,094	31,728,094	31,117,938	31,728,094	31,728,094	31,117,938	31,728,094	31,728,094	26,210,165	26,210,165	26,210,165
STATION DESIGN																
Useable Storage	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
Switch Time (min.)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
NG Session Time (min.)	284	284	284	284	284	284	284	284	284	284	284	284	284	234	234	234
Flow Rate/hose (scfm)	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Min. Comp. Size (scfm)	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Max Storage (scf)	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965
Design daily NG demand (scf)	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	122,031	100,808	100,808	100,808
Min. Comp. HP	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
Cycle Time (min)	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440
Number of Hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Autos per day	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	9.1	9.1	9.1
Light Trucks per day	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.3	73.7	73.7	73.7
Heavy Gasoline per day	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	6.3	6.3	6.3
Heavy Diesel per day (Ded.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy Diesel per day (Dual)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Auto NG per fill (scf)	537	537	537	537	537	537	537	537	537	537	537	537	537	537	537	537
Lt Truck NG per fill (scf)	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Heavy Gas. NG per fill (scf)	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683
Heavy Ded. Dies. NG per fill (scf)	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683
Heavy Dual Dies. NG per fill (scf)	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342
Station Setup Cost Factor	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
Compressor Salvage Value																
Storage Vessel Salvage Val.																
Dispenser Salvage Value																
Dryer Salvage Value																
Labor Time Loss Calculations:																
Gasoline fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Diesel fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Gasoline/diesel switch time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Labor Cost ($/hour)	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15
Number of Gasoline hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Number of Diesel hoses	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number of Autos/day	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25
Number of Lt Trucks/day	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36
Number of Heavy Gas/day	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84
Number of Heavy Diesel/day	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dedicated Gasoline Session Time	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152
Dedicated Diesel Session Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

OTHER FACTORS																
Work days/year	260															
Fast-fill onboard storage	92.5%															
3000 psi comp factor	259.67															
100 psi comp factor	7.92															
Fuel in an "empty" tank (gal)	2															
NG to Gasoline Factor	123															
NG to Diesel Factor	139															
Station Maint cost/gas. gal. equiv.	$0.045															
Electric cost ($/kWh)	$0.063															
No. days off for tank recert.	5															
Discount Rate	10.0%															

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	NPV
SAVINGS																	
Gasoline Price Diff.	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	0	1,500,403
Automobiles	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	8,075	0	72,343
Light Trucks	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	131,510	0	1,178,150
Heavy Duty Trucks	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	27,896	0	249,911
Diesel Price Diff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,482	167,462	167,482	0	1,500,403
COSTS																	
Infrastructure																	
Land																	0
Station setup	12,506	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-89,845
Compressor	41,439	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7,504	-65,829
Storage Vessels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-133,127	-258,625
Dispenser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2,500	-24,857
Dryer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1,000	-9,943
Subtotal	53,945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-144,131	-449,099
Vehicle																	
Conversion Kit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-89,889
Tanks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-132,500
Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-175,872
OEM	0	98,000	0	0	0	98,000	0	0	0	98,000	0	0	0	98,000	0	-28,000	-82,748
Subtotal	0	98,000	0	0	0	98,000	0	0	0	98,000	0	0	0	98,000	0	-28,000	-481,009
Operating																	
Station Maint.	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	9,611	0	-104,032
Cylinder Recert.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-25,228
Power	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	12,046	0	-129,171
Labor - fueling time loss	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	10,691	0	-144,493
NG Fuel Tax	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	0	-165,160
Additional Training																	
Subtotal	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	49,868	0	-568,084
Total Costs	103,812	147,868	49,868	49,868	49,868	147,868	49,868	49,868	49,868	147,868	49,868	49,868	49,868	147,868	49,868	-172,131	-1,498,191
Savings - Cost	63,669	19,614	117,614	117,614	117,614	19,614	117,614	117,614	117,614	19,614	117,614	117,614	117,614	19,614	117,614	172,131	2,212
NPV	13,856	3,881	21,154	19,231	17,483	2,650	14,448	13,135	11,941	1,810	9,868	8,971	8,156	1,236	6,740	9,865	
NPV-cumulative	-148,358	-144,477	-123,323	-104,093	-86,610	-83,960	-69,511	-56,376	-44,436	-42,625	-32,757	-23,785	-15,630	-14,393	-7,653	2,212	
Discount Factor	4.595	5.054	5.560	6.116	6.727	7.400	8.140	8.954	9.850	10.835	11.918	13.110	14.421	15.863	17.449	17.449	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
VEHICLE DATA																	
Automobiles:																	
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	
Number New Conversions																	
Number Kits Transferred																	
Number Conversions Retired																	
Number OEM		10				10				10				10			
Number OEM Retired		10				10				10				10		10	
Number Vehicle Needing Recert.																	
Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	
CNG MPG Adjust. Factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	
CNG MPG	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Dual-Fuel Gasoline MPG	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	
Annual NG consump (scf)	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	1,263,734	0	
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Conv. labor cost	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800	
Tank cost	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Fuel Capacity/tank (scf)	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual NG Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	
On-board gasoline capacity	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
VEHICLE DATA																	
Light Trucks:																	
Number of Vehicles	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	0	
Number New Conversions																	
Number Kits Transferred																	
Number Conversions Retired																	
Number OEM		120				120				120				120			
Number OEM Retired		120				120				120				120		120	
Number Vehicle Needing Recert.																	
Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
CNG MPG Adjust. Factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	
CNG MPG	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Dual-Fuel Gasoline MPG	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	
Annual NG consump (scf)	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	20,580,805	0	
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Conv. labor cost	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	
Tank cost	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Fuel Capacity/tank (scf)	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	
Number tanks/veh.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual NG Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	
On-board gasoline capacity	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
VEHICLE DATA																	
Heavy Duty Gasoline:																	
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	
Number New Conversions																	
Number Kits Transferred																	
Number Conversions Retired																	
Number OEM		10				10				10				10			
Number OEM Retired		10				10				10				10		10	
Number Vehicle Needing Recert.																	
Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	
CNG MPG Adjust. Factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	
CNG MPG	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	
Dual-fuel MPG Adjust. Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Dual-Fuel Gasoline MPG	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	
Annual NG consump (scf)	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	4,365,625	0	
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	
Conv. Kit Salvage Value	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Conv. labor cost	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	
Tank cost	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	$900	
OEM Salvage Value Difference	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Fuel Capacity/tank (scf)	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	
Number tanks/veh.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	
% NG miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual NG Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	
On-board gasoline capacity	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
VEHICLE DATA																	
Heavy Duty Diesel:																	
Number of Ded. CNG Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Number of Dual-Fuel Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Number New Ded. Conversions																	
Number Ded. Kits Transferred																	
Number Ded Conversions Retired																0	
Number New Dual Conversions																	
Number Dual Kits Transferred																	
Number Dual Conversions Retired																0	
Number OEM (Ded.)																	
Number OEM Retired (Ded.)																	
Number Ded. Veh. Needing Recert.			0			0			0			0			0		
Number Dual Veh. Needing Recert.			0			0			0			0			0		
Diesel MPG	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Ded. CNG MPG Adjust. Factor	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	
Ded. CNG MPG	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Dual-Fuel MPG Adjust. Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Dual-Fuel MPG	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Annual miles traveled per vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Annual NG consump (scf)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Annual diesel consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ded. Conversion Kit Cost	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	
Ded. Conv. Kit Salvage Value	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	
Ded. Conv. labor cost	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	
Dual Conversion Kit Cost	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	
Dual Conv. Kit Salvage Value	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	
Dual Conv. labor cost	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	
Tank cost	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference (Ded.)	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800	
OEM Salvage Value Difference	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	
Fuel Capacity/tank (scf)	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	
Number Tanks/Ded. vehicle	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Number Tanks/Dual vehicle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Tank Recert. Cost/tank	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	
% NG of fuel consumed (dual-fuel)	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	
Maint. Cost Difference/year (Ded.)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Maint. Cost Difference/year (Dual)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual NG Fuel Tax per vehicle	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	$48	
On-board diesel capacity	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
FUEL PRICES																	
Natural Gas Price/mcf	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	$1.950	
Gasoline Price/gallon	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	
Diesel Price/gallon	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	
NG price/gallon gasoline equivalent	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	$0.239	
NG price/gallon diesel equivalent	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	$0.271	
Total NG consump (scf)	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	26,210,165	0	
STATION DESIGN																	
Useable Storage	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	
Switch Time (min.)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
NG Session Time (min.)	234	234	234	234	234	234	234	234	234	234	234	234	234	234	234	0	
Flow Rate/hose (scfm)	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	
Min. Comp. Size (scfm)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	
Max Storage (scf)	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	244,965	
Design daily NG demand (scf)	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	100,808	0	
Min. Comp. HP	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	
Cycle Time (min)	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	
Number of Hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Autos per day	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	0.0	
Light Trucks per day	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	0.0	
Heavy Gasoline per day	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	0.0	
Heavy Diesel per day (Ded.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Heavy Diesel per day (Dual)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Auto NG per fill (scf)	537	537	537	537	537	537	537	537	537	537	537	537	537	537	537	537	
Lt Truck NG per fill (scf)	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	
Heavy Gas. NG per fill (scf)	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	
Heavy Ded. Dies. NG per fill (scf)	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	2,683	
Heavy Dual Dies. NG per fill (scf)	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	1,342	
Station Setup Cost Factor	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	
Compressor Salvage Value	$8,586															$7,504	
Storage Vessel Salvage Val.																$133,127	
Dispenser Salvage Value																$2,500	
Dryer Salvage Value																$1,000	
Labor Time Loss Calculations:																	
Gasoline fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	
Diesel fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	
Gasoline/diesel switch time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Labor Cost ($/hour)	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	
Number of Gasoline hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Number of Diesel hoses	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Number of Autos/day	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	0.00	
Number of Lt Trucks/day	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	0.00	
Number of Heavy Gas/day	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	0.00	
Number of Heavy Diesel/day	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Dedicated Gasoline Session Time	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	0	
Dedicated Diesel Session Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

APPENDIX B.

SPREADSHEET ANALYSIS FOR "FAVORABLE" PROPANE FLEET

Summary of sample analysis for "favorable" propane fleet
Complete analysis on next 14 pages

SAVINGS	30 year NPV	% of Savings	Incremental Savings/Mile
Gasoline Price Diff.	$534,613	100.0%	$0.0180
Automobiles	$25,777	4.8%	$0.0122
Light Trucks	$419,790	78.5%	$0.0165
Heavy Duty Trucks	$89,046	16.7%	$0.0420
Diesel Price Diff.	$0	0.0%	$0.0000
Maintenance	$0	0.0%	$0.0000
Total Savings	$534,613	100.0%	$0.0180
COSTS		**% of Costs**	**Incremental Cost/Mile**
Infrastructure			
Land	$0	0.0%	$0.0000
Station setup	($8,746)	1.7%	($0.0003)
Storage/Dispenser	($56,672)	11.0%	($0.0019)
Subtotal	($65,418)	12.7%	($0.0022)
Vehicle			
Conversion Kit	($75,017)	14.5%	($0.0025)
Tanks	($39,800)	7.7%	($0.0013)
Labor	($102,046)	19.8%	($0.0034)
OEM	($36,317)	7.0%	($0.0012)
Subtotal	($253,180)	49.0%	($0.0085)
Operating			
Station Maint.	($14,140)	2.7%	($0.0005)
Labor - fuel time loss	($18,767)	3.6%	($0.0006)
Propane Fuel Tax	($165,160)	32.0%	($0.0056)
Additional training	$0	0.0%	$0.0000
Subtotal	($198,067)	38.3%	($0.0067)
Total Costs	($516,666)	100.0%	($0.0174)
Savings - Cost	$17,948	N/A	$0.0006

VEHICLE DATA	# Vehicles in Year 30	MPG	Annual Miles per vehicle	LPG Conversion Cost per vehicle	OEM Cost Differential per vehicle
Automobiles	10	19.0	22,500	$1,600	$400
Light Trucks	120	14.0	22,500	$1,190	$400
Heavy Duty Gasoline	10	5.5	22,500	$1,200	$450
Heavy Duty Diesel	0	9.0	30,000	-	-
Dedicated	-	-	-	$3,325	$1,400
Dual-fuel	-	-	-	$3,535	N/A
Total	140				

DISCOUNT RATE	10.0%

FUEL PRICES	
Large Volume	
Propane Price/gallon	$0.50
Gasoline Price/gallon	$0.89
Diesel Price/gallon	$0.85

OTHER FACTORS	
Labor Cost ($/hr)	$15.00

STATION DESIGN	
Storage tank water volume (gal)	14,400
Number of dispenser hoses	2

MAJOR ASSUMPTIONS

1. OEM vehicles are available at the beginning of year 11.
2. Diesel conversions are assumed available at the beginning of year 6.
3. Vehicles are sold off at the end of the year when they reach the following mileage totals:

Automobiles	90,000
Light Trucks	90,000
Heavy Duty Gasoline	90,000
Heavy Duty Diesel	150,000

Benefit/vehicle/year	$13.60
Incremental Benefit/mile	$0.0006

SMALL VOLUME PROPANE PURCHASE

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SAVINGS																
Gasoline Price Diff.		-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	16,294	16,294	16,294
Automobiles		-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	786	786	786
Light Trucks		-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	-3,090	12,794	12,794	12,794
Heavy Duty Trucks		-656	-656	-656	-656	-656	-656	-656	-656	-656	-656	-656	-656	2,714	2,714	2,714
Diesel Price Diff.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	0	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	-3,936	16,294	16,294	16,294
COSTS																
Infrastructure																
Land																
Station setup	1,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Storage/Dispenser	10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	11,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle																
Conversion Kit	81,100	0	0	0	0	0	0	0	0	0	0	0	0	-21,000	0	0
Tanks	39,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor	49,900	0	0	0	0	49,900	0	0	0	49,900	0	0	0	0	0	0
OEM	0	0	0	0	0	0	0	0	0	0	0	0	0	56,500	0	0
Subtotal	170,800	0	0	0	0	49,900	0	0	0	49,900	0	0	0	35,500	0	0
Operating																
Station Maint.		500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Labor - fueling time loss		2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	523	523	523
Propane Fuel Tax		17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520
Additional Training																
Subtotal	0	20,574	20,574	20,574	20,574	20,574	20,574	20,574	20,574	20,574	20,574	20,574	20,574	18,543	18,543	18,543
Total Costs	182,300	20,574	20,574	20,574	20,574	70,474	20,574	20,574	20,574	70,474	20,574	20,574	20,574	54,043	18,543	18,543
Savings - Cost	-182,300	-24,509	-24,509	-24,509	-24,509	-74,409	-24,509	-24,509	-24,509	-74,409	-24,509	-24,509	-24,509	-37,749	-2,249	-2,249
NPV	-182,300	-22,281	-20,256	-18,414	-16,740	-46,202	-13,835	-12,577	-11,434	-31,557	-9,449	-8,590	-7,809	-10,935	-592	-538
NPV-cumulative	-182,300	-204,581	-224,837	-243,251	-259,991	-306,194	-320,028	-332,606	-344,039	-375,596	-385,046	-393,636	-401,445	-412,380	-412,972	-413,511
Discount Factor	1.000	1.100	1.210	1.331	1.464	1.611	1.772	1.949	2.144	2.358	2.594	2.853	3.138	3.452	3.797	4.177
Cost per vehicle per year	-331.89															

LARGE VOLUME PROPANE PURCHASE

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SAVINGS																
Gasoline Price Diff.		52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	67,623	67,623	67,623
Automobiles		2,533	2,533	2,533	2,533	2,533	2,533	2,533	2,533	2,533	2,533	2,533	2,533	3,260	3,260	3,260
Light Trucks		41,245	41,245	41,245	41,245	41,245	41,245	41,245	41,245	41,245	41,245	41,245	41,245	53,099	53,099	53,099
Heavy Duty Trucks		8,749	8,749	8,749	8,749	8,749	8,749	8,749	8,749	8,749	8,749	8,749	8,749	11,263	11,263	11,263
Diesel Price Diff.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	0	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	52,526	67,623	67,623	67,623
COSTS																
Infrastructure																
Land																
Station setup	8,550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Storage/Dispenser	57,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	65,550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle																
Conversion Kit	81,100	0	0	0	0	0	0	0	0	0	0	0	0	-21,000	0	0
Tanks	39,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor	49,900	0	0	0	0	49,900	0	0	0	49,900	0	0	0	0	0	0
OEM	0	0	0	0	0	0	0	0	0	0	0	0	0	56,500	0	0
Subtotal	170,800	0	0	0	0	49,900	0	0	0	49,900	0	0	0	35,500	0	0
Operating																
Station Maint.		1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Labor - fueling time loss		2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	2,554	523	523	523
Propane Fuel Tax		17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520
Additional Training																
Subtotal	0	21,574	21,574	21,574	21,574	21,574	21,574	21,574	21,574	21,574	21,574	21,574	21,574	19,543	19,543	19,543
Total Costs	236,350	21,574	21,574	21,574	21,574	71,474	21,574	21,574	21,574	71,474	21,574	21,574	21,574	55,043	19,543	19,543
Savings - Cost	-236,350	30,953	30,953	30,953	30,953	-18,947	30,953	30,953	30,953	-18,947	30,953	30,953	30,953	12,580	48,080	48,080
NPV	-236,350	28,139	25,581	23,255	21,141	-11,765	17,472	15,884	14,440	-8,035	11,934	10,849	9,863	3,644	12,661	11,510
NPV-cumulative	-236,350	-208,211	-182,630	-159,375	-138,234	-149,999	-132,526	-116,643	-102,203	-110,239	-98,305	-87,456	-77,594	-73,950	-61,289	-49,779
Discount Factor	1.000	1.100	1.210	1.331	1.464	1.611	1.772	1.949	2.144	2.358	2.594	2.853	3.138	3.452	3.797	4.177
Benefit per vehicle per year	13.60															

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Automobiles:																
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number New Conversions	10															
Number Kits Transferred						10				10						
Number Conversions Retired						10				10				10		
Number OEM														10		
Number OEM Retired																
Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Propane MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1.1	1.1	1.1
Propane MPG (gasoline equivalent)	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	20.9	20.9	20.9
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual Propane consump (gal)		16,014	16,014	16,014	16,014	16,014	16,014	16,014	16,014	16,014	16,014	16,014	16,014	14,558	14,558	14,558
Annual gasoline consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
Conv. labor cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570
Tank cost	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100
Propane tank water volume (gal)	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120
On-board gasoline capacity	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Light Trucks:																
Number of Vehicles	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Number New Conversions	120															
Number Kits Transferred						120				120						
Number Conversions Retired						120				120				120		
Number OEM														120		
Number OEM Retired																
Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Propane MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1.1	1.1	1.1
Propane MPG (gasoline equivalent)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.4	15.4	15.4
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual Propane consump (gal)		260,796	260,796	260,796	260,796	260,796	260,796	260,796	260,796	260,796	260,796	260,796	260,796	237,087	237,087	237,087
Annual gasoline consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion Kit Cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
Conv. labor cost	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340
Tank cost	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100
Propane tank water volume (gal)	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120
On-board gasoline capacity	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Heavy Duty Gasoline:																
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number New Conversions	10															
Number Kits Transferred						10				10						
Number Conversions Retired						10				10				10		
Number OEM														10		
Number OEM Retired																
Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Propane MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1.1	1.1	1.1
Propane MPG (gasoline equivalent)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	6.1	6.1	6.1
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual Propane consump (gal)		55,320	55,320	55,320	55,320	55,320	55,320	55,320	55,320	55,320	55,320	55,320	55,320	50,291	50,291	50,291
Annual gasoline consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion Kit Cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
Conv. labor cost	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340
Tank cost	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100
Propane tank water volume (gal)	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192
On-board gasoline capacity	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VEHICLE DATA																
Heavy Duty Diesel:																
Number of Ded. Propane Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Dual-Fuel Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number New Ded. Conversions							0									
Number Ded. Kits Transferred																
Number Ded Conversions Retired												0				
Number New Dual Conversions							0									
Number Dual Kits Transferred																
Number Dual Conversions Retire												0				
Number OEM (Ded.)												0				
Number OEM Retired (Ded.)																
Diesel MPG	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Ded. Propane MPG Adjust. Factor	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.8	0.8	0.8	0.8	0.8
Ded. Propane MPG (diesel equiv.)	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	7.2	7.2	7.2	7.2	7.2
Dual-Fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel MPG	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Annual miles traveled per vehicle	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Annual Propane consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual diesel consump (gal)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ded. Conversion Kit Cost	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630
Ded. Conv. Kit Salvage Value	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Ded. Conv. labor cost	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330
Dual Conversion Kit Cost	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040
Dual Conv. Kit Salvage Value	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Dual Conv. labor cost	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130
Tank cost	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference (Ded.)	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400
OEM Salvage Value Difference	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Propane tank water volume (gal)	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
Number Tanks/Ded. vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number Tanks/Dual vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane of fuel consumed (dual-fuel	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Maint. Cost Difference/year (Ded.)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maint. Cost Difference/year (Dual)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192
On-board diesel capacity	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45

Period	Begin 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FUEL PRICES																
Propane Price to small fleet/gallon	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670
Propane Price to large fleet/gallon	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500
Propane cost at refinery/gallon	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430
Transportation cost/gallon	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030
Supplier markup for small fleet/gal	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210
Supplier markup for large fleet/gal	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040
Federal tax/gallon	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Gasoline Price/gallon	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890
Diesel Price/gallon	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850
Annual Fuel Price Adjustment	0.0%															
Total Propane consump (gal)	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	332,130	301,936	301,936	301,936
STATION DESIGN																
Switch Time (min.)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Propane Session Time (min.)	172	172	172	172	172	172	172	172	172	172	172	172	172	156	156	156
Propane fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Storage water volume (gal)	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400
Supply of propane on-site (weeks)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0
Number of Hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Autos per day	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	2.86	2.86	2.86
Light Trucks per day	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	43.99	39.99	39.99	39.99
Heavy Gasoline per day	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	5.97	5.97	5.97
Heavy Diesel per day (Ded.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heavy Diesel per day (Dual)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Auto Propane per fill (gal)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Lt Truck Propane per fill (gal)	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
Heavy Gas. Propane per fill (gal)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Heavy Ded. Dies. Propane per fill (gal)	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
Heavy Dual Dies. Propane per fill (gal)	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
Station Setup Cost Factor	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Labor Time Loss Calculations:																
Gasoline fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Diesel fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Gasoline/diesel switch time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Labor Cost ($/hour)	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15
Number of Gasoline hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Number of Diesel hoses	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number of Autos/day	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25
Number of Lt Trucks/day	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36
Number of Heavy Gas/day	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84
Number of Heavy Diesel/day	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dedicated Gasoline Session Time	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152
Dedicated Diesel Session Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

OTHER FACTORS	
Work days/year	260
Tank fill percentage	80%
Fuel in an "empty" tank (gal)	2
Gasoline to Propane Factor	1.35
Diesel to Propane Factor	1.53
Discount Rate	10.0%

SMALL VOLUME PROPANE PURCHASE

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	NPV
SAVINGS																	
Gasoline Price Diff.	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	0	15,764
Automobiles	786	786	786	786	786	786	786	786	786	786	786	786	786	786	786	0	760
Light Trucks	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	12,794	0	12,378
Heavy Duty Trucks	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	2,714	0	2,626
Diesel Price Diff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	16,294	0	15,764
COSTS																	
Infrastructure																	
Land																	0
Station setup	450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1,598
Storage/Dispenser	3,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5,000	-10,366
Subtotal	3,450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5,000	-11,964
Vehicle																	
Conversion Kit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-75,017
Tanks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-39,800
Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-102,046
OEM	0	42,500	0	0	0	42,500	0	0	0	42,500	0	0	0	42,500	0	-14,000	-36,317
Subtotal	0	42,500	0	0	0	42,500	0	0	0	42,500	0	0	0	42,500	0	-14,000	-253,180
Operating																	
Station Maint.	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	0	-4,713
Labor - fueling time loss	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	0	-18,767
Propane Fuel Tax	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	0	-165,160
Additional Training																	
Subtotal	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	18,543	0	-188,640
Total Costs	21,993	61,043	18,543	18,543	18,543	61,043	18,543	18,543	18,543	61,043	18,543	18,543	18,543	61,043	18,543	-19,000	-453,785
Savings - Cost	-5,699	-44,749	-2,249	-2,249	-2,249	-44,749	-2,249	-2,249	-2,249	-44,749	-2,249	-2,249	-2,249	-44,749	-2,249	19,000	-438,021
NPV	-1,240	-8,853	-405	-368	-334	-6,047	-276	-251	-228	-4,130	-189	-172	-156	-2,821	-129	1,089	
NPV-cumulative	-414,751	-423,604	-424,009	-424,377	-424,711	-430,758	-431,034	-431,285	-431,514	-435,644	-435,833	-436,004	-436,160	-438,981	-439,110	-438,021	
Discount Factor	4.595	5.054	5.560	6.116	6.727	7.400	8.140	8.954	9.850	10.835	11.918	13.110	14.421	15.863	17.449	17.449	

LARGE VOLUME PROPANE PURCHASE																	
Period	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**End 30**	**NPV**
SAVINGS																	
Gasoline Price Diff.	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	0	534,613
Automobiles	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	3,260	0	25,777
Light Trucks	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	53,099	0	419,790
Heavy Duty Trucks	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	11,263	0	89,046
Diesel Price Diff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Savings	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	67,623	0	534,613
COSTS																	
Infrastructure																	
Land																	0
Station setup	900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8,746
Storage/Dispenser	6,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-28,500	-56,672
Subtotal	6,900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-28,500	-65,418
Vehicle																	
Conversion Kit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-75,017
Tanks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-39,800
Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-102,046
OEM	0	42,500	0	0	0	42,500	0	0	0	42,500	0	0	0	42,500	0	-14,000	-36,317
Subtotal	0	42,500	0	0	0	42,500	0	0	0	42,500	0	0	0	42,500	0	-14,000	-253,180
Operating																	
Station Maint.	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	0	-14,140
Labor - fueling time loss	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	0	-18,767
Propane Fuel Tax	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	0	-165,160
Additional Training																	
Subtotal	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	19,543	0	-198,067
Total Costs	26,443	62,043	19,543	19,543	19,543	62,043	19,543	19,543	19,543	62,043	19,543	19,543	19,543	62,043	19,543	-42,500	-516,666
Savings - Cost	41,180	5,580	48,080	48,080	48,080	5,580	48,080	48,080	48,080	5,580	48,080	48,080	48,080	5,580	48,080	42,500	17,948
NPV	8,962	1,104	8,648	7,861	7,147	754	5,906	5,369	4,881	515	4,034	3,667	3,334	352	2,755	2,436	
NPV-cumulative	-40,817	-39,713	-31,065	-23,204	-16,057	-15,303	-9,397	-4,027	854	1,369	5,403	9,071	12,405	12,757	15,512	17,948	
Discount Factor	4.595	5.054	5.560	6.116	6.727	7.400	8.140	8.954	9.850	10.835	11.918	13.110	14.421	15.863	17.449	17.449	

Period	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**End 30**
VEHICLE DATA																
Automobiles:																
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0
Number New Conversions																
Number Kits Transferred																
Number Conversions Retired																
Number OEM		10				10				10				10		
Number OEM Retired		10				10				10				10		10
Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Propane MPG Adjust. Factor	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Propane MPG (gasoline equivalent)	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel Gasoline MPG	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
Annual Propane consump (gal)	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	14,558	0
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion Kit Cost	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
Conv. labor cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570
Tank cost	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330	$330
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100
Propane tank water volume (gal)	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120
On-board gasoline capacity	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

Period	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**End 30**	
VEHICLE DATA																	
Light Trucks:																	
Number of Vehicles	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	0	
Number New Conversions																	
Number Kits Transferred																	
Number Conversions Retired																	
Number OEM		120				120				120				120			
Number OEM Retired		120				120				120				120		120	
Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
Propane MPG Adjust. Factor	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
Propane MPG (gasoline equivalent)	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Dual-Fuel Gasoline MPG	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	
Annual Propane consump (gal)	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	237,087	0	
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conversion Kit Cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	
Conv. labor cost	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	
Tank cost	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	$280	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	
Propane tank water volume (gal)	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual Propane Fuel Tax per vehicle	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	$120	
On-board gasoline capacity	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30	
VEHICLE DATA																	
Heavy Duty Gasoline:																	
Number of Vehicles	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	
Number New Conversions																	
Number Kits Transferred																	
Number Conversions Retired																	
Number OEM		10				10				10				10			
Number OEM Retired		10				10				10				10		10	
Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	
Propane MPG Adjust. Factor	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
Propane MPG (gasoline equivalent)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	
Dual-fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Dual-Fuel Gasoline MPG	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	
Annual miles traveled per vehicle	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	
Annual Propane consump (gal)	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	50,291	0	
Annual gasoline consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conversion Kit Cost	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	$570	
Conv. Kit Salvage Value	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	
Conv. labor cost	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	$340	
Tank cost	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	$290	
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
OEM Cost Difference	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	$450	
OEM Salvage Value Difference	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100	
Propane tank water volume (gal)	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	
Number tanks/veh.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
% Propane miles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Maint. Cost Difference/year	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
Annual Propane Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	
On-board gasoline capacity	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30
VEHICLE DATA																
Heavy Duty Diesel:																
Number of Ded. Propane Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Dual-Fuel Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number New Ded. Conversions																
Number Ded. Kits Transferred																
Number Ded Conversions Retired																
Number New Dual Conversions																
Number Dual Kits Transferred																
Number Dual Conversions Retire																
Number OEM (Ded.)	0					0					0					
Number OEM Retired (Ded.)	0					0					0					0
Diesel MPG	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Ded. Propane MPG Adjust. Factor	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Ded. Propane MPG (diesel equiv.)	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Dual-Fuel MPG Adjust. Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dual-Fuel MPG	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Annual miles traveled per vehicle	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Annual Propane consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual diesel consump (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ded. Conversion Kit Cost	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630	$1,630
Ded. Conv. Kit Salvage Value	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Ded. Conv. labor cost	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330	$1,330
Dual Conversion Kit Cost	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040	$2,040
Dual Conv. Kit Salvage Value	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Dual Conv. labor cost	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130	$1,130
Tank cost	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365	$365
Tank Salvage Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
OEM Cost Difference (Ded.)	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400
OEM Salvage Value Difference	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Propane tank water volume (gal)	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
Number Tanks/Ded. vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number Tanks/Dual vehicle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% Propane of fuel consumed (dual-fuel	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Maint. Cost Difference/year (Ded.)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maint. Cost Difference/year (Dual)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Propane Fuel Tax per vehicle	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192	$192
On-board diesel capacity	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45

Period	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	End 30
FUEL PRICES																
Propane Price to small fleet/gallon	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670	$0.670
Propane Price to large fleet/gallon	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500	$0.500
Propane cost at refinery/gallon	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430	$0.430
Transportation cost/gallon	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030	$0.030
Supplier markup for small fleet/gal	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210	$0.210
Supplier markup for large fleet/gal	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040	$0.040
Federal tax/gallon	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Gasoline Price/gallon	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890	$0.890
Diesel Price/gallon	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850	$0.850
Total Propane consump (gal)	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936	301,936
STATION DESIGN																
Switch Time (min.)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Propane Session Time (min.)	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156	0
Propane fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Storage water volume (gal)	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400
Supply of propane on-site (weeks)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Number of Hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Autos per day	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	0.00
Light Trucks per day	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	0.00
Heavy Gasoline per day	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	0.00
Heavy Diesel per day (Ded.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heavy Diesel per day (Dual)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Auto Propane per fill (gal)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Lt Truck Propane per fill (gal)	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
Heavy Gas. Propane per fill (gal)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Heavy Ded. Dies. Propane per fill (gal)	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
Heavy Dual Dies. Propane per fill (gal)	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
Station Setup Cost Factor	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Labor Time Loss Calculations:																
Gasoline fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Diesel fill rate (gal/min)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Gasoline/diesel switch time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Labor Cost ($/hour)	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15
Number of Gasoline hoses	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Number of Diesel hoses	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number of Autos/day	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	0.00
Number of Lt Trucks/day	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	46.36	0.00
Number of Heavy Gas/day	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	0.00
Number of Heavy Diesel/day	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dedicated Gasoline Session Time	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	0
Dedicated Diesel Session Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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