WHAT ARE THE PROSPECT FOR NATURAL GAS VEHICLES IN THE PITTSBURGH REGION?

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Policy Analysis Project Report

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Please do not cite or quote this report, or any portion thereof, as an official Carnegie Mellon University report or document. As a student project, it has not been subjected to the required level of critical review. This report presents the results of a one-semester university project involving 22 undergraduate students from the Department of Engineering and Public Policy and the Department of Social and Decision Sciences at Carnegie Mellon University. In completing this project, students contributed skills from their individual disciplines and gained experience in solving problems that require interdisciplinary cooperation. The project was managed by graduate students and monitored by faculty advisors. An advisory panel of academic and industry experts provided suggestions, information, and expertise.

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EXECUTIVE SUMMARY

Through developments in natural gas extraction in areas like Marcellus Shale, Pittsburgh has turned to natural gas as a potential, and profitable, solution to energy demands in the area. As the development of natural gas production becomes more prevalent for the Pittsburgh region, the application of using this local energy source to power vehicles as a replacement to gasoline and petroleum has become a topic of interest. Besides being local, natural gas has some clear advantages that warrant the development and evaluation of new applications, including those in the transportation realm. However, limited infrastructure, traditional industry conventions, and little technology understanding present a set of obstacles that must be overcome in order for natural gas vehicles to become accepted in Pittsburgh. The purpose of this report is to identify these opportunities and challenges, and identify effective policies that may support the adoption of natural gas vehicles in the Pittsburgh Metropolitan Statistical Area.

Vehicle Recommendations

Within the scope of this report, the economics, environmental impact, energy security, social welfare, and technology development will be considered in determining the answer to several overarching questions regarding natural gas. Specifically, what types of vehicles make the most sense in the Pittsburgh area? To answer this question, this report will examine boats, buses, cars, trains, and trucks as potentially viable options for natural gas conversion. Through industry surveys, quantitative analysis, and comprehensive background research, the viability of each transportation mode was assessed.

Based on the results of our research and analysis, policy options were created and evaluated against a set of criteria to identify the optimal recommendation for policy makers regarding natural gas vehicles in Pittsburgh. To create these recommendations, a balance of different goals was considered to adequately satisfy individual firms and consumers as well as government and industry.

The overall conclusion of the vehicle analysis of this report is that converting on-the-road vehicles to natural gas is overly emphasized relative to water vehicles. Most existing and past policies have been designed to promote car, truck, and bus conversion. However, this analysis concludes that boats may provide more benefit in areas like energy security, environmental impact, and economic welfare than the vehicle types historically considered. In fact, Pittsburgh currently ranks as the second largest inland port in the United States, and the potential for boat travel in the three rivers, the Ohio, Monongahela, and Allegheny, presents an opportunity to encourage conversion of natural gas boats. Therefore, policymakers considering new methods should expand their vehicle options to include boats as a viable avenue to promote natural gas consumption.

An important note regarding the vehicle analysis is that the quantitative analysis concluded that there is a large dependence on the fuel price differential on the economics of each vehicle. To account for this dependence, sensitivity analysis was conducted on each vehicle type, and upper and lower bounds were found for the payback period of each vehicle. For the purposes of the conclusions of this report, the best guess scenarios were compared against each other.

Policy Recommendations

This report also considers different policy options that may assist in the development of natural gas vehicles in the Pittsburgh area. This report considers several policy paths, which are organized into three main categories: status quo (no change), vehicle economic incentives, and infrastructure service provisions. These groupings are designed to represent the overall types of expected policies. Within these categories, policies were developed and analyzed for individual vehicles as well in over-arching themes including public education, maintenance and training, regulation, research and development, and general economic incentives.

These policy options were evaluated against four criteria, overall effectiveness, economic efficiency, responsiveness, and equity. Each policy option was given a score in each category, and the policy option that performed the best was further analyzed and recommended to policymakers.

This analysis has found that most of the policies currently in place are adequate for the current goals being met. In terms of each policy option, the analysis concluded that status quo – that is, a continuation of existing policies and measures – is the best course of action, with the exception of boats, where an infrastructure service provision would produce advantageous effects. However, in order to speed up the adoption process, some additional policy foci should be considered. The major obstacle for natural gas vehicles is currently the chicken and egg problem caused by under-developed infrastructure that limits the growth of the demand for natural gas vehicles. Carefully crafted policy addressing this infrastructure issue, especially with respect to public-access and off-road fueling stations may accelerate and amplify the benefits associated with natural gas conversion.

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1.0 INTRODUCTION

1.1 Project Course Overview

This is the final report from an Engineering and Public Policy / School of Decision Science Project Course designed to evaluate the prospects for natural gas vehicles in the Pittsburgh Region. A group of 20 undergraduate EPP and SDS students, led by 4 project managers and 2 professors, assessed the most sensible vehicle conversion for the Pittsburgh metropolitan region.

Natural gas is an odorless, nontoxic gaseous mixture of hydrocarbons that currently accounts for 25% of the energy used in the United States. One third of the natural gas used in the US goes towards residential and commercial uses; however, only 0.1% of natural gas is used for transportation fuel (U.S. DOE, 2013), with transportation accounting for 28% of fuel used in 2011 (U.S. EIA, 2012). In transportation, natural gas can either come in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) (U.S. DOE, 2013).

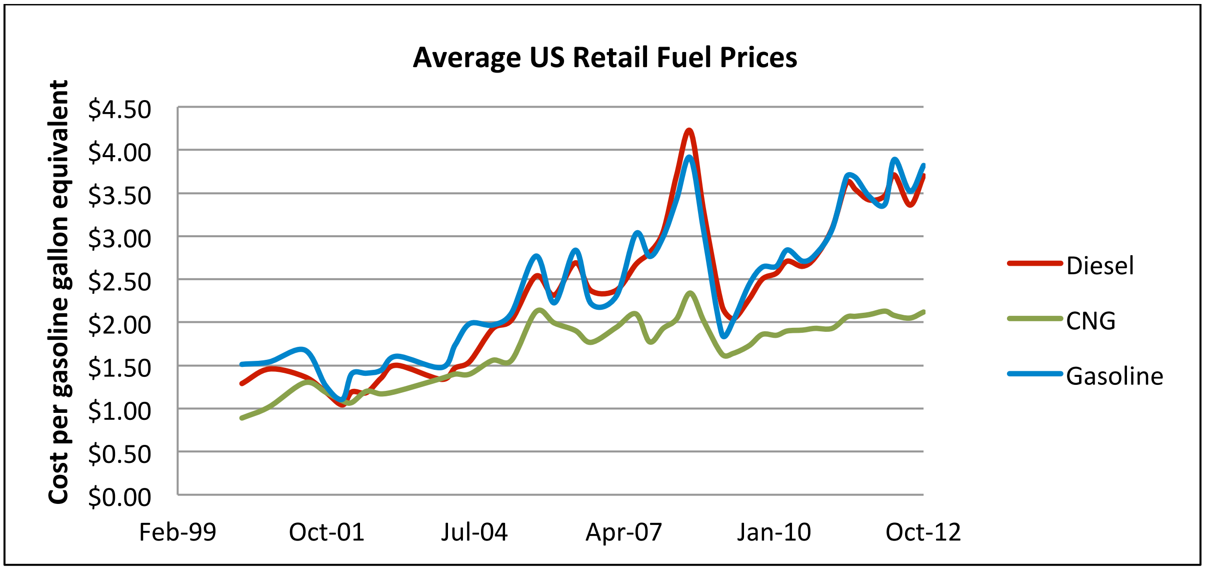

Figure 1: The average US retail fuel prices for diesel, gasoline, and compressed natural gas (U.S. DOE, 2013)

According to America's Natural Gas Alliance, natural gas burns cleaner than other fuel sources, and emits 25% CO_2 than gasoline or diesel vehicles. Figure 1, above, shows that CNG has been consistently less expensive than diesel or gasoline (U.S. DOE, 2013). Approximately 98% of the natural gas used in the US comes from domestic locations (ANGA), whereas 49% of the petroleum used in the US is imported (U.S. DOE, 2013). In Pennsylvania, the Marcellus Shale provides an abundance of locally produce natural gas. At first glance, natural gas powered vehicles have the potential to decrease emissions, reduce the cost of transportation, and increase US energy security. Thus, natural gas vehicles seem to be a good candidate for implementation. The goal of this research is to apply data-driven methods to the evaluation of the prospect of natural gas vehicles in the Pittsburgh metro region.

1.2 Questions Addressed

Prospects for Natural Gas Vehicles

We analyze the prospects for natural gas vehicles strictly in the Pittsburgh Metropolitan Statistical Area. The Pittsburgh Metropolitan Statistical Region (Pittsburgh MSA), as defined by the Federal Office of Management and Budget, consists of Allegheny County, Armstrong County, Beaver County, Butler County, Fayette County, Washington County, and Westmoreland County. Overall, the goal of our research was ultimately to see which types of vehicle conversions make the most sense in this region.

Vehicle Types

Five different vehicle types were examined: boats, buses, cars, trains, and trucks. These vehicle types were selected as a representative cross-section of major transport vehicles used in the region. Subsequent sections present further details on the specific vehicle fleets that were examined for each vehicle type.

Government, Industry, and Foundations

Depending on the stakeholder, the objectives and needs will differ. For the government, industry, and foundations, the primary goal is to replace fossil fuel used with natural gas use. Replacing fossil fuels with natural gas will decrease fossil fuel consumption, and is believed to reduce environmental pollution, spur economic development, and contribute to energy security. Ultimately, the government and others in industry would like to know which natural gas vehicle sectors are the priority in terms of environmental, economic, and energy security needs.

Individual Firms, Businesses, and Consumers

For private firms, reducing cost is the ultimate goal. There are potential economic benefits for natural gas vehicles owners as a result of the price differential between natural gas and fossil fuels. However, private firms are also concerned with the cost and availability of fueling infrastructure and maintenance infrastructure for serve natural gas vehicles. Other obstacles for private firms and consumers include safety concerns and uncertainty in the future of natural gas prices.

2.0 Methodology

2.1 Information Gathering Methodology

Literature Review

Before conducting our own research and analysis, it was important to determine the pre-existing information available in the field. The main goal was to ascertain information regarding technologies associated with natural gas a fuel source, existing policies regarding natural gas, emissions associated with burning natural gas, current infrastructure supporting natural gas, and finally the economics associated with natural gas. Each vehicle group gathered information regarding natural gas vehicles in their respective fields. The groups looked primarily to academic journals and other peer reviewed sources for information. However, as natural gas is a relatively new alternative fuel for many vehicle groups, there was not a host of information available through the Internet. The groups instead, turned to many sources of grey literature that had not been peer reviewed and studies done by advocacy groups. While the data gathered by the groups were, at face, reasonable, it is important to note that much of the information came from these non-reviewed sources.

Survey

Although data is widely available through the Internet and through other means, we found greater utility in firsthand information we gathered by our own means. Conducted on our own accord, we limited the scope of examination to exclusively the Pittsburgh region and gathered information particular to our investigation. Furthermore, local features and concerns were better addressed through an internal inquiry. Information accessible to the public must be utilized in tandem with data gathered specifically for our analysis to conduct a comprehensive study on natural gas as an alternative fuel source.

Our attempt in gathering information relevant to our analysis was centered about interview style surveys conducted with industry leaders. This form of inquiry was tailored to target those individuals whose policy considerations and decisions are critical to the conversion of commercial vehicles to natural gas. We defined this group as leaders of commercial industries who may consider converting their fleets to run on alternative fuel sources. The chief objective of the interview was to identify the criteria necessary for these industry leaders to make the switch.

The questions were differentiated into three distinct question archetypes: economics, acceptability, and extraneous factors. The first section targeted information necessary for us to analyze the economic implications of natural gas conversion. The second archetype, acceptability, addressed concerns industry leaders may hold outside of fuel and conversion costs. The final section of the survey covered questions that do not fit neatly to the aforementioned subdivisions. The questions were crafted to fit the needs of our analysis, taking into account what information would likely be readily available to the subjects reached. The interview was ultimately conducted by the student researcher via telephone. This was done to ensure comprehensiveness and professionalism. The script is included in the Appendix.

2.2 Quantitative Analysis Methodology

In order to present policy recommendations about Natural Gas Vehicles in the Pittsburgh region, several types of analyses were conducted with the quantitative information collected through research and surveys. The vehicle-specific data necessary for the various calculations included the costs associated with updating and maintaining a Natural Gas engine, fuel savings, vehicle lifetime, and reduction of pollutants. The results of each vehicle's analysis were first completed separately and then compared in order to reach a conclusion.

The quantitative analysis has been broken down into categories involving pollutant emissions, energy independence, economic supply curve, and payback period analysis. The overall purpose of the analysis is to determine the feasibility of certain types of NGVs in the Greater Pittsburgh Region. Pollutant emissions and energy independence deal with the acceptability of the public to the technology in question, while the economic supply curve and payback period analysis concern vehicle and fleet owners. These two groups are targeted separately in order to investigate all of the effects that a change in vehicle engine type would have on society. As the goal of the project is to assess the viability of policies that would have a positive impact on the community, these factors must be taken into account before any specific policy recommendations involving natural gas vehicles are made.

Payback Period Methodology

The first quantitative analysis performed on the vehicles was the payback period analysis. We determine the payback period for a specific natural gas vehicle in order to find out whether or not the private and public benefits of the investment will outweigh the costs within a desired period of time. The data required to perform this analysis include the capital costs associated with converting a vehicle to a natural gas engine, annual operation and maintenance costs, annual vehicle miles traveled, fuel economy in miles per gallon, typical lifetime of the vehicle, savings from particulate matter ($PM_{2.5}$) reduction, and an estimated discount rate. Independent of vehicle type, the difference in fuel price between natural gas and gasoline or diesel is also considered in the analysis. The net present value (NPV) analysis is performed for a duration at least as long as the vehicles expected lifetime.

The NPV analysis was done using an Excel spreadsheet. The total annual expenses are recorded to update the operation costs, as shown in the equations below.

$$\text{Annual Expenses (year 0)} = \text{ Engine Upgrade}$$

$$\text{Annual Expenses (year } 1 - n) = \text{ Operations Costs}$$

The fuel savings and savings from PM reduction are then calculated and recorded. The fuel savings is determined by dividing the annual vehicle miles traveled by the fuel economy of the vehicle in MPG and multiplying it by the difference in fuel price, as shown in the equation below.

$$Fuel\ Savings = \frac{Miles\ Traveled}{MPG} * \ \Delta\, fuel\ price$$

The annual net costs are then calculated and recorded in another column.

$$Net\ Cost = Savings - Expenses$$

In order to convert all of these values into today's dollars, the annual net cost is divided by the quantity one plus the discount rate (r) raised to the number of the year in the investment (n). The payback period is the year in which the NPV of the vehicle reaches $0.

$$NPV = \frac{Net\ Costs}{(1+r)^n}$$

A full example of a NPV calculation for a specific vehicle is shown in Table 1. As seen in the rightmost column, the net present value of the investment becomes positive during the sixth year, thus indicating that the payback period for this vehicle is calculated to be 6 years.

The procedure is executed for all vehicle and engine types in our analysis using optimistic, pessimistic, and best guess values for each input parameter. The payback periods will are considered in the analysis of each vehicle and in the policy recommendations to benefit the Greater Pittsburgh region.

Table 1: Net Present Value Calculation Example

Year	Engine	O&M	Fuel Savings	PM2.5	Net	NPV
0	$(50,000.00)	$-	$-	$-	$(50,000.00)	$(50,000.00)
1	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$(40,275.76)
2	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$(31,101.95)
3	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$(22,447.42)
4	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$(14,282.76)
5	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$(6,580.25)
6	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$686.27
7	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$7,541.47
8	$-	$(1,000.00)	$10,538.46	$769.23	$10,307.69	$14,008.64

Sensitivity Analysis Methodology

When looking at the sensitivity for each parameter used in the payback analysis, the maximum and minimum for each parameter was used to construct a tornado diagram. This diagram best represents the effect of uncertainty in each parameter. In order to assess how much the uncertainty affected the payback period, each maximum or minimum was cycled through several payback period analyses. This means that the payback period was calculated an additional ten times in order to construct the tornado diagram. For example, below is the tornado diagram for trains (Figure 2):

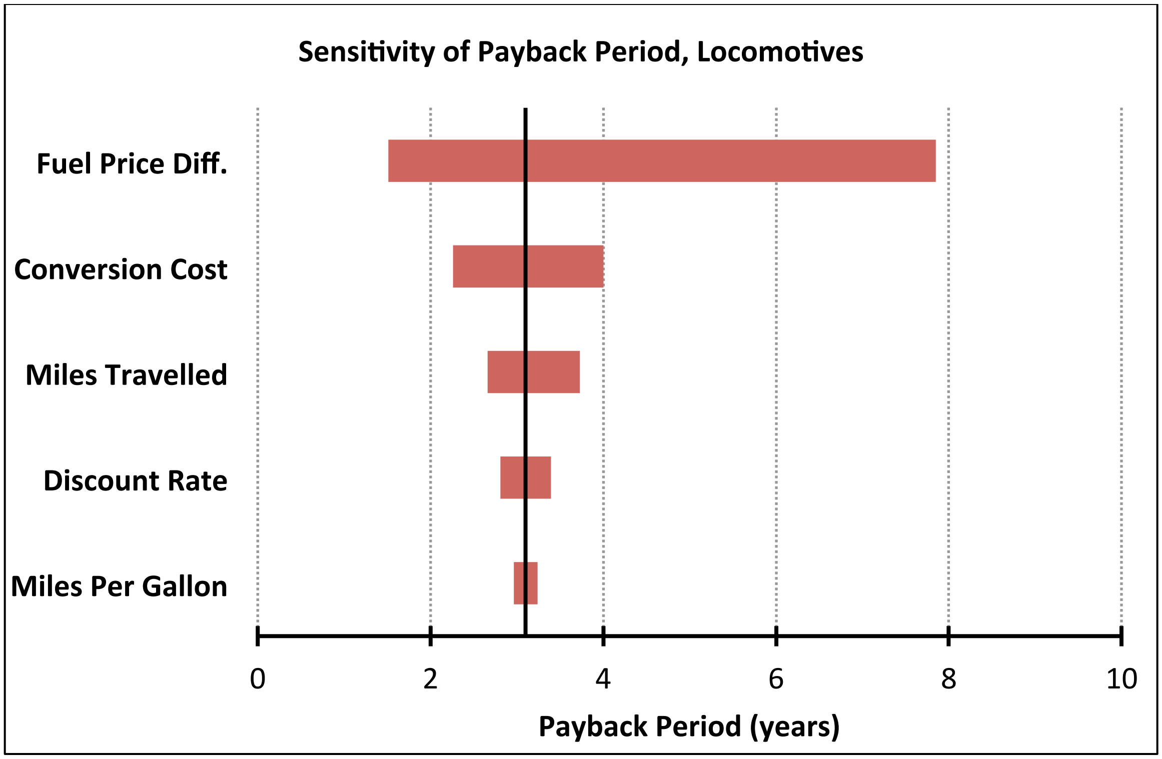

Figure 2: Payback period sensitivity analysis for trains.

The sensitivity analysis is ordered by the parameter with largest range of uncertainty in payback period. In this diagram, the uncertainty in the fuel price differential has the largest range of potential payback periods. The largest possibility, assuming that the price goes to as $0.78, is almost a payback period of eight years while with if the price goes as high as $3.25, the payback period drops to nearly two years.

Supply Survey Methodology

Supply curves are used to compare various types of natural gas vehicles in their relative economic, environmental, and energy independence goals so that the different natural gas vehicles can be prioritized based on these needs. The Y-axis of the supply curve is defined to be the unit cost per unit variable; the X-axis is defined as the quantity of the variable. The variables in this case are: reduction in air pollutants, reduction in oil imported, and the private and social benefits associated with conversion. There are the three different categories of supply curves: pollutant emission, energy independence and economics. They are ultimately used for the analysis on feasibility and effectiveness of converting to Natural Gas Vehicles in Pittsburgh.

Pollutant Emission Supply Curve

The first step in plotting the emission supply curve (Figure 3) is to gather the related quantitative data on emissions and vehicles. The required quantitative data are: natural gas and oil price differential, annual vehicle miles travelled, one time capital cost of conversion, the total reduction in emission over the vehicle lifetime per vehicle type, the total life span of the vehicle, and the number of conversions.

We considered many different particulate emissions for constructing the supply curve, for illustration purposes we use $PM_{2.5}$ emission in this example. The Y-axis in this case is defined as the "c" (Unit Net Cost) of production per ton $PM_{2.5}$ reduction. "c" is defined as: (Cost – Benefit); if the cost exceeds the benefit, the value is on the positive Y-axis; if the benefits outweigh the cost, the value is on the negative Y-axis which indicates that this data point is benefit rather than cost. Note that C (Cost) is calculated using K (Cost of Conversion per vehicle) divided by t (Total Reduction of $PM_{2.5}$ Over per Vehicle Life Time); B (Benefit) is calculated using t (Total Mileage over vehicle's life time) multiplied by P (Fuel Price Difference).

On the other hand, the X-axis is defined as T (total amount of $PM_{2.5}$ reduction). Upon knowing the X (total number of conversion of each vehicle type), T can be calculated using: (X*t) for each vehicle type.

The last step is to plug in the data for each vehicle type, locate the data points and plot the graph. Normally, a horizontal line in the plot will represent each vehicle.

$$Y \text{ axis unit: } \frac{\$\, c \text{ (Unit Net Cost)}}{\text{Ton PM2.5 Reduced}} = \frac{\frac{(C(Cost) - B(Benefit))}{Conversion}}{\frac{(Ton\ of\ PM2.5\ Reduced)}{Conversion}}$$

$$C(Cost) = \frac{K\ (Cost\ of\ Conversion\ per\ Vehicle)}{t(Total\ Reduction\ of\ PM2.5\ Over\ per\ Vehicle\ Life\ time)}$$

$$B(\text{Benefit}) = D(\text{Total Mileage per Vehicle over life time}) * P(\text{Fuel Price Difference})$$

$$\begin{aligned} X\ axis: T(Total\ PM2.5\ Reduction\ in\ Tons) \\ &= X(Number\ of\ Conversion) \\ &* t(Total\ Reduction\ of\ PM2.5\ Over\ per\ Vehicle\ Life\ time) \end{aligned}$$

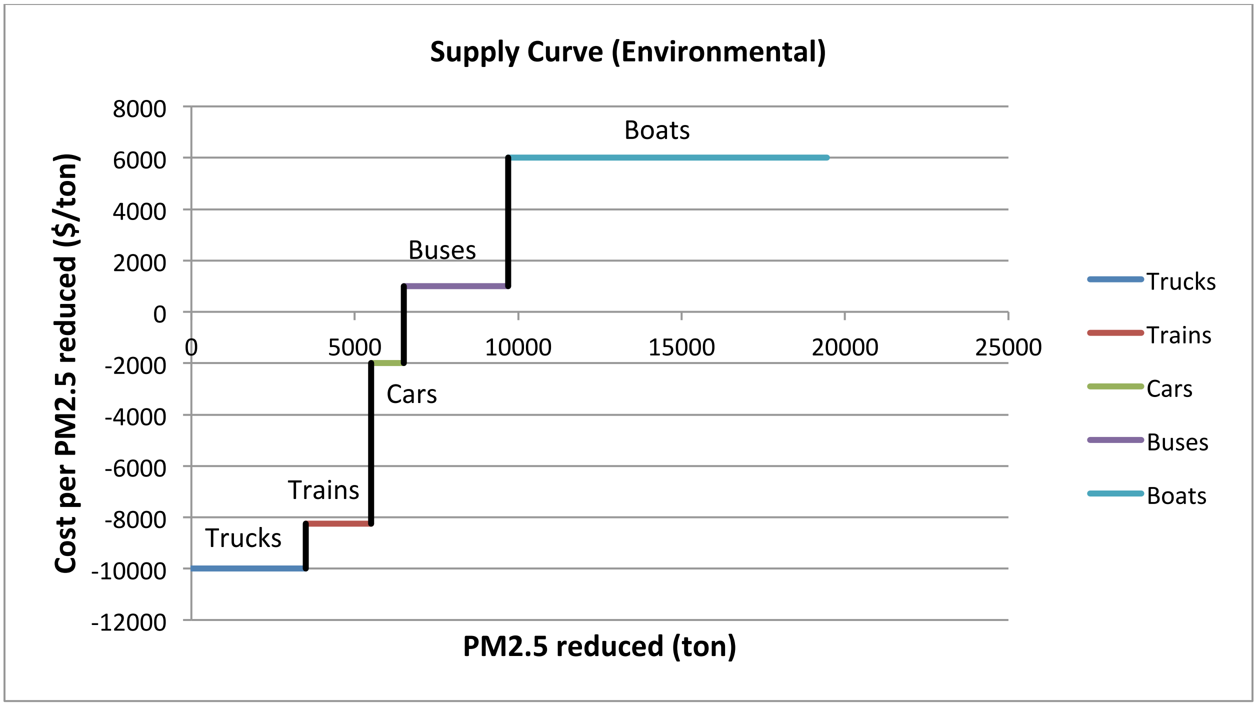

Figure 3: Environmental supply curve, specifically looking at PM2.5 .

Energy Independence Supply Curve

The first step in plotting the energy Independence supply curve (Figure 4) is to gather the related quantitative data on emissions and vehicles. The required quantitative data are: Natural Gas and oil price difference, annual mileage, one time capital cost on conversion, the total reduction in oil usage over their lives per vehicle type, the total life span of the vehicle, the number of conversions.

This analysis includes reduction of fuel imported by vehicle as the variable of interest, and is calculated using D (Total Mileage over vehicle's life time) multiplied by P (Fuel Price Difference). The X-axis is defined as T (Total reduction of imported oil). Upon determining X (total number of conversion of each vehicle type), T can be calculated using: (X*t) for each vehicle type.

$$Y\ axis\ unit\text{:}\ \frac{\$\ c\ (Unit\ Net\ Cost)}{Gal\ imported\ oil\ Reduced} = \frac{\frac{(C(Cost) - B(Benefit))}{Conversion}}{\frac{(Gal\ imported\ oil\ Reduced)}{Conversion}}$$

$$C(Cost) = \frac{K\ (Cost\ of\ Conversion\ per\ Vehicle)}{I\ (Total\ Gallon\ reduction\ of\ imported\ oil\ per\ vehicle)}$$

$$B(Benefit) = D(Total\ Mileage\ per\ Vehicle\ over\ life\ time) * P(Fuel\ Price\ Difference)$$

$$X\ axis: T(Total\ gallon\ reduction\ of\ imported\ oil\ per\ vehicle)$$
$$= X(Number\ of\ Conversion)$$
$$* t(Total\ reduction\ of\ imported\ oil\ per\ vehicle\ Over\ per\ Vehicle\ Life\ time)$$

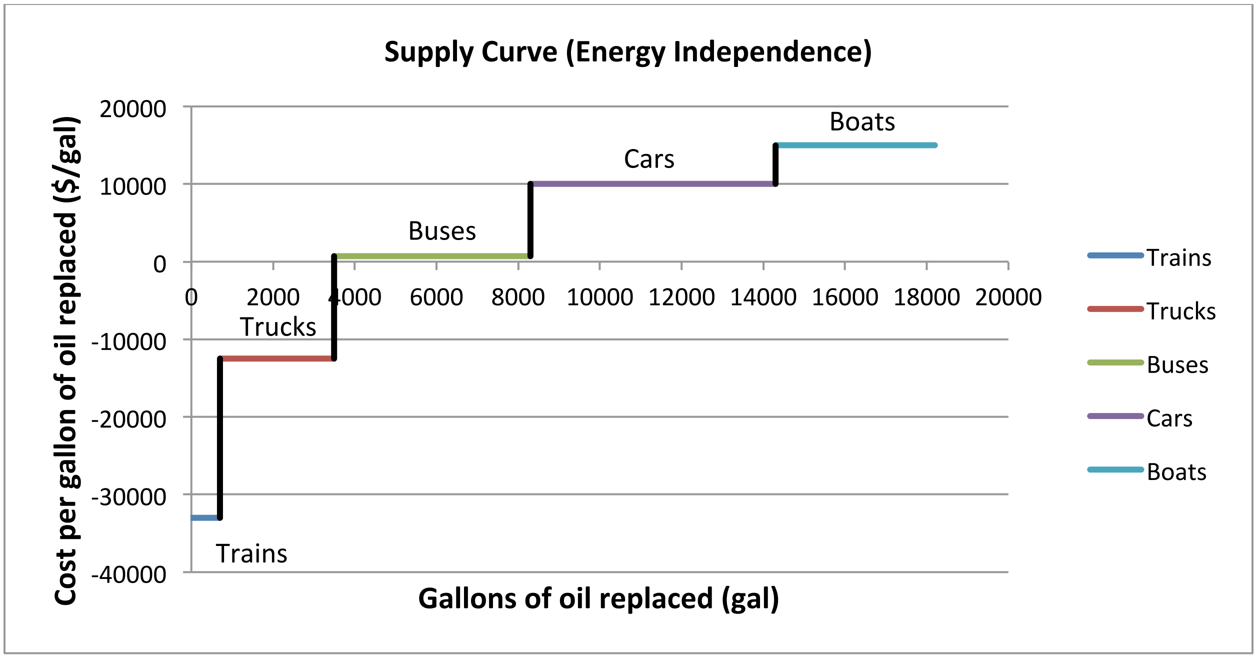

Figure 4: Energy Independence supply curve considering data such as price difference between natural gas and oil, annual mileage, conversion cost, oil use reduction ver vehcile type life, total life span, total conversions.

Private (Economic Supply Curve)

The concept behind the economic supply curve (Figure 5) is similar to the previous two types of supply curves. However, the axes are defined slightly differently.

$$Y\ axis\ unit: \$\ c\ (Unit\ Net\ Cost) = \frac{\frac{C(Cost)}{Conversion}}{\frac{(B(Benefit) - C(Cost))}{Conversion}}$$

$$C(Cost) = K\ (Cost\ of\ Conversion\ per\ Vehicle)$$

$$B(Benefit) = D(Total\ Mileage\ per\ Vehicle\ over\ life\ time) * P(Fuel\ Price\ Difference)$$

$$X\ axis: (B(Benefit) - C(Cost))$$

Social (Economic Supply Curve)

$$Y\ axis\ unit: \$\ c\ (Unit\ Net\ Cost) = \frac{\frac{C(Cost)}{Conversion}}{\frac{(B(Benefit) - C(Cost))}{Conversion}}$$

$$C(Cost) = \frac{K\ (Cost\ of\ Conversion\ per\ Vehicle)}{A\ (Total\ number\ Reduction\ in\ health\ problems\ and\ death)}$$

$$B(Benefit) = The\ value\ of\ reduction\ in\ health\ problems\ and\ \ death\ (in\ \$)$$

$$X\ axis: (B(Benefit) - C(Cost))$$

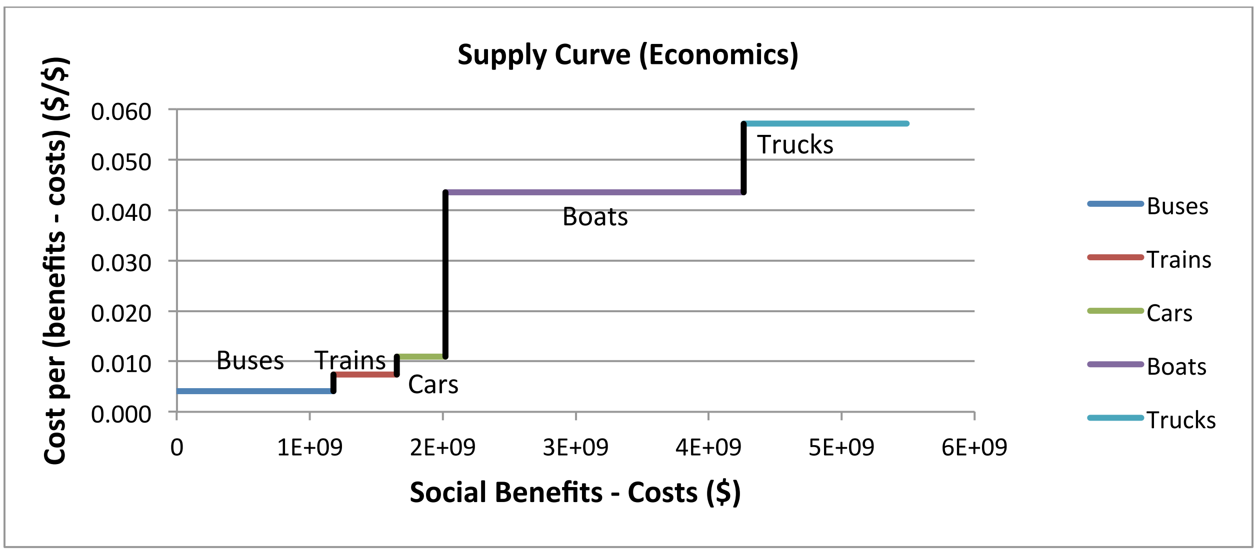

Figure 5: Economic supply curve.

2.3 Policy Analysis Methodology

Having gathered a collection of useful data at the conclusion of the research stage, the questions originally posed during the introduction of this analysis still remain. Specifically, what kind of policies are effective for promoting the use of natural gas vehicles in Pittsburgh, and on what criteria should these policies be evaluated?

To organize our analysis and presentation of these ideas, we employed a structure based on Eugene Bardach's *A Practical Guide to Policy Analysis: The Eightfold Path to More Effective Problem Solving*. This guide breaks down policy analysis into the following steps (Bardach, Eugene, 2005):

- I. Define the Problem as a Series of Questions
- II. Assemble Some Evidence
- III. Construct the Alternatives
- IV. Select the Criteria
- V. Conduct an Analysis to Project the Outcomes
- VI. Confront the Tradeoffs
- VII. Decide!
- VIII. Tell your story

Each of these steps is visited in the policy analysis methodology, framing the analysis of this report in a complete and succinct manner that will facilitate proper communication.

First, it is important to understand what kind of policies can influence the adoption of natural gas vehicles in the Pittsburgh region. These policies can exist on the federal, state, and local levels. Further, these policies generally fall into several major categories: Education, Maintenance and Training, Research and Development, Regulation, and Economic Incentive. And most specifically, each of these categories of policies can affect a specific vehicle, a collection of vehicles (for example, over-the-road vehicles), or natural gas vehicles as a whole. The figure below (Figure 6) summarizes the breakdown of the existing policies.

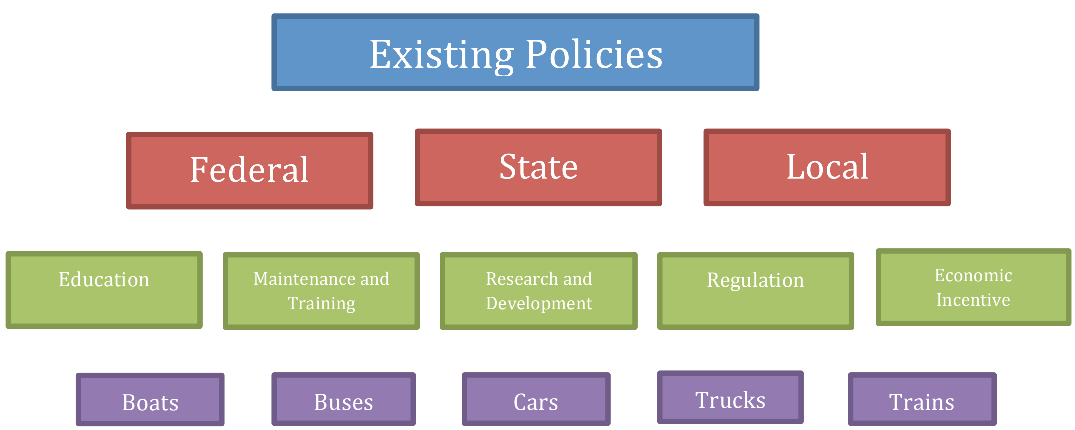

Figure 6: Policy categories as they relate to specific vehicles.

Education focuses on increasing public awareness of the facts regarding natural gas vehicles. For fleet managers considering adopting natural gas technology, education policies play a crucial role in providing information that influences the decision to invest in natural gas vehicle infrastructure and technology.

Maintenance and Training policies also have significant influence over the viability of natural gas technology. For all vehicles, the need to have educated and efficient mechanics and inspectors maintaining the operation and safety of the vehicles is necessary. Traditionally trained mechanics are accustomed to working on petroleum-based engines, but natural gas engine and fuel technology require additional knowledge, which is gained through supplemental training in the natural gas vehicle realm.

Research and Development policy pertains to the actual advancement of natural gas vehicles. Setbacks like engine power, vehicle range, and fuel storage have commonly reduced the acceptability of natural gas vehicles. However, advancements in the development of these technologies, with the aid of policy support, can greatly improve the feasibility of natural gas vehicles in the near future.

Regulation bases itself in policies that encourage adoption by setting legal limits to certain aspects of a vehicle and its usage. Commonly, these regulations may refer to emissions, fuel provisions, or some specific taxation efforts.

Economic Incentive policies refer to any financial enticements that government might provide in order to encourage the adoption of a natural gas vehicle. Historically, these grants have existed on the state and federal levels, and are usually designed around providing money for vehicle purchase and infrastructure developments.

After identifying specific categories in which to investigate policies, the next step is to research and assess the current policies that already exist in the Pittsburgh region. The purpose of this analysis is to determine what has already been tried, what policies appear to be working, and which policies have been lapsed due to lack of effect. To accomplish this task, it is important to look at specific bills and legislation that have been passed and that have been used by Pittsburgh companies and consumers for the purposes of natural gas vehicles. This research provides a status quo base case of current policies that can provide context for future recommendations.

Further, interviews and surveys with fleet owners and company executives can provide insight as to what governmental policies would significantly influence their decision to adopt a natural gas fleet. These conversations can inform policymakers of what policies are actually impacting decisions regarding adoption and acceptance in different industries and vehicle types.

After identifying existing policies and their impact, the next step was to create new potential policy options for consideration. To accomplish this task, two main avenues were considered: vehicle economic incentives and infrastructure service provisions. Vehicle economic incentives include the most common forms of government policies, where there is a specific action created for a given vehicle on a relatively per unit basis. This may include a tax break per vehicle, a grant program for the purchase or conversion of vehicles, or some other sort of government financial support for the development of natural gas vehicles. Infrastructure service provisions shift the focus from vehicles to the actual infrastructure supporting them. Traditionally, this infrastructure pertains to refueling stations and maintenance garages, but other smaller forms of infrastructure, such as safety equipment, are also present. These provisions are designed to encourage the establishment of sufficient infrastructure to support the adoption of natural gas vehicles.

From here, the next step is to evaluate these policy options on a variety of metrics measuring their efficiency. To accomplish this, four categories were developed to predict the effect of different policy options on the area.

- **Overall Effectiveness (O):** This metric defines the extent to which goals will be met if this policy option is put into place.
- **Economic Efficiency (E):** Economic efficiency investigates the amount of output that is achieved from a given input. In other words, an economically efficient policy would have the "best bang for the societal buck".
- **Political Responsiveness (R):** This metric is an overall measure of how citizens' preferences are met. This criterion looks into how likely it is that politicians implementing this policy option would be willing to accept and respond to it.
- **Equity (Q):** Equity considers the fairness of a specific policy option. This metric examines whether or not the policy option is fair and equitable.

For each of the mentioned categories, a score was given to each option denoting its performance in that metric. If the policy option was beneficial when considered against the criteria, a "+" was assigned, showing a positive result. If the policy option had a neutral effect in a given criteria, a "0" was assigned, suggesting that the policy does not promote nor demote the objective. Finally, if the policy option was not beneficial in achieving the desired outcomes, a negative score was assigned, denoted by "-".

Finally, these scores were compared across each of the options for each vehicle type and each policy type. The option with the most positive impact on our goals was chosen as the most advantageous policy and was identified as the best choice for our recommendations.

2.4 Fuel Price Differential

Fuel price differential play an important role in calculating the natural gas conversion benefits and it also determines the level of accuracy of the feasibility analysis. The definition for price differential is the difference between two different types of vehicle fuels, the unit is in $/gallon. For example, the CNG and Diesel price differential is defined as the price difference between CNG and Diesel. Fuel price can be affected by many factors, so as fuel price differential. Global economy, supply and demand for fuels, the fuel drilling technology as well as efficiency of fuel usage can all drive the fluctuation on fuel price. We set our price differential value base on the historical price differential for the past 13 years; all the fuel price were extracted from AFDC (Alternative Fuels Data Center) and US Energy Information Administration (EIA).

For our purposes, there are three sets of price differential needs to be assumed: CNG & Diesel price difference for bus and truck; CNG & Gasoline price difference for taxi and passenger cars; LNG & Diesel price difference for boats and trains. Each of the three price differentials has three sets of values: best guess, minimum and maximum values, all of which can be observed in Table 2. For example, in Table 2, the maximum price differential between CNG and Diesel is $1.89 (AFDC, 2013), which is also the maximum value between 2000 and 2013. For the best guess case, the current value is adopted for both price differentials for CNG and Diesel as well as CNG and Gasoline. However, the historical average value is used for LNG and Diesel price differential. These values are used in quantitative analysis for calculating the benefits associated with natural gas vehicle conversion for best guess, optimistic and pessimistic cases. The formula for calculating benefits is shown below:

$$\text{Benefit} = \text{Miles traveled} * \text{Fuel price differential}$$

Table 2: Summary of Fuel Price Differential

	CNG & Diesel	CNG & Gasoline	LNG & Diesel
Best Guess	$1.89	$1.39	$1.91
Minimum	$0.24	$0.05	$0.63
Maximum	$1.89	$1.51	$3.46

From AFDC, we extract all the CNG price, diesel and gasoline for both national average and central Atlantic average (Regional) from 2000 to 2013. Because our analysis is done specifically for the natural gas conversion in Pittsburgh region, so using central Atlantic average fuel price will result in more accurate analysis.

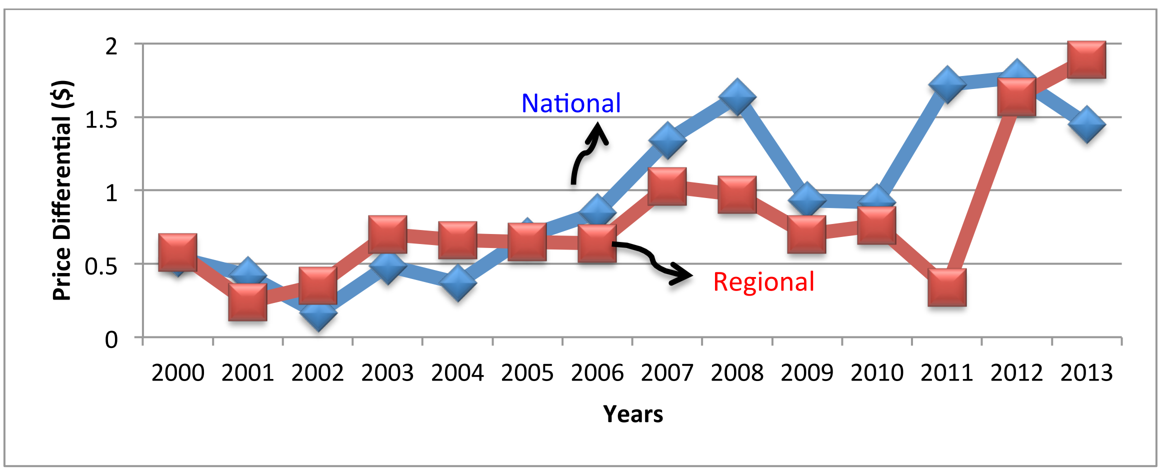

Figure 7: CNG & Diesel Price Differential

From Figure 7, the historical minimum CNG & Diesel price difference is $0.24/gal and the historical maximum between 2000 and 2013 is $1.89/gal; the current price difference as of 2013 is also $1.89/gal (AFDC, 2013). Thus, we assume the best guess fuel price is $1.89/gal, or the current price difference, we also assume the historical maximum and minimum fuel price difference as maximum and minimum price difference for our analysis.

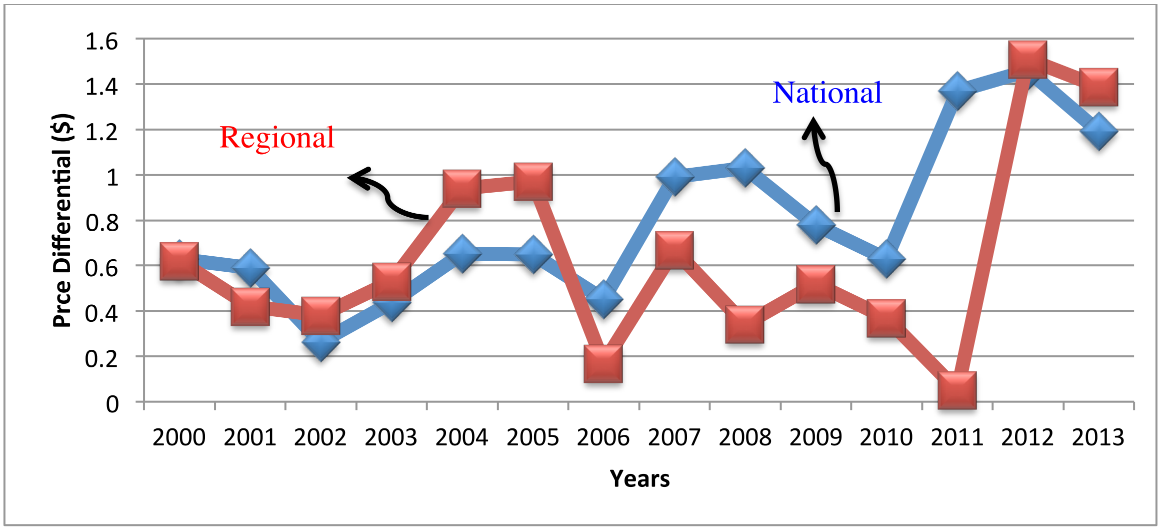

Figure 8: CNG & Gasoline Price Differential

In addition to CNG and Diesel price differential, in Figure 8, the historical minimum CNG & gasoline price difference is $0.05/gal and the historical maximum is $1.51/gal between 2000 and 2013; the current price difference as of 2013 is $1.39/gal (AFDC, 2013). Thus, we assume the best guess fuel price is $1.39/gal, or the current price difference, we also assume the historical maximum and minimum fuel price difference as maximum and minimum price difference for our analysis.

The third fuel price differential is the LNG & Diesel price differential, there is limited data on regional LNG prices, so we extract national LNG price from EIA from 2000 to 2013.

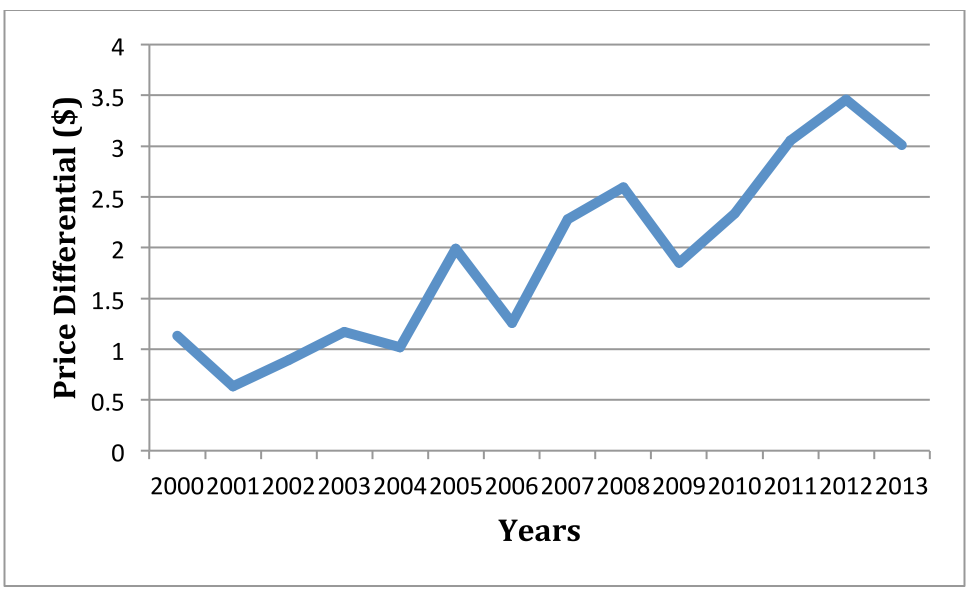

Figure 9: LNG & Diesel Price Differential.

From Figure 9, the historical minimum Diesel and LNG price difference is $0.632/gal and the historical maximum is $3.46/gal; the current price difference as of 2013 is $1.91/gal (EIA, 2013).

Thus, we assume that the best guess fuel price is $1.91/gal, or the historical price difference; we also assume the historical maximum and minimum fuel price difference as maximum and minimum price difference for our analysis.

3.0 Analysis by Vehicle

3.1 Cars

Introduction

One of the largest areas of potential natural gas adoption is the light-duty vehicle, or cars, market. Cars comprise the largest amount of vehicles currently in use, and vary greatly in scope. In addition, cars are the largest transportation source for greenhouse gases (EPA, 2013). There is a very large potential gain to be had with natural gas. The analysis separated the types of vehicles into two types, general passenger cars for use by private consumers, and fleets of cars used in high transit amounts, such as taxis. There are approximately 500 taxis, as well as 700,000 passenger cars in the Pittsburgh region (Pennsylvania Department of Transportation (PDOT), 2012). The reason for this change was the large difference in miles travelled between the two, and the difference in technologies (Pennsylvania Department of Transportation (PDOT), 2012). For the purposes of the analysis, medium-duty vehicles such as pickup trucks were not looked at. While Bi-Fuel pickup trucks do exist, data about the usage and prevalence of such vehicles is not yet available, making any analysis suspect. A similar lack of data on Dual Fuel vehicles is why they are also removed from the analysis, making it focused on purely CNG powered vehicles compared to the current gasoline powered vehicles.

Information Gathering

Technology

This analysis focuses on public taxi fleets and passenger vehicles; the MV1 taxi model and Honda Civic Sedan model are used for taxi fleets and passenger vehicles. The technology assumptions needed for analysis are number of vehicles, annual fuel consumption; annual miles traveled, and fuel efficiency. According to the traffic statistics from the Department of Transportation, it is shown that each taxi travels 83,000 miles per year (National Renewable Energy Laboratory (NREL), 2011) and each passenger car travels 12,000 miles each year (Pennsylvania Department of Transportation (PDOT), 2012). Natural gas efficiency measured in miles per gallon (mpg) for the MV-1 ranges from approximately 11-16 mpg and for the Honda Civic ranges from 27-38 mpg (Honda, 2013). The MV-1 is a large vehicle designed to be handicap accessible. The Honda Civic is an example of a small sedan currently in the NG market; some restrictions to this vehicle are its small trunk space and limited range due to fuel tank size. The annual consumption of fuel is calculated using fuel economy and annual miles traveled. It shows that MV1 taxi consumes 6400 gallons of fuels annually and each Honda Civic passenger car consumes approximately 370 gallons of fuels (National Renewable Energy Laboratory (NREL), 2011). This analysis only focuses on dedicated CNG cars; dual-fuel engines and bi-fuel engines exist for light-duty trucks, however due to lack of data, these engine types have been excluded from the report, and we are only considering dedicated engine for natural gas cars.

Environment and Emissions

The introduction of NGV will have significant environmental and energy impacts that must be considered when evaluating the efficiency of such a technology. NGV engines will decrease carbon dioxide emissions and PM2.5 emissions, however, will have increased methane emissions.

The use of natural gas affects the emissions of greenhouse gases like carbon dioxide, noxious gases, and methane. The use of compressed natural gas is said to emit lower amounts of carbon dioxide when compared to using gasoline to fuel vehicles by almost 20% according to data provided by the fueleconomy.gov website (Fuel Economy, 2013). According to Natural Gas Vehicles for America, use of compressed natural gas reduces noxious oxide emissions by 87% compared to gasoline vehicles (Natural Gas Vehicles for America (NGVA), 2012). Methane emission from CNG use actually increases when compared to gasoline fuel use. Older studies have found that 7.9% of the increased methane emissions were due to emissions from shale gas wells, loose pipefittings (Fuel Economy, 2013) in distribution lines, or intentional release. However, recent studies have found that after 2006, methane emissions from natural gas use has decreased by 45% (Porter, Eduardo, 2013).

Despite changes in emissions to the above mentioned greenhouse gasses, the effect on particulate matter emissions is more of a concern to human health. Particulate matter of 2.5 micrograms or less pose the biggest threat to humans if inhaled. The particles can travel deep into the lungs and may even reach as far as into the bloodstream and may result in heart attacks, decreased lung function, and even premature death. In addition, fine particles like 2.5-particulate matter can cause a haze or reduced visibility in the environment. Due to the direct relationship between particulate matter and health effects, the emissions for 2.5-particulate matter is the only emission factor discussed in our analysis (EPA, 2013).

An average natural gas powered car, consumes about 1.69 MJ/km which is 53.4% of the 3.16 MJ/km used by petroleum-fueled cars (Hart, David, 1998). An automatic, 5-speed 2011 Honda Civic with four cylinders and 1.8L has a fuel economy of 28 mpg. A comparable gasoline powered Honda Civic has a fuel economy of 29 mpg (Vankatesh, Aranya; Jaramillo, Paulina; Griffin, W. Michael; Matthews, H. Scott, 2011).

Natural gas is more than 90% methane in composition. Even so, natural gas exhibits the highest Hydrogen/Carbon ratio of all fossil fuels. A higher hydrogen/carbon ratio is preferred because this would mean more water vapor emissions than carbon dioxide into the atmosphere. Natural gas typically has a carbon content of 75% which is 11% lower compared to oil and petroleum energy sources. In addition, natural gas has very low quantities of contaminants, and as a result low 'secondary' emissions, including particulate, benzene, and lead. The reduction in PM2.5 is shown in Table 3 below.

Table 3: PM2.5 reduction

Vehicle	$PM_{2.5}$ Emissions (g/gal-eq)*	
	Natural gas	Gasoline
Taxi (MV-1)	0.39	0.40
Passenger Car (Civic)	0.17	0.18

* Based on GREET model (1.0.8123), http://greet.es.anl.gov/greet/

Although NGV reduces PM2.5 and C02, because NGV get fewer mpg the emissions reduction of PM2.5 is essentially negligible. The GREET model predicts small variances in PM2.5 for natural gas cars, and based on this model, we use the assumption that PM2.5 is insignificant for our analysis.

According to Vankatesh, Jaramillp, Griffin, and Matthews the probability of significantly reducing greenhouse gas emission through the use of CNG passenger cars is very low. It is expected that an average reduction of 30 g of CO2e/MJ will result with use of CNG passenger cars such as the CNG Civic. This average reduction is measured when compared to a gasoline powered Civic (Vankatesh, Aranya; Jaramillo, Paulina; Griffin, W. Michael; Matthews, H. Scott, 2011).

The EPA released estimates that double their initial approximations for the quantity of methane that is discharged from natural gas distribution lines (Lustgarten, Abraham, 2012). This underestimation in natural gas leakage must be investigated further to understand the potential effects on the environment, if any. A study by Mr. Howarth for total methane loss, estimated a range from 3.6 to 7.9 percent for the shale gas industry (Howarth, Robert W; Santoro, Renee; Ingraffea, Anthony, 2011). However, it must be understood that some included techniques in methane emission estimates may be unconventional and highly unlikely to be used. His study, partnered with data from the Goddard Institute for Space Studies at NASA, concluded that the shale gas greenhouse gas footprint can be at times "20% more and twice has high, as coal per unit of energy". The study also warned of aerosol particles intensifying the greenhouse gas effects of methane, over a 20-year period of methane. In about that same amount of time, the federal government seeks to quadruple the shale gas production (Zeller, Jr; Tom, 2011).

Survey Information

The cars group focused their survey gathering on fleet owners in the vicinity of Pittsburgh. Bob Delucia, CEO of Star Transportation, responded to the survey. Star Transportation, which owns several fleets in the area including Veteran's Taxi and Classy Cab have already begun using specific natural gas vehicles, namely the MV-1 Mobility Vehicle, in their fleet. The other organizations contacted were not able to respond, but the data provided by Star Transportation supported much of the findings throughout our analysis.

Star Transportation commands a fleet of around 100 vehicles and owns 17 natural gas cars. They expect acquire an additional 8 natural vehicles throughout 2013. Each vehicle travels 300-500 miles a day, and is on call for 24 hours. They refuel 2-3 times a day. A typical vehicle in the fleet lasts roughly 8 years (DeLucia, 2013). While looking to purchase new vehicles, Star Transportation prefers payback periods of less than two years. One of the biggest issues for their natural gas fleet currently is the infrastructure. They utilize the two public fueling stations, EQT and Giant Eagle, for their fueling needs, but that limits their range. Given their fleet will sometimes head across the border into West Virginia, it makes their natural gas vehicles unable to service all their needs as a fleet. They were able to purchase these vehicles through the Act 13 subsidies introduced last year.

Assumptions for Payback Analysis

Table 4: Passenger Car Assumptions

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal-eq)	Lifetime (yr)	Price differential ($/gal-eq)	Total vehicle number (#)	Adoption Rate (%)
Best Guess	$8,000	8%	12,000	31.000	5	$1.39	719000	50%
Pessimistic	$7,000	3%	10,000	20.900	4	$0.05	700000	10%
Optimistic	$9,000	12%	14,000	39.000	6	$1.51	750000	100%

Table 5: Taxi Assumptions

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal-eq)	Lifetime (yr)	Price differential ($/gal-eq)	Total vehicle number (#)	Adoption Rate (%)
Best Guess	$10,500	8%	83,000	13.500	8	$1.39	417.5	50%
Pessimistic	$10,000	3%	20,000	11.000	7	$0.05	335	10%
Optimistic	$11,000	12%	146,000	16.000	9	$1.51	500	100%

The values seen in Table 5 used to in the payback analysis are all estimated according from different sources. The conversion cost for compressed natural gas VPG MV-1 taxis is estimated to be $51,000 according to the value for a new vehicle as reported by the Star Transportation Group (DeLucia, 2013). The average miles traveled by a natural gas VPG MV-1 taxi per year is unavailable and is therefor assumed to be the same as the average miles traveled per year by a gasoline powered taxi. The value is estimated to be between 20 to 146 thousand miles according to a National Renewable Energy Laboratory (NREL) 2011 paper entitled Fueling Infrastructure and Economics (National Renewable Energy Laboratory (NREL), 2011). The average miles per gallon for taxis is estimated to be between 11 and 16 using data about CNG MV-1 from the fueleconomy.gov (Fuel Economy, 2013). The vehicle lifetime is assumed to be 8 years, the same as that for a gasoline vehicle because data for the CNG MV-1 was not available. This value is taken from an interview with Bob DeLucia, the CEO of the Star Transportation Group (DeLucia, 2013). The total number for natural gas vehicles is the same as gasoline since we treat it as a conversion of the entire fleet of vehicles. Similar to vehicle lifetime, the value comes from an interview the CEO of Star Transportation Group, Bob DeLucia (DeLucia, 2013).

The conversion cost for Honda compressed natural gas Civic passenger car, as seen in Table 4, is estimated to be $8,000 according to price difference for a new natural gas Civic compared to a gasoline one as reported by Honda on their website (Honda, 2013). We assume there to be a range on conversion, but this value to be our best guess. The average miles traveled by a Honda NG Civic per year is unavailable and is therefor assumed to be the same as the average miles traveled per year by a gasoline powered Honda Civic. The gasoline vehicle value is estimated to be between 12 thousand miles according to a National Renewable Energy Laboratory (NREL) 2011 paper entitled Fueling Infrastructure and Economics (National Renewable Energy Laboratory (NREL), 2011). The average mile per gallon for taxis is estimated to be between: 23 – 32.8 (Chicago Transportation Authority (CTA), 2012). According to historical data from CTA, there is 5% increase for gasoline cars and 20% increase for the new NG cars for the past ten years (Chicago Transportation Authority (CTA), 2012). Thus, after taking 5% off from 23 and adding 20% to 32.8, we have an estimate for natural gas car MPG to be 23-32.8. The best guess MPG is assumed to be 31 as the Honda civic MPG average from Honda Civic website. The vehicle lifetime is assumed to be 5 years. The value is taken from a report on Transportation and Energy Issues by APS (APS, 2013). The total number of natural gas cars is assumed to be 719,000, the number of registered gasoline vehicles in Allegheny County. We use this number along with our adoption rate to determine the amount of gain for conversion. The value is taken from a 2012 report on Vehicle Registrations in Pennsylvania (Pennsylvania Department of Transportation (PDOT), 2012).

One assumption we make regarding the $PM_{2.5}$ is that there is no difference between gasoline cars and natural gas cars regarding the PM. We base this on the GREET model, which shows that the PM differences are small (see table 1 in emissions). This would mean that there is a small difference in $PM_{2.5}$, however the PM is measured per gallon of fuel consumed. We also know that natural gas cars are slightly less efficient than gasoline cars, which means the slight reduction in PM is offset by the slight increase in fuel consumption. This results in an insignificant difference, so we treat it as such in our analysis.

Payback Period Analysis

Pre-existing Analysis

Other states have had success implementing taxi programs, such as the Barwood fleet in Maryland, which has had success with natural gas taxis. Implemented in 1996, they successfully transitioned part of their fleet into natural gas. With subsidies from the state of Maryland covering the conversion costs, the fleet found that overall the CNG taxis were 75% cheaper to run over a long period of time, with lower maintenance costs. One of the major concerns for private users, trunk space, was not a concern for this taxi fleet, as they estimated they lost less than 0.5% of fares from lack of space. Even with the limited access to refueling stations, the Barwood Company considers the CNG vehicles to be a great success (NREL, 1999).

There are several qualitative factors that come to light in regards to private consumer's use of natural gas vehicles. A study done by Sonia Yeh showed that for consumers to feel comfortable with alternative fuel vehicles they need 10-20% of available fueling stations to be able to service their needs. In addition, the desired payback period for alternative fuel vehicles is under four years. Consumers, even though they may use vehicles for longer than that time period, would only feel comfortable investing money into a more expensive alternative fuel vehicle if they believed it would pay itself off in under four years (Yeh, Sonia, 2007).

Pittsburgh Specific Analysis

The net present value (NPV) for both a natural gas passenger car and taxi is dependent on factors including the vehicle's conversion cost, discount rate, miles traveled, miles per gallon, particulate matter reduction, vehicle lifetime, and fuel price differential. However, because there is little particulate matter reduction in natural gas use, this factor can be ignored in determining NPV. The value used for the number of vehicles is taken from the data collected with Star Transportation Group and the miles traveled is estimated using values the miles per gallon and fuel consumption. Table 6 shows the input parameters for passenger cars while Table 7 shows these input parameters for taxis. As can be seen in Table 6, the average passenger car economic lifetime is assumed to be 5 years, with a pessimistic lifetime of 4 years at best and optimistic of 6 years in a pessimistic assumption. The miles traveled per vehicle are calculated to be on average, 12,000 miles per year after assuming a 31 miles per gallon equivalent on average for passenger car. In calculating the NPV for both vehicle types, three possible guesses were evaluated ranging from an optimistic estimate, to a pessimistic, to the most probable outcome. The best guess estimate is ultimately the most probable NPV for both passenger cars and taxis.

Figure 10 presents the three estimate payback times for each factor upon which the NPV for passenger cars was calculated upon. As can be seen from Table 6, the average conversion cost for a NG passenger car is $8,000 with payback time of 18 years on average, with pessimistic cost of $7,000 and optimistic cost of $9,000; the corresponding payback times are 15 years and 19 years. With these numbers, our analysis concluded that payback on natural gas conversion does not occur within the car's economic lifetime. Table 6 shows the pessimistic economic lifetime for a passenger car to be four years with six years being the optimistic. As shown in Figure 10, not even our most optimistic guess shows a convincing payback period during or before the economic lifetime for a passenger car. Not seen on the graph, the quickest payback period would be between eight and nine years at best. Figure 11 shows the sensitivity analysis on payback period for passenger cars. With how sensitive payback is to fuel price differential, the uncertainty of fuel prices results in our inability to calculate a confident payback period. As can be seen in Figure 11, the payback period would be an estimated 655 years at worst with the assumed optimistic fuel price differential. The optimistic guess for the payback period would be 15.88 years assumed with the pessimistic fuel price differential. Our best guess, however, is that the payback period would be somewhere around 18.48 years (as seen in Table 7). The best guess payback period is still longer than the car's economic lifetime; therefore, implementing natural gas passenger car does not prove to be economically feasible.

Table 6: Passenger Car Assumption

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal -eq)	Lifetime (yr)	Price differential ($/gal-eq)	Total vehicle number (#)	Adoption Rate (%)
Best Guess	$8,000	8%	12,000	31.000	5	$1.39	719000	50%
Pessimistic	$7,000	3%	10,000	20.900	4	$0.05	700000	10%
Optimistic	$9,000	12%	14,000	39.000	6	$1.51	750000	100%

Table 7: Passenger Car Payback Time

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal-eq)	Price Differential ($/gal-eq)
Best Guess	18.48	18.48	18.48	18.48	18.48
Pessimistic	15.09	15.74	20.73	11.61	654.57
Optimistic	19.43	18.53	14.78	21.74	15.88

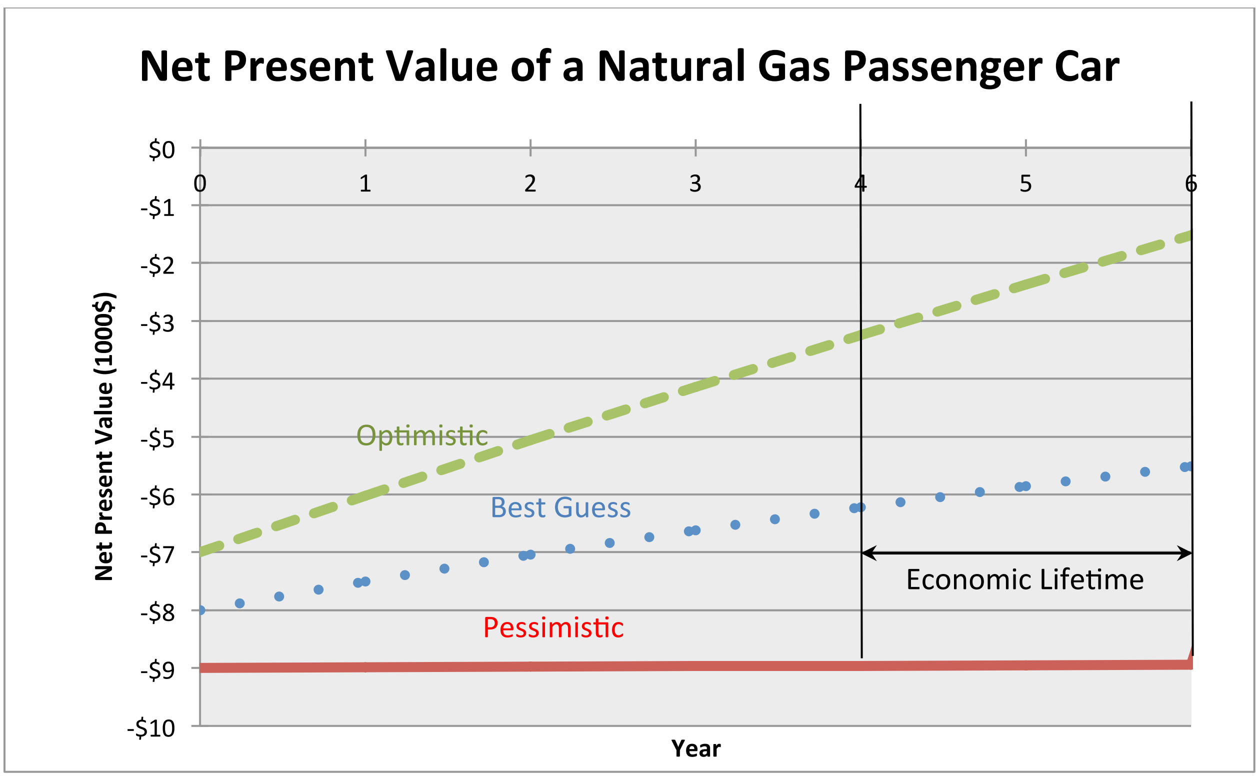

Figure 10: Net Present Value for natural gas passenger cars.

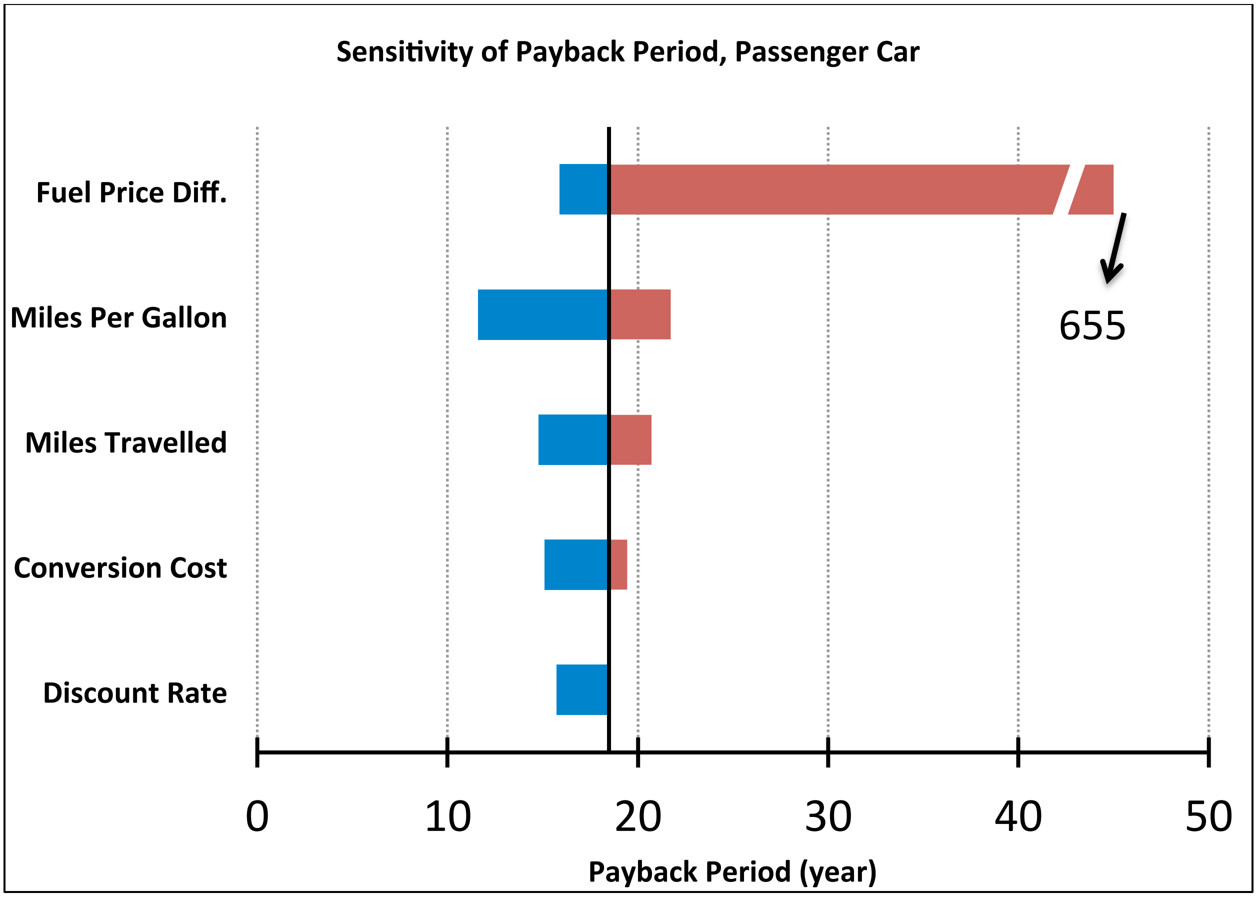

Figure 11: Passenger Car Sensitivity Analysis

Figure 12 presents the three estimate payback times for each factor upon which the NPV for taxis was calculated upon. As can be seen from Table 8, the average conversion cost for a NG taxi is $10,500 with a vehicle economic lifetime of eight years on average. With these averages, our analysis concluded that payback period occurs within one to two years as a best estimate. Unlike the estimated payback period for passenger car, the taxi's payback period is well before the vehicle's economic lifetime, as seen in Figure 12. The same graph shows that an optimistic guess predicts the payback period to be earlier than a year. As seen in Figure 13, this payback period is highly dependent on the fuel price differential. However, it is important to note that unlike passenger cars, taxis' payback period is also dependent on miles traveled. Similar to passenger cars, the payback period with the optimistic fuel price differential is still large, at 1.3 years with the most optimistic fuel differential, and at 52 years as the worst estimate as seen in Table 9. This result seems to show that implementing natural gas taxis does not seem to be economically feasible if the fuel price is very volatile, but in the best guess and optimistic conditions the payback period is much less than the lifetime.

Table 8: Taxi Assumptions

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal-eq)	Lifetime (yr)	Price differential ($/gal-eq)	Total vehicle number (#)	Adoption Rate (%)
Best Guess	$10,500	8%	83,000	13.500	8	$1.39	417.5	50%
Pessimistic	$10,000	3%	20,000	11.000	7	$0.05	335	10%
Optimistic	$11,000	12%	146,000	16.000	9	$1.51	500	100%

Table 9: Taxi Payback Time

	Payback Period (year)				
	Conversion Cost	Discount	Miles Travelled	MPG	Price Differential
Best Guess	1.35	1.35	1.35	1.35	1.35
Pessimistic	1.28	1.27	6.82	1.09	52.87
Optimistic	1.42	1.42	0.75	1.62	1.24

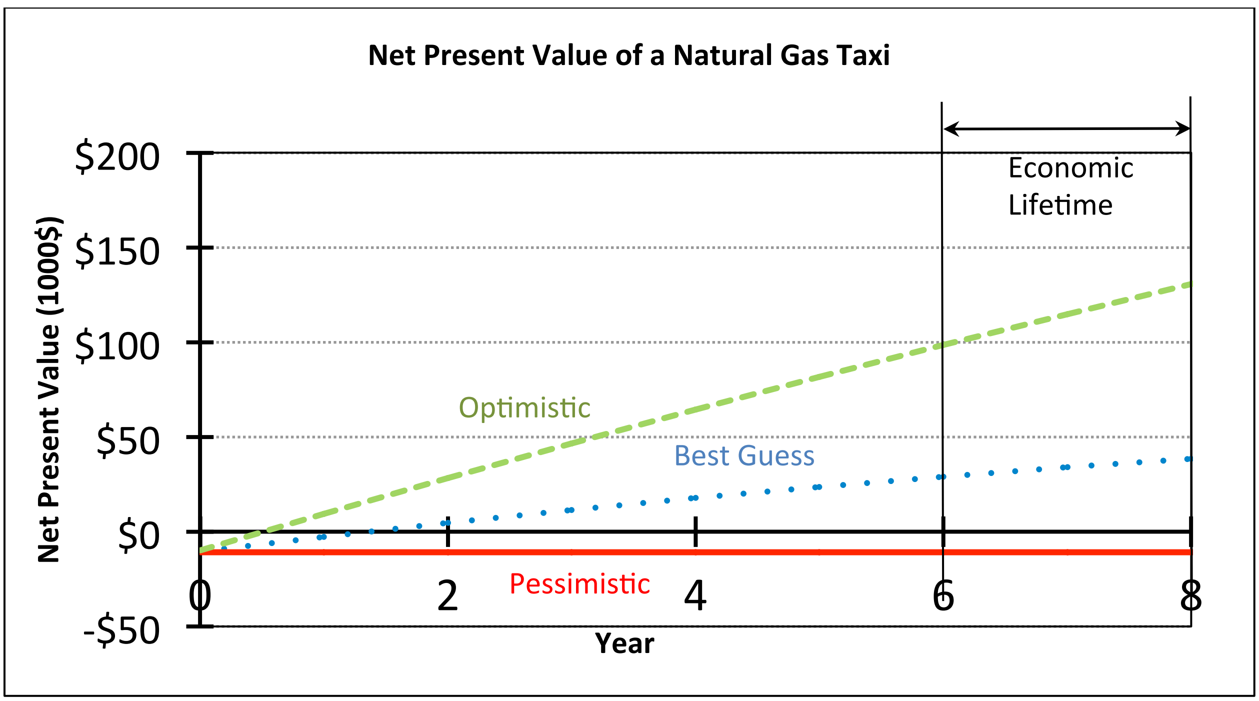

Figure 12: Net Present Value for natural gas taxis.

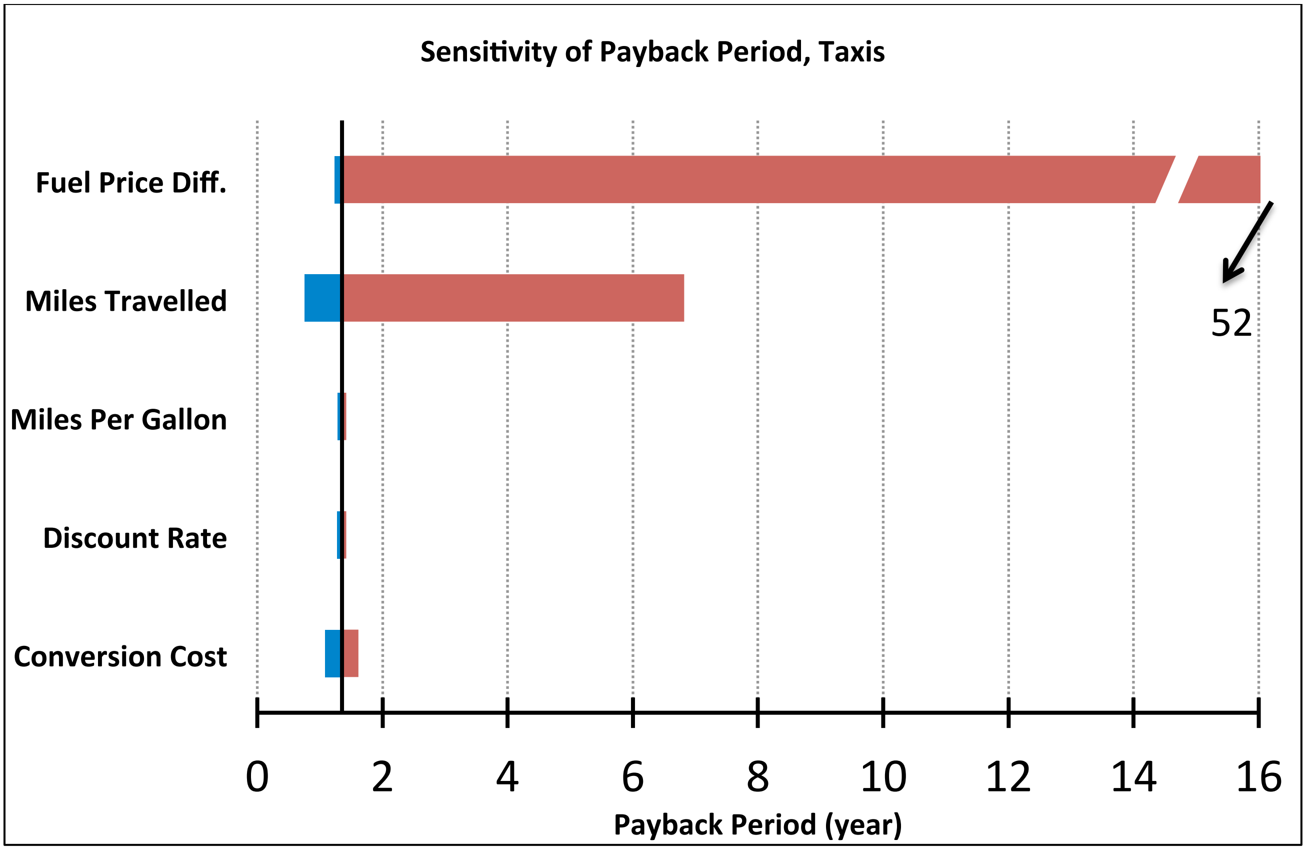

Figure 13: Payback period Sensitivity Analysis for taxis.

Infrastructure

On the federal level, the Energy Policy Act of 2005 created an income tax credit for large or home fueling stations. This provision has been extended until the end of 2013. A current estimate of a home fueling station would be $7,500 to $10,000. Also, to encourage stations to use natural gas fuel, a tax credit, under the federal Safe, Accountable, Flexible, Efficient Transportation Equity Act, is given to sellers of natural gas. This policy has also been extended to the end of 2013. An estimated cost for a public fueling station is between $0.6M and $1.2M.

Pittsburgh has two main public fueling NG stations, EQT and Giant Eagle. Both stations are being utilized by Veteran's Taxi, however lack of fueling stations outside the immediate Pittsburgh area causes a range barrier for taxis (DeLucia, 2013).

The lack of natural gas infrastructure in the city of Pittsburgh is restricting the usage of natural gas passenger cars and taxis. In the city of Pittsburgh, there are currently only two CNG public fueling stations: EQT and Giant Eagle. Both are CNG fast-fill stations open 24 hours a day, seven days a week. However, according to data collected from an interview with Star Transportation Group, lack of private refueling stations is the largest obstacle preventing the company from widely using natural gas vehicles for taxi fleets. Star Transportation is the owner of taxi companies such as Classy Cab and Veterans' Taxi, which readily serve the city of Pittsburgh. A similar assumption about lack of infrastructure affecting demand is made for the usage of passenger car vehicles. Passenger cars would require the same fueling stations as do taxi fleets, and therefore, it can be inferred that limited infrastructure restricts the demand for CNG passenger cars as well.

The development of CNG infrastructure is being stunted by various regulations and policies that are presently or have been enacted in the past. The data with Star Transportation Group in specific, showed that the Natural Gas Energy Development Program administered by Pennsylvania's Department of Environmental Protection under Act 13 of 2013, is allocating $20 million in grants for the purchase or conversion to a natural gas vehicle (Pennsylvania Department of Environmental Protection (PADEP), 2013). However, this program in specific prohibits Program funding to be used for the development of fueling stations or any other fueling infrastructure. The program grants up to $25,000 per vehicle for home fueling stations enough to construct two stations, which range in cost from $7,500 to $10,000 each. The cost for constructing a public fueling station is more expensive, ranging from $0.6 to $1.2 million. There existed some policies in place to assist fleets, such as the PA Alternative Fuels Incentive Grant, which have grants as large as $700,000 to facilitate the building of fueling stations (Pennsylvania Department of Environmental Protection (PADEP), 2013). However, the program is closed and there is no longer enough incentive for the development of public stations. The Energy Policy Act of 2005 provides up to a $30,000 income tax credit for the development of fueling stations. Again, this funding is sufficient enough to cover the costs of home fueling stations but not larger stations accessible to the public.

Findings

Veteran's Taxi is the only Pittsburgh taxi fleet utilizing natural gas with 17 MV-1 taxis running on CNG. Based on an interview with Bob DeLucia, CEO of Star Transport, parent company of Veteran's Taxi, their biggest barriers are fueling stations outside the immediate Pittsburgh region (DeLucia, 2013). Veterans Taxi uses the two public fueling stations in Pittsburgh, EQT and Giant Eagle. The lack of infrastructure limits their CNG fleet from making long ranged trips extending outside of the city.

NGV slightly reduces the PM2.5 emissions compared to gasoline emissions, however, because NGV gets lower mpg efficiency, the PM2.5 emissions reduction for cars is essentially negligible.

The payback period for a passenger vehicle, using best guess assumptions, would be approximately 19 years. This exceeds to assumed 6-year owner lifetime. The payback analysis is most strongly affected by the fuel differential price, which is difficult to foresee. The payback period is also heavily dependent on the amount of miles traveled. Even with the most optimistic assumptions, a passenger vehicle payback period is expected to be over 15 years.

However, because of the significant increased amount of miles traveled, the payback period for a taxi, with best guess assumptions, is around 1.5 years. Based on an interview the lifetime of a taxi is 8 years, and the hopeful payback back period is 2 to 3 years. Both the optimistic payback analysis and best guess payback analysis fall within 2 years. Because of the large sensitivity to fuel differential price, the worst case could be upward 50 years.

Policies

Existing Policy

Pennsylvania has created its own incentives for NGVs. In 2012, the Pennsylvania Department of Environmental Protection (PA DEP) created Act 13, a three-year Natural Gas Energy Development Program. This program provided $20 million in grant funds over three years for municipal and commercial fleets to convert or purchase NGVs. In addition, PA DEP held multiple seminars across the state to educate the public on this technology advancement and opportunity. According to PA DEP the purpose of this program, "is to help municipal and commercial fleet owners make informed decisions regarding converting fleets" (Pennsylvania Department of Environmental Protection (PADEP), 2013). On the local level, Pittsburgh currently has no policies, specific to the city, in place to promote NGVs, however they are making a push to educate municipal and commercial fleets on the opportunity of cheaper, cleaner fuel. Applications for medium to light-vehicles will be opening in May 2013 (Pennsylvania Department of Environmental Protection (PADEP), 2013).

For passenger vehicles, Pennsylvania has Alternatives Fuels Rebates for the purchase of new plug-in hybrid, plug-in electric, natural gas, propane and hydrogen fuel cell vehicles. Consumers can receive up to $1000 on a new purchased compressed natural gas fueled vehicle. Flexible fuel and diesel vehicles are not eligible (Pennsylvania Department of Environmental Protection (PADEP), 2013).

The Energy Policy Act of 2005, as mentioned above, also provided an income tax credit for the purchase of new natural gas vehicles. This incentive expired in 2010 because the IRS determined that a sales contract of a new NGV was not enough to claim the tax credit. The only provision within this act that was extended through 2013 was the bonus depreciation at 50 percent of original cost (Natural Gas Vehicles for America (NGVA), 2012).

Federal EPA regulations make converting a light-vehicle to natural gas a strict process. In 1997, an amendment to the Clean Air Act prevented any "tampering" to the car engine (EPA, 2013), which does not make the conversion to a natural gas tank an easy process. The EPA has established exceptions to this regulation if the car owner shows that the engine conversion was done under proper EPA standards so that the engine does not increase emissions (EPA, 2013). All converted natural gas vehicles are considered re-built and re-titled, and must be EPA inspected and certified, and all new natural gas cars must be EPA certified. These inspections can only be performed at inspection stations with proper certification to do so (Shauk, Zain, 2012). This certification process is hindering natural gas conversions of personal vehicles because the in-depth process and the potential scarcity of NGV EPA certified inspection stations and mechanics.

Policy Analysis

The analysis of the potential policies for cars focused on looking at four different criteria for the analysis: the overall effectiveness at meeting the policy goal, the economic efficiency for the goal, the political responsiveness of the policy, and how equitable the policy would be. Overall efficiency focused on how successful the policy would be at meeting the desired end goal of the outcome.

Economic efficiency focused on the economics of the policy, and whether it would be the most fiscally efficient policy to achieve that goal. Political responsiveness focused on how receptive citizens would be to the policy. Equity focused on how fair and equitable the distribution and risk and funds in the policy were.

When looking at car specific policy, the analysis focused on three different types of policies. The first was looking at the status quo, or the policies currently in place. For both fleet/taxi cars and passenger cars, the status quo was AFIG, or Alternative Fuels Incentive Grant. Under AFIG and Act 13, a variety of funds are available for natural gas vehicles in Pennsylvania. The analysis also looked at how viable improving the economics of purchasing cars would be. Finally, policies improving infrastructure in the Pittsburgh region were analyzed. Figures 14 and 15 shown below provide a visual representation of how those policies were analyzed, with + to denote effective in the area, 0 to denote neutrality, and a – to denote ineffectiveness.

Option	O	E	R	Q
A: Status Quo: Alternative Fuels Development Program - Does not provide enough incentive - $1000 does not make NG vehicles economical - Is responsive, as all taxpayers can take advantage - No sharing of risk	-	-	+	+
B: Vehicle Economic Incentive: Bring back the Policy Act of 2005 (lapsed in 2010) - Subsidies and targets private individuals - Still does not make average vehicles viable - Federal Policy, do not all taxpayers would benefit - Reduces risk to individuals	+	-	-	+
C: Infrastructure Service Provision: Funding for private and public stations. - Infrastructure is costly, and is currently needed to increase adoption - Risk of putting money into infrastructure without enough demand for fuel - Tax payers are still getting the same benefit - Shifts risk onto infrastructure without knowing demand	+	-	0	-

Figure 14: Policy analysis for natural gas passenger cars.

Looking at passenger cars, the status quo is a very ineffective policy in place. The current policy, AFIG, offers up to $1,000 toward the purchase of a new natural gas car. However, this policy is ineffective in many regards. Since the goal of the policy is to get private consumers to purchase cars, the policy fails in stated goals. Natural gas passenger cars are not bought for a variety of reasons, some economic, but others related to the design of the cars with limited range and fueling availability. In addition, the policy fails economically since the numerical analysis shows that natural gas passenger cars are very inefficient from a monetary perspective. With payback periods greater than the economic lifetime, the afforded incentive is simply not enough to make those cars economically efficient. A $1,000 subsidy would drop the conversion cost to $7,000, but that still puts the payback time well over the lifetime, at 16 years. The policy is responsive politically, since the people benefitting from the policies are the ones paying for. The policy is state funded and granted to the whole state, so it is responsive in that matter. The policy is also equitable, since it simply subsidizes the cost of the new vehicles and is fair in its distribution of risk and funds.

The second suggested policy was to improve the subsidies for purchasing a car, but it is an ineffective overall policy. Much like the status quo policy, AFIG, it only addresses the economics of purchasing new natural gas vehicles, and does not address the other qualitative concerns new consumers may have about the vehicles. In addition, the economics of passenger cars right now are so inefficient that any reasonable policy would not provide enough to warrant many consumers to purchase new cars. For the payback time to drop below 3 years, the time period that most consumers are comfortable with when purchasing vehicles such as natural gas, the conversion cost would have to drop below $1,400, when it is currently $8,000. The policy to make payback periods less than 3 years for the average consumer would have to subsidize over 80% of the conversion cost, which is simply infeasible. The policy is politically responsive because, much like AFIG, the people benefitting are the ones paying for it. Also like AFIG, the policy is equitable since it is just a larger subsidy.

The third suggested policy was to provide infrastructure funding to develop more private and public stations in the greater Pittsburgh region. This policy's goal is to provide greater access to fueling stations to the users of cars, thus reducing the concerns of infrastructure to potential new buyers. As such, the policy would be somewhat effective overall in reaching its stated goals. However, infrastructure is not the only barrier in the way of purchasing new vehicles for consumers, so the policy would not be as effective in regards to the goal. The policy may not be economically efficient, as the economics of new fueling stations depends heavily on the demand going through the station. The level of subsidies offered for developing new stations may not be enough to incentives private developers to create the stations since there is a large risk associated with building new stations due to current lack of demand. The responsiveness would also be low with the policy since the taxpayers would not necessarily be seeing a benefit. The policy is also inequitable, since there is still a large risk on those building new stations without there being associated demand. The policy helps mitigate some of that risk, but it still exists.

Option	O	E	R	Q
A: Status Quo: Alternative Fuels Development Program - Currently being taken advantage of - Payback analysis shows taxis don't need this - Currently effective due to being taken advantage of - Benefits accrued to first adopters	+	-	+	+
B: Vehicle Economic Incentive: Bring back the Policy Act of 2005 (lapsed in 2010) - Will be effective in saving money - Analysis shows taxis are viable without subsidy - No group is developing an additional cost - Risk increases for those taking policy, decreases for those not involved	+	+	+	0
C: Infrastructure Service Provision: Funding for private and public infrastructure. - Infrastructure is costly, and is currently needed to increase adoption - Risk of putting money into infrastructure without enough demand for fuel - Tax payers are still getting the same benefit - Shifts risk onto infrastructure without knowing demand	+	0	+	-

Figure 15: Policy analysis for natural gas taxis.

For taxis, the current status quo policy in place is the AFIG grants for fleets. This grant offers a large sum to fleets seeking to convert their vehicles to natural gas, with up to 20m being afforded to fleets over 3 years. This policy is very effective in reaching its stated goals, as it incentivizes new vehicles being purchased by fleets, and this is seen occurring in Pittsburgh by companies such as Veteran's Taxi. However, this policy does not address the qualitative concerns especially that of access to fueling stations. However, this policy may not be very economically efficient, given that the payback analysis shows that taxis would be viable without any subsidies, at fewer than 2 years, so money may be wasted with this policy. The policy is responsive since it is much like the private consumer part of AFIG, and the fact that it is in place currently with little resistance. The policy is also equitable, since it does not unfairly shift funds or risk onto other parties

A policy suggestion that may be considered is that of reducing or removing the funding currently in place for fleets. The goal of this policy would be to shift resources from a vehicle that is already viable into another area, perhaps to address another barrier to their adoption. As such, reducing resources would be effective in that regard. Economically, since the analysis shows that these vehicles are already viable, reducing the resources would be beneficial and more effective. As the payback period for the best guess is already under 2 years, there is little need for the existing policies and reduction in subsidies would reduce waste on the government's part. This policy would be politically responsive, since those paying for it would need to pay less, and would not oppose it. This policy is also equitable, because it reduces risk on the governments and taxpayers' part. It increases risk on those who purchase new vehicles, but since they are already fairly viable, such a risk should not be a concern.

Finally, the last suggestion is to increase the infrastructure availability by subsidizing the construction of new fueling stations. Much like the effectiveness for private fleets, such policy would be somewhat effective at reducing one of the barriers that fleets have regarding utilizing new natural gas vehicles. Unlike with passenger cars, infrastructure is the single largest barrier for taxi fleets. The concerns of smaller range and trunk space are not as large, and in fact fleets such as Veterans Taxi have not considered them issues (DeLucia, 2013). Infrastructure is the barrier to adopting more vehicles, and therefore addressing that barrier is important to achieve the goal of greater adoption. Such a policy would be of variable economic efficiency, since demand for new vehicles is shakier, and increased spending could be risky. However, since natural gas vehicles are fairly viable as fleet cars, it would be likely to be more economically efficient since infrastructure is the largest barrier for fleets. However, this policy would not necessarily be very responsive, as all may not immediately feel the benefit and the infrastructure is risky. It would also not be the most equitable, because infrastructure is risky, and while it reduces the risk of an important component toward utilizing those vehicles, it may not reduce it enough leaving it still inequitable.

Recommendations

Based on the payback analysis, and the analysis of the policies, the best area to go forward seems to be increasing use of taxi and fleet natural gas cars. The payback period of passenger cars is simply too long to be viable, and focusing on addressing the other barriers does not suggest that the cars would be adopted after the barriers are solved. Therefore, focusing on taxi cars seems most relevant. Given that taxi cars are by themselves so viable, there are two possible recommendations. Both focus on shifting current AFIG resources. The AFIG resources toward passenger cars do not seem viable given how ineffective it is, and the AFIG resources toward fleets seem excessive given how effective they are. The first is to **shift resources from the current policies in place and move them toward addressing infrastructure issues.** Taxis are already very viable without additional fiscal assistance, but the biggest barrier they face is the lack of infrastructure. Shifting resources would allow that barrier to be addressed, while reducing the excessive spending on a subsidy that is not necessary. Shifting current resources already in place, as opposed to adopting new ones, also reduces the risk that the government would take on, making the movement of current resources ideal. The second recommendation is to **shift resources way from current policies in place and move them toward other vehicles or issues.** The one concern with shifting resources toward taxis is the relatively small amount of them in the Pittsburgh region. With only around 500 vehicles to convert, even converting every single taxi may not provide to be worth the large costs new infrastructure would warrant. Depending on the size of the subsidies to develop infrastructure, the small amount of demand that all the fleet vehicles would offer may not provide economically viable. Unfortunately, with how inefficient natural gas cars are for private consumer use, it is unlikely that there would be sufficient increased demand from the public to warrant large subsidies to such public infrastructure, making shifting resources to better alternatives in other vehicles a more fruitful endeavor.

3.2 Buses

Introduction

One important possible venue for adoption of natural gas vehicles is in the public bus transportation system. Buses have been seen to be plausible options because of their significant consumption of diesel, contribution to air pollution, and repeated travel routes. Natural gas buses have been in use since the mid-1930s when they were first adopted in Italy (Yeh, Sonia, 2007). A common aspect of existing natural gas bus systems is "strong government promotion" encouraging the transition with subsidies, rebates, and/or tax incentives (Yeh, Sonia, 2007). In this study we examine large urban transportation buses, shuttle buses, and school buses.

While some believe that natural gas technology is new and therefore risky territory, many large-scale implementations occurring both nationally and internationally have been successful. The technology for all bus type engines is readily available and proven elsewhere in the world and in the U.S. However, the transition to natural gas buses is by no means inevitable. In 2000, 1,140 buses were replaced with 450 new clean running diesel vehicles in Bogota, Columbia instead of being replaced by highly recommended compressed natural gas vehicles (CNG Now, 2013) (Valderrama Andres; Beltran, Isaac, 2000). Not only were CNG vehicles a viable option because of the amount of natural gas located within Columbia, but also because natural gas proved to be a reliable and cleaner fuel than the diesel currently used. The question of CNG performance amidst steep hills and high elevation paired with the lack of governmental incentives, argued to take the "least technical resistance path of diesel" (Valderrama Andres; Beltran, Isaac, 2000). In California, the Placentia-Yorba Linda Unified School District replaced 6 diesel buses with CNG alternatives. The drivers have been impressed with the power, and feel of the buses, while parents and administrators have noted the lack of dirty exhaust. In Pittsburgh, UPMC is replacing 20 diesel-powered shuttle buses with 20 CNG-powered buses.

Technology

Currently there are two CNG school buses available on the market, the 'SAF-T-LINER HDX CNG' by Thomas Built Buses and the 'All American RE' by Blue Bird. Both buses run on the Cummings ISL G compressed natural gas engine. The HDX CNG is a Class-D school bus and can hold 90 passengers. Class D buses are larger than the standard Class-C school buses and have the entrance door in front of the front axle. Thomas Built Buses plan to release a Class-C CNG bus in 2015 (Milkin, Mike). The All American RE is also a Class-D school bus with seating for 84 passengers. As documented by Natural Gas vehicles for America, the available engines for school, shuttle, and transit buses are the Cummins Westport Inc. 8.9L ISL G spark-ignited engine and the Emission Solutions Inc. 7.6L NG Phoenix spark-ignited engine.

Environment and Emissions

Pittsburgh, through its past, gained the reputation for being the "Smokey City" for emitting a lot of environmentally unfriendly toxins into the city's air. However, since this dark past, Pittsburgh has made great efforts to improve the air quality and bring the city into a brighter future. One of the more important strategies is to curb the emissions from the city's transportation vehicles.

A study done in Delhi, India demonstrates the environmental benefits of reducing air pollution via cleaner exhaust CNG buses. The support for this initiative came in 2001 following a lawsuit regarding air quality. Expressing the severity of the pollution problem in this area, "Delhi's polluted air is blamed for 40% of emergency hospital admissions of patients with breathing and heart complaints" (Goyal, Sidhartha, 2003). Following many extensive ambient air quality tests and studies, the Indian government decided to continue with the implementation of the conversion to a CNG fleet and has since seen "decreasing trend of pollutants concentrations" (Goyal, Sidhartha, 2003). However, A recent study in Finland even found that "the CNG vehicles, on average, [had particle mass and number emissions] equivalent to CRT filter equipped diesel vehicles" (Nylund, Nils-Olof; Erkkila, Kimmo, 2004).

Survey Information

The buses group sought out to gather information by conducting a survey constructed to gain valuable information that was not readily available online or in other data. The bus group was investigating three types of buses in the Pittsburgh region because they serve different purposes, use different technology, and require various amounts of economic assistance. For the bus group project, transit, school, and shuttle buses in the Pittsburgh region were the types of buses for analysis. In order to get the most information from the survey, the group decided to contact fleet managers for each of the bus type. The thinking behind the decision of whom to issue the survey to was that these people would know the most about the economic aspects as well as the technological aspects of their fleet. The fleet managers would also have the best knowledge of their vehicles fuel usage and miles traveled.

The bus group reached out to Ken Robinson, Garage Manager from the Port Authority, numerous Pittsburgh school district transportation managers, and Bart Wyss, the Assistant Director of Transportation and Operations for UPMC. Significant data was not gathered from the Port Authority or the Pittsburgh school districts. However, a complete survey was obtained from Bart Wyss of UPMC. Through that survey, the bus group learned that the UPMC fleet had a total of 54 shuttle buses that were in operation. Thirteen of those were already CNG powered and that Mr. Wyss had just put in an order for seven more CNG powered shuttle buses that were to be delivered in June of this summer. We learned that currently at UPMC's fleet burns on average per month 5,270 gallons of Diesel and 4,904 equivalent gallons of CNG for a total monthly average of 10,174 gallons used. The fleet on average travels 565,488 miles per year with the shuttle bus vehicles. The typical lifespan of UPMC shuttle bus is approximately a million miles per engine and they are working on a vehicle replenishment program that would turn over every seven years. The cost to retrofit a current shuttle bus from diesel to CNG capabilities is $22,000-$28,000 and the cost to purchase brand new CNG operated shuttle buses costs $84,000 for a 22 passenger shuttle bus and $104,000 for a 33 passenger shuttle bus. Another important difference that was learned from Bart in comparison to the other buses as well as vehicles is that UPMC shuttle buses refuel once daily at public fueling stations and do not view this as a problem. Transit and school buses face many infrastructure problems while the shuttle buses do not experience this. Also, Mr. Wyss informed us that UPMC plans to convert their entire employee shuttle bus fleet to CNG as well as eventually other UPMC operated vehicles. The finding that UPMC is already converting their fleet to natural gas led the bus group to conclude that an analysis of shuttle buses was not necessary.

Economic Feasibility

The economic feasibility of natural gas buses depends on the type of bus and also the governmental subsidies, tax breaks, and policies that may be in place to help offset the steep startup cost. There are several instances of natural gas bus adoption in the Pittsburgh region, but all have taken advantage of existing incentive programs.

UPMC is replacing 20 diesel-powered shuttle buses with 20 CNG-powered buses. Funded by $500,000, this program will also promote CNG to other businesses in the Pittsburgh region as well as in other vehicles used at UPMC. UPMC claims that this program creates of jobs, reduces diesel usage by 65,000 gallons per year, and avoids 214 tons of greenhouse gas that would have been emitted from the diesel-powered shuttle buses. (UPMC Adds Natural Gas Vehicles, Charging Stations, 2013)

The Port Authority has shown some interest in converting to natural gas vehicles (Litvak, Anya, 2012). However they are concerned about the costs of converting to Natural gas. According to a study done by EQT Corp, it would cost the Port Authority approximately $20 million to convert to natural gas and then the Port Authority would see saving of $3 million annually (Fontaine, 2012). The Port Authority could recoup its losses in approximately seven years. However, past Port Authority CEO Steve Bland felt that the service did not have the funds to pay for the initial upfront cost. EQT directors did note that the Port Authority could receive $8 million in grants to help shoulder the $20 million burden and the $3 million in grants has been set aside to fund fueling station conversions.

School bus fleets have very different characteristics than a public transportation system. The school bus fleets in the Pittsburgh area are not well suited for a conversion to natural gas. The Pittsburgh Public School district contracts over 30 different bus operators to service the students in the region. This makes it infeasible to build any refueling infrastructure, as it would only service one company's buses. Additionally, school buses in this region do not travel nearly as many miles as transit buses, so the savings on fuel costs will be much lower than for transit buses.

Infrastructure

An important aspect of a potential switch to a new fuel source is the availability of the fuel both for private and public use. In the Pittsburgh Metropolitan area there are three CNG fueling stations available to the public (CNG Now, 2013). Giant Eagle is also planning to build two more stations in Cranberry and Waynesburgh (Leonard, Kim, 2013). However, the number of NG fueling stations pales in comparison to the number of traditional gasoline/diesel fueling stations in Pittsburgh. If natural gas vehicles are to be a viable option, more of these stations would need to be built. There are also over 20 natural gas refueling stations that are privately owned and operated (Shipley, Eric, 2002).

For the Port Authority to invest in natural gas buses, they would need to invest in both a refueling site and an adapted garage for storing the natural gas vehicles. The Port Authority estimates that they would need $18 million in startup capital to retrofit one of their current garages, and one of their maintenance facilities (Schmitz, Jon, 2012). Additionally to service the bus fleet's needs, they would need to use a fast-fill refueling method so the buses could fuel quickly and return to their routes. This is more costly than a time-fill refueling system.

Assumptions for Payback Analysis

School Buses

The table below (Table 10) has the values used as parameters for the School Bus Payback Analysis. The conversion cost data comes from a feasibility study of natural gas vehicle conversion for Wyoming Public School Districts. The number of miles traveled per year was obtained from the National Transit Database in a document entitled "Transit Agency Information. The range of miles traveled was between 8,000 and 12,000 miles. The average, 10,000 miles, was used as the best guess. The fuel efficiency in mpg ranged from 3 to 7 mpg from a summary given by the American School Bus Council when discussing the environmental benefits of school buses. The school bus average lifetime ranges from 8 to 15 years according to the National Associate of State Directors of Pupil Transportation Services' report on school bus replacement considerations. From this range, the average school bus' lifetime is 11.5 years, which was rounded to 12 years for this analysis. The total number of school buses comes from the Pennsylvania Department of Motor Vehicles' 2012 Report on Registration.

Table 10: Input Parameters for School Bus Payback Analysis

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/ gal-eq)	PM2.5 Reduction (tons/yr)	Lifetime (yr)	Price differenti al ($/gal-eq)	PM2.5 Reduction Benefit ($savings/ton)	Total vehicle number (#)
Best Guess	30,000	5%	10,000	5.000	9.95E-03	12	1.89	240,000	6794
Minimum	20,000	3%	8,000	3.000	3.00E-06	8	0.24		5000
Maximum	40,000	7%	12,000	7.000	7.00E-06	15	2.00		7000

Transit Buses

The table below (Table 11) has the values used as intimal parameters for the Transit Bus Payback Analysis. The conversion cost data comes from the same data for school buses, as both types of buses use the same engines. The number of miles traveled per year was obtained from the National Transit Database in a document entitled "Transit Agency Information. The number of miles traveled for all cases was obtained from a presentation by Ellen Mclean, the Interim Chief Executive Officer at Port Authority of Allegheny County. The fuel efficiency in mpg ranged from 4 to 7 mpg was calculated using the miles traveled per vehicle and data on the number of gallons of fuel used per vehicle, both from the National Transit Database. The transit bus average lifetime ranges from 4 to 5 years comes from personal communication with Ken Robinson of the Allegheny Port Authority. Form the range the average of 4.5 years was used at the best guess lifetime. The total number of school buses comes from the Pennsylvania Department of Motor Vehicles' 2012 Report on Registration.

Table 11: Input Parameters for Transit Bus Payback Analysis

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/ gal-eq)	PM2.5 Reduction (tons/yr)	Lifetime (yr)	Price differential ($/gal-eq)	PM2.5 Reduction Benefit ($savings/ton)	Total vehicle number (#)
Best Guess	50,000	5%	65,219	6.550	0.01518	4.5	1.89	240,000	687
Minimum	30,000	3%	39,103	4.000	0.01841	4	0.24		667
Maximum	70,000	7%	143,793	7.000	0.05133	5	2.00		700

Pittsburgh Payback Analysis

For the quantitative analysis for both transit and school buses was completed by completing both payback period and supply curve analysis. No analysis was completed for shuttle buses because of the significantly small fleet size and because UPMC already implemented the transition to CNG operated buses. The payback period calculated for transit buses is 2.92 years and 10.92 years for school buses. This school bus payback period is nearly the same as the best guess estimate of its lifetime of twelve years and thus does not show a good return on investment to occur within an ideal time frame. The transit bus's short payback period shows that investment into diesel to CNG conversion would pay itself off very quickly and offer good returns. Like all other vehicle fleets studied, the most sensitive variable in determining payback period is the fuel price differential. The high volatility and exceedingly difficult task of predicting future petroleum and natural gas fuels makes the guesses inaccurate and subject to change. The extensive supply curve analysis consisted of creating individual economic benefit, environmental benefit, energy independence, and social welfare supply curves for both transit and school buses. The supply curve analysis in each case of economic, environmental energy independence, and social welfare benefit all showed that the magnitude of the total benefits was greater for school than transit buses and this is because of the significantly larger fleet size. The net benefit dollar amount was always greater for transit than school buses because of the good conversion cost leading to solid economic benefit, the poorer emission rate leading to greater PM2.5 reduction, and the lesser fuel economy leading to more gallons of petroleum replaced. The proceeding series of charts summarize the results of the payback analysis using the number discussed in section 3.2.3. 6

School Buses

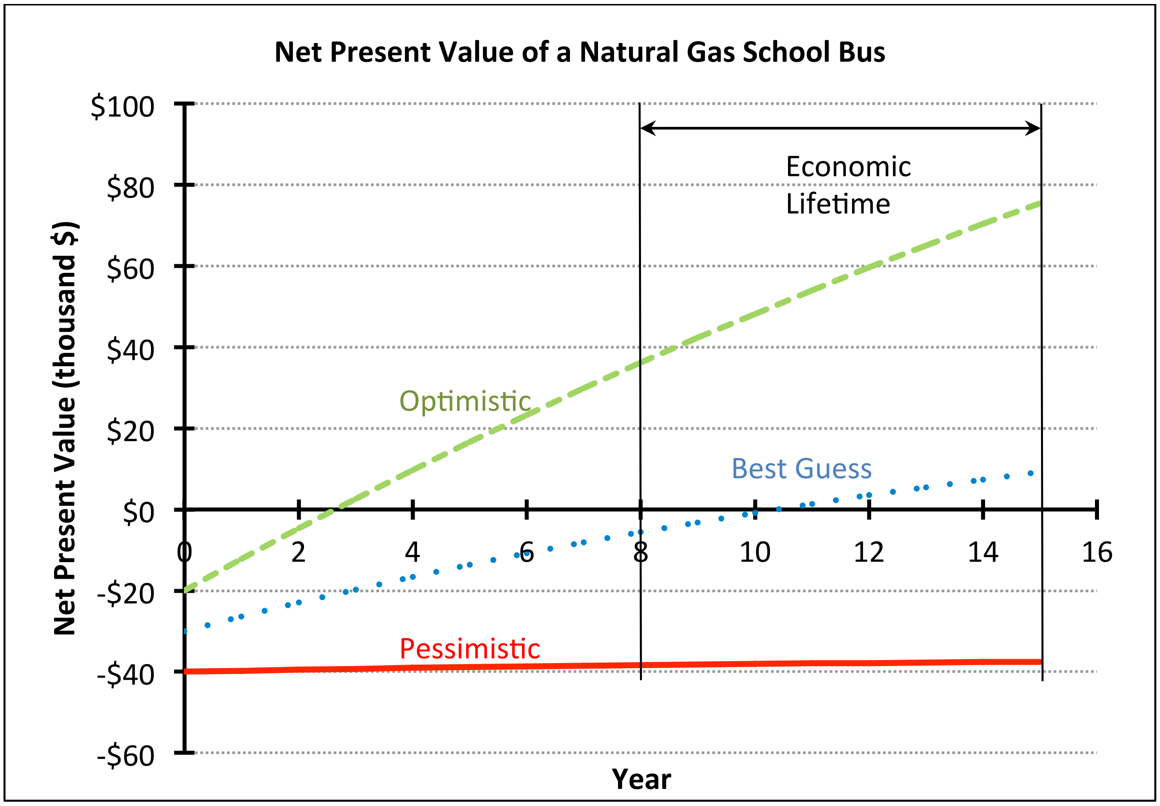

Figure 16: Net Present Value for natural school buses.

Figure 16 summarizes the expected payback periods for school buses. On the graph, the optimistic, best guess, and pessimistic net present values for each for the natural gas school buses are plotted. For the optimistic case, it would take approximately three years to recover the initial conversion costs for the natural gas bus. For the best guess, it would take approximately ten years to recover the cost. For the pessimistic guess, it would take over 15 years to recover the conversion costs, which is outside of the expected lifetime of the vehicle. Using the best guess, conversion costs are recovered within the economic lifetime of the vehicle, indicating it is useful to convert to natural gas, but the benefits would not be reaped until the end of the life of the bus.

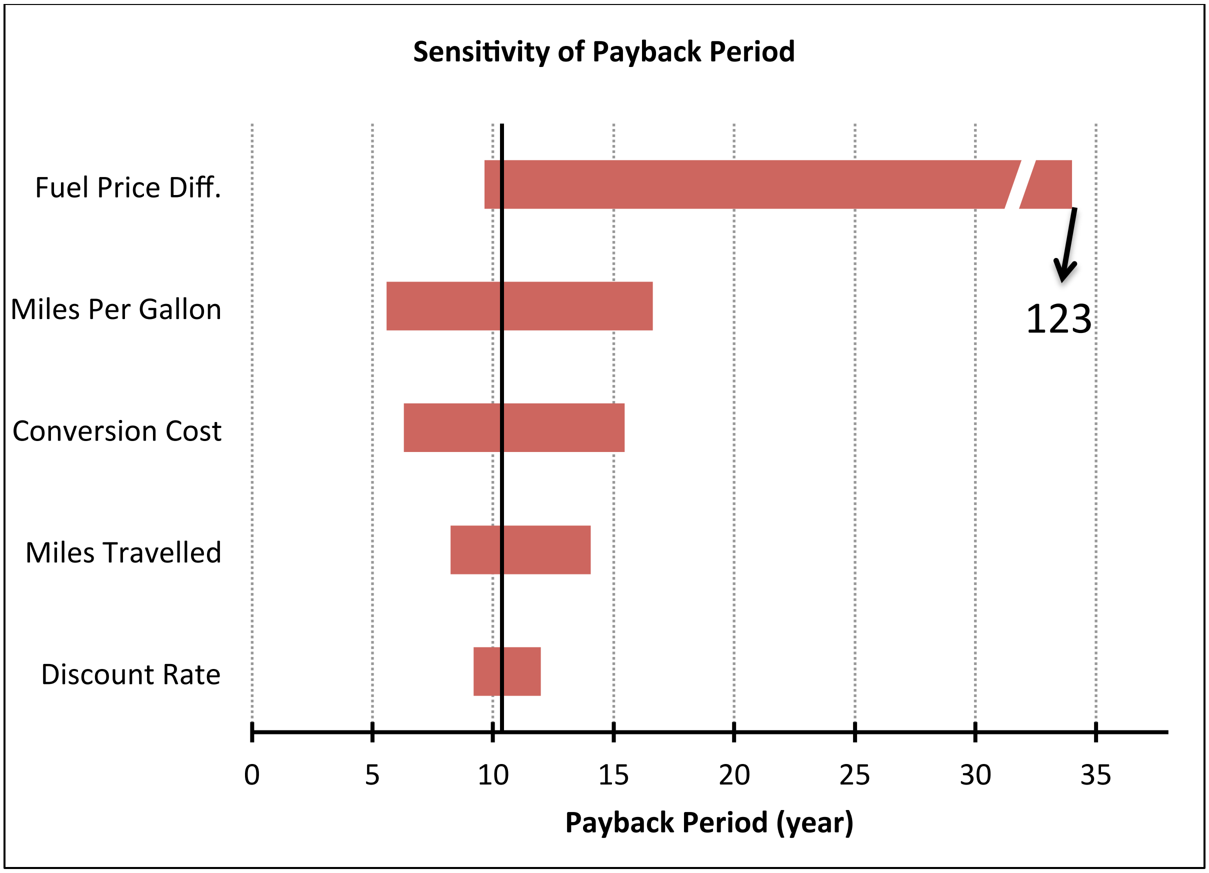

Figure 17: Tornado diagram of payback period sensitivity analysis.

The tornado diagram (Figure 17) above looks at the sensitivity of payback periods due to the sensitivity of the five parameters on the left hand side of the figure. The payback periods run from the best guess of the parameter on the left and the pessimistic guess on the right. The sensitivity of the fuel price differential leads to payback periods ranging between 3 and 123 years. From this chart, one can deduce that there is a large uncertainty in the payback period based on changes in the price differential. More confidence is needed in the price differential in order to ensure potential vehicle conversions will see payback periods within the economic lifetime of the school bus.

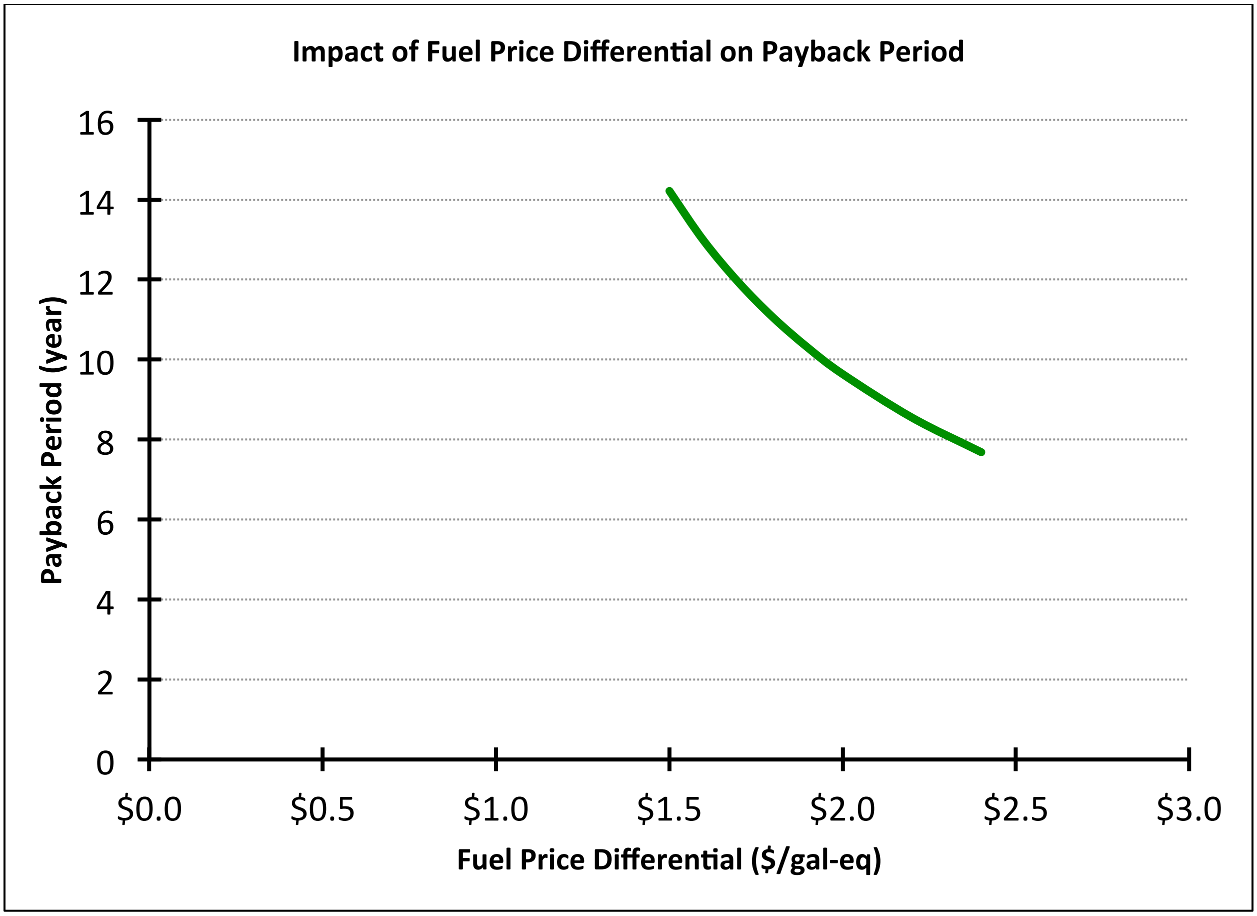

Figure 18: Fuel price differential impact on payback period for school buses.

Figure 18 looks at the impact of fuel price differentials on the payback periods for school buses in the Pittsburgh area. As the price differential increases from $1.50 to $2.40, the payback period decreases from 14 to 7 years.

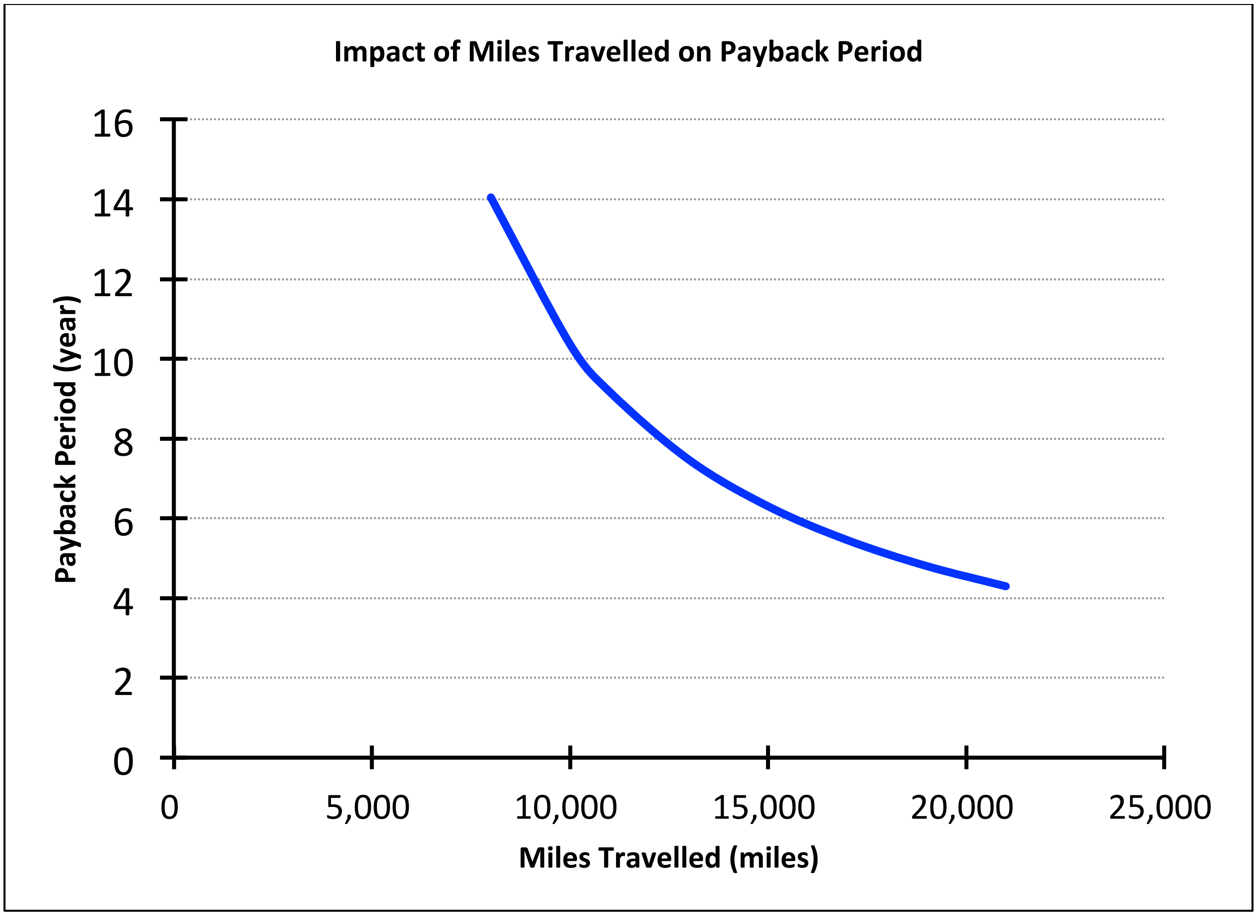

Figure 19: Miles traveled impact on payback period for school buses.

Figure 19 looks at the impact of miles travelled on the payback period for school buses in the Pittsburgh region. As the number of miles traveled increases from 8,000 to 21,000 miles, the payback periods decreases from 14 to 4 years.

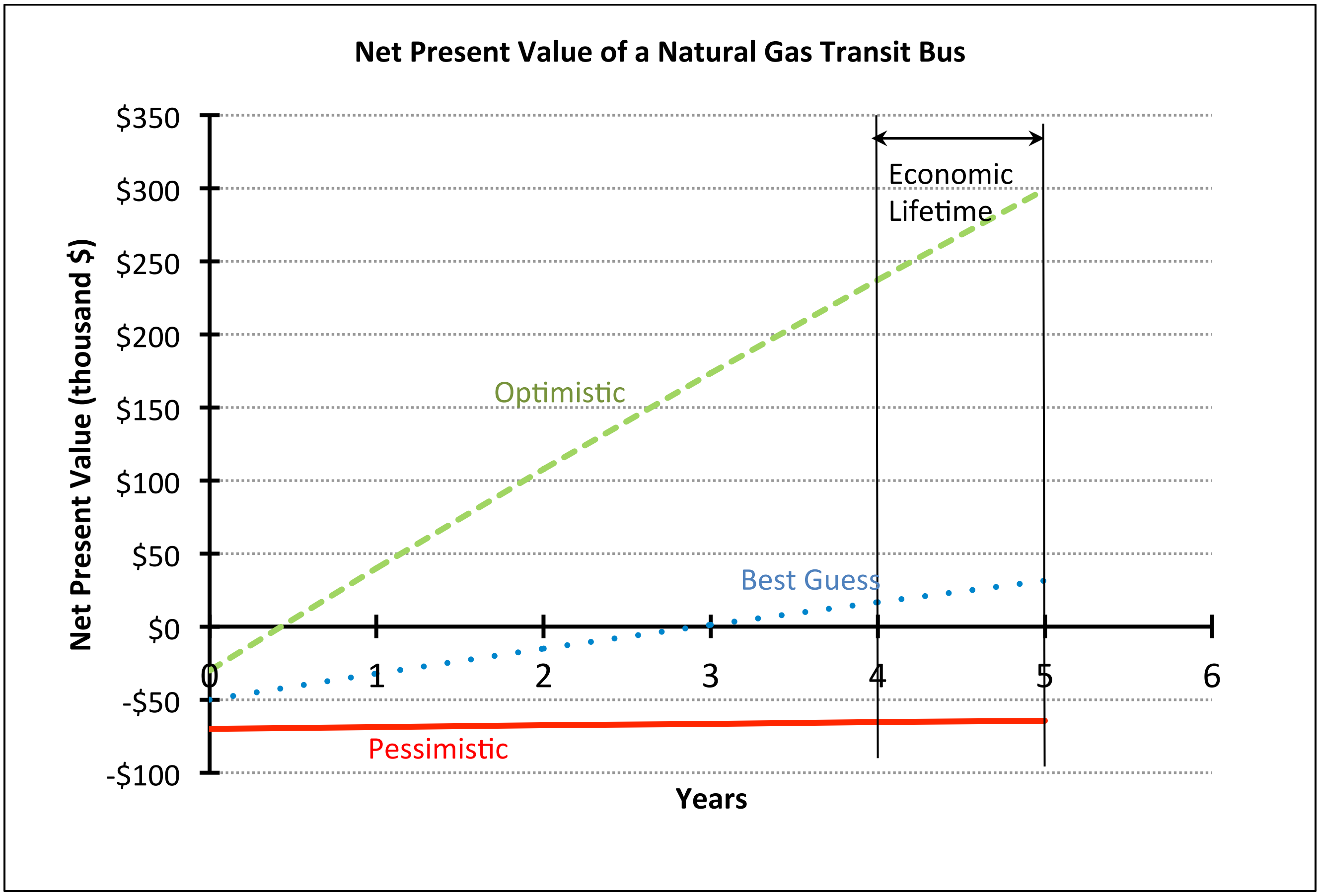

Figure 20: Net present value for natural gas transit buses.

Figure 20 summarizes the expected payback periods for transit buses. For the optimistic case, it would take less than one year to recover the initial conversion costs for the natural gas bus. For the best guess, it would take three years to recover the cost. For the pessimistic guess, it would take over 5 years to recover the conversion costs, which is outside of the expected lifetime of the vehicle. Using the best guess, conversion costs are recovered within the economic lifetime of the vehicle, indicating it is useful to convert to natural gas, and benefits would be reaped for one to two years before the bus needs to be retired.

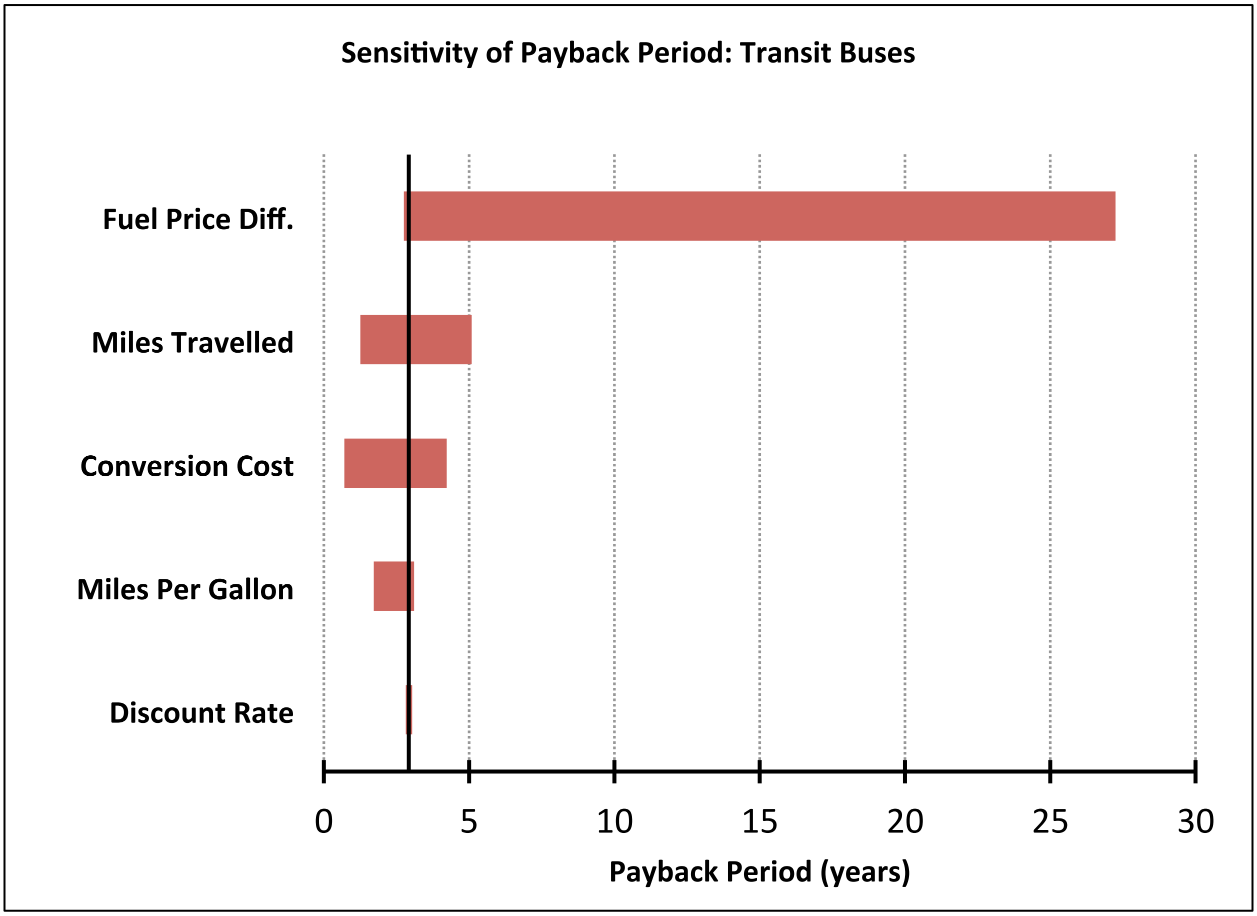

Figure 21: Tornado diagram for the payback sensitivity analysis on transit buses.

The tornado diagram above (Figure 21) looks at the sensitivity of payback periods due to the sensitivity of the five parameters on the left hand side of the figure. The payback periods run from the best guess of the parameter on the left and the pessimistic guess on the right. The sensitivity of the fuel price differential leads to payback periods ranging between 3 and 27 years. From this chart, one can deduce that there is little confidence in the payback period based on changes in the price differential. More confidence is needed in the price differential in order to ensure potential vehicle conversions will see payback periods within the economic lifetime of the transit bus.

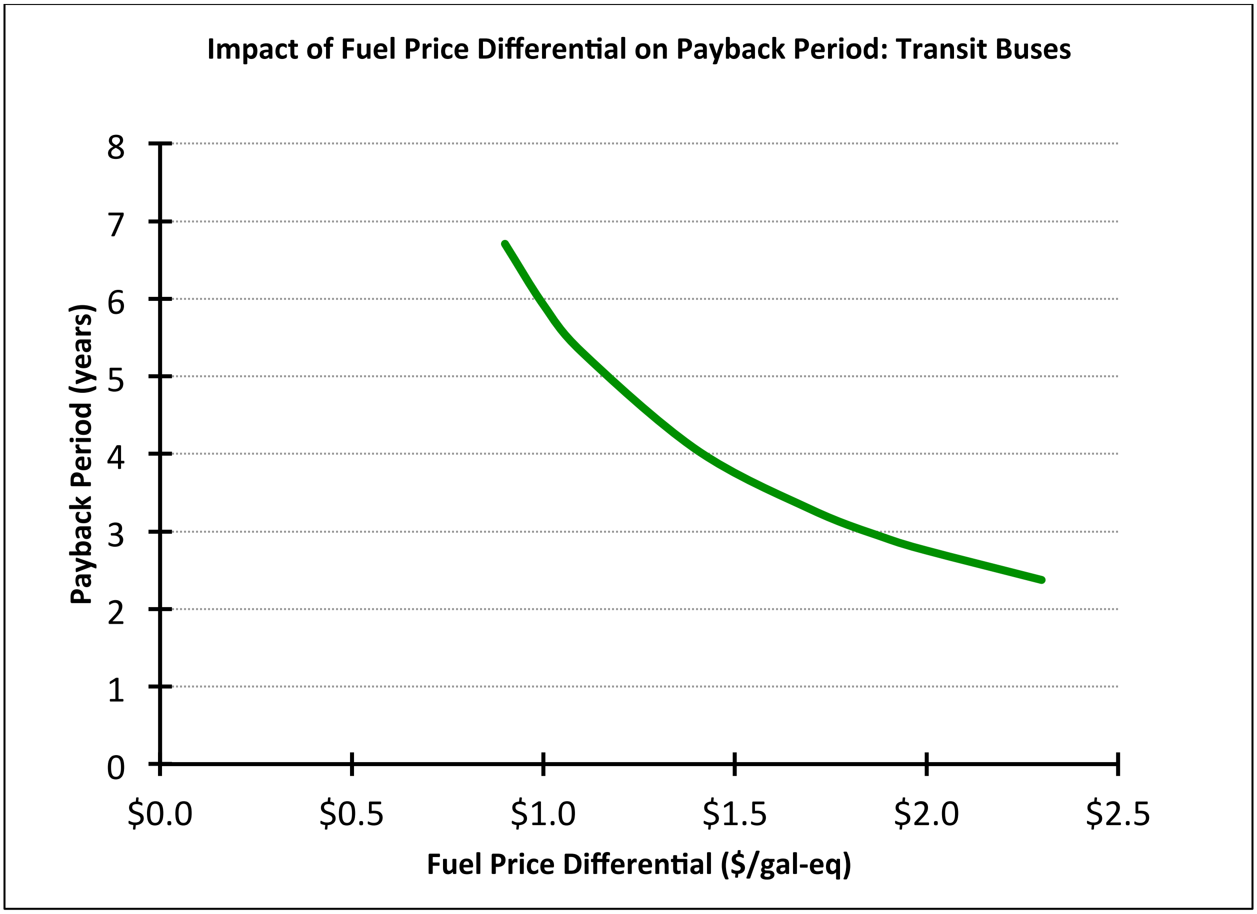

Figure 22: Fuel price differential impact on payback period of transit buses.

This chart (Figure 22) looks at the impact of fuel price differentials on the payback periods for transit buses in the Pittsburgh area. As the price differential increases from $0.90 to $2.30, the payback period decreases from 7 to 2 years.

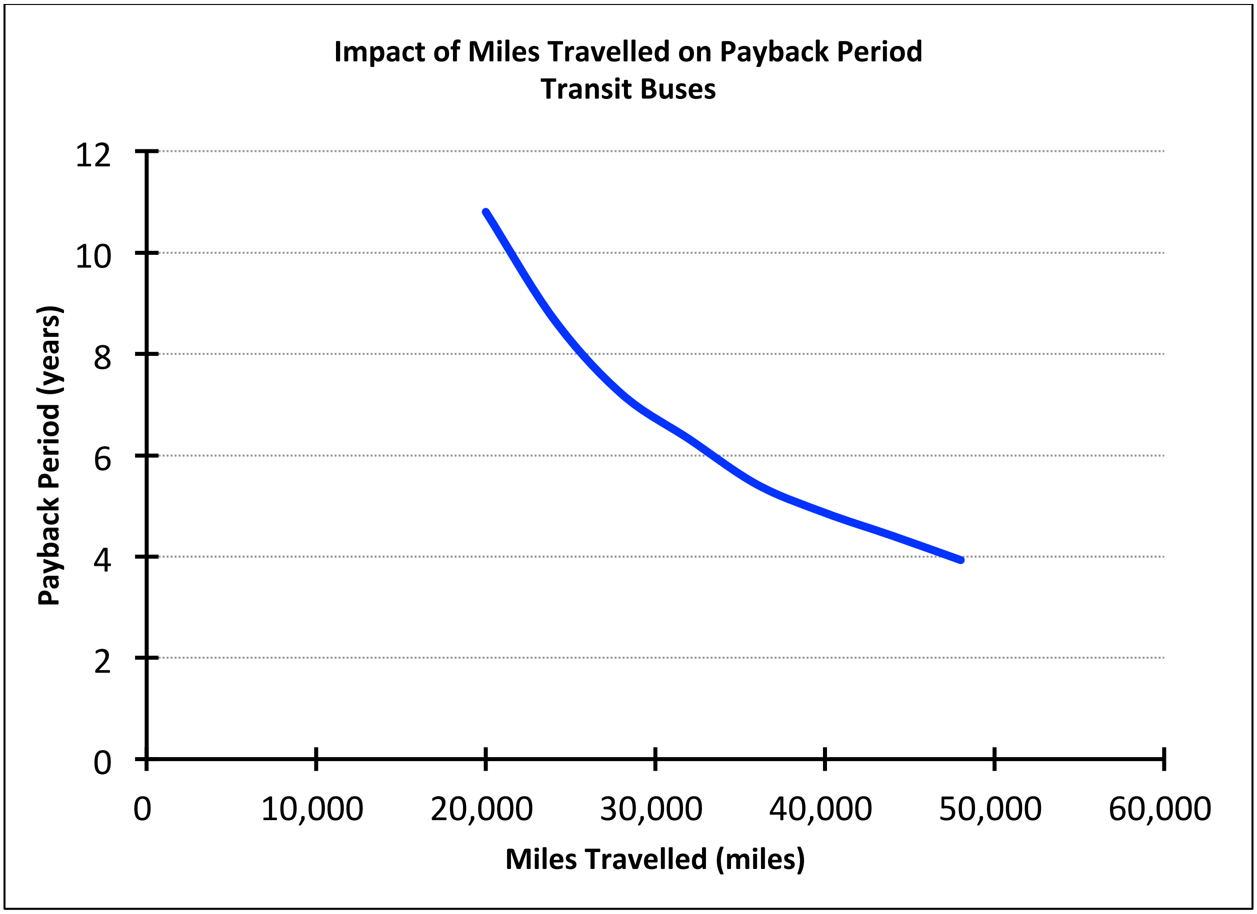

Figure 23: Miles traveled impact on payback period for transit buses.

This chart (Figure 23) looks at the impact of miles travelled on the payback period for transit buses in the Pittsburgh region. As the number of miles traveled increases from 20,000 to 48,000 miles, the payback periods decreases from 11 to 4 years.

Conclusions

While both transit and school bus conversions make economic, environmental, energy security, and social welfare sense, school bus conversions were not recommended due to the highly fractured organization of school bus ownership and rentals among school districts. The conversion of transit buses is recommended due to the short payback period and highly beneficial supply curve results.

Policies

The Pennsylvania Department of Environment Protection began a grant program on December 1, 2012. This natural gas vehicle program is worth $20 million. School buses, public and private business fleets with vehicles weighing 14,000 lbs. or more are eligible for the grant. During 2012-2013 $10 million will be distributed with $5 million of that for local transportation. $7.5 million will be given in 2013-2014. The remaining $2.5 million will be given in the 2013-2014 fiscal year (Boyer, Brittany, 2012). There are a few major grant programs available to school bus operators. Grants are available by the Clean Cities Program, through the DOE's State Energy

Program Special Projects program. Many other incentives and grants are available on the state level.

Four possible policy options to promote natural gas buses were analyzed, taking into consideration the policy options' effectiveness in reaching policy goal, economic efficiency, political responsiveness and equity (Figure 24). The first option would be to remain at the status quo. However there has been no natural gas adoption by bus fleets so far, so this is not an effective option. Another option would be a 'Vehicle Economic Incentive'. This policy gives an incentive of $5,000 per natural gas vehicle for purchasers of over 5 vehicles. This policy is not effective, as the incentive is insignificant to the total vehicle cost. This policy is very politically feasible as the local government is in favor of natural gas. This policy is not equitable however, because it does not apply to non-fleet purchasers.

Another policy option would be an 'Infrastructure Service Provision', which would provide a subsidy to develop natural gas fueling infrastructure. This would be an effective policy, as it would reduce the risk exposure and financial burden of investment on the station operators. This would be a politically feasible policy, as it would promote natural gas use in the region. However the policy would not be equitable as it picks a fuel winner in natural gas. The final policy considered would be to create an exception for the Port Authority of Pittsburgh for the provision that requires new buses to be purchased for all service regions. This is a major barrier to any natural gas bus investment, because refueling stations would need to be set up at all garages, greatly increasing the infrastructure investment. This is effective in reaching the policy goal, and would be economically efficient, as it will not cost anything. However the provision in contained within article VI of the Civil Rights act, so the politically feasibility of creating an exception to that law is uncertain. It will not be an equitable policy, as only some regions will receive the new buses. PAT has stated that it is not in favor of this exemption and that it can work around the requirement by buying new diesel buses at the same time as NG buses to keep all of their garages at the same average bus-age.

Option	O	E	R	Q
A: Status Quo - There has been no NG bus adoption so far. - The status quo does not achieve the policy goal. - No additional funding required. - Doesn't apply to the individual.	-	-	+	-
B: Vehicle Economic Incentive - Current incentive of $5,000 is insignificant to fleet managers. - If the incentive worked it would be effective, but if it didn't work, it would not be efficient. - Local government is very pro shale gas. - Doesn't apply to the individual	+	0	+	-

Figure 24: Policy analysis for natural gas buses.

O=Effectiveness in reaching policy goal; E=Economic Efficiency (Best Bang for Buck);

R=Political Responsiveness; Q=Equity (Winners and Losers)

+ = Positive 0 = Neutral -- = Negative

Findings

Through the entirety of the research and analysis we have reached various findings regarding each bus type: transit, school, and shuttle. The technology for each bus type is readily available. Natural gas transit buses can be purchased for approximately $379,000. Eighteen percent of the transit operations in the US are already using CNG for their entire transit bus fleet. This proves that it is definitely possible for a bus transit fleet to operate solely on natural gas. However, the bus group has found through the research and analysis that the main issue holding back the Pittsburgh Port Authority from converting their fleet to CNG is that lack of fueling infrastructure in the Pittsburgh Region. Also, there is a lack of funds, and the need to invest in all operation areas. Although under our model assumptions the payback period for CNG transit buses would return the investment within a reasonable timeframe, there is not a sufficient amount of funds available to convert the bus fleet, build the fueling infrastructure, and rebuild the bus garages to comply with CNG regulations. Also, with other budget cutbacks across Pennsylvania for education and other infrastructure needs, there is not a lot of support to invest funds in CNG.

Through the research and analysis the bus group performed, it was found that it is not feasible for Pittsburgh school buses to convert their fleets to operate on natural gas. Like transit buses, one of the main reasons why this is not possible is due to the lack of infrastructure. Since there are only two public CNG fueling stations in the Pittsburgh region, it is not possible that all of the Pittsburgh school districts refuel at only those two stations. Another hurdle in the way of CNG school buses in the Pittsburgh region is in the economics. In the school bus analysis, the group members found that the payback period for school buses was approximately ten years. With the extremely low budget that school districts have, it is not possible for them to invest in CNG school buses and infrastructure with the payback period not being until ten years down the road. Also, the Pittsburgh school districts just recently updated 19 contracts with bus companies. These new contracts will in turn save the school districts money. The extra money that is being saved from signing these new contracts could potentially be used to begin the conversion into natural gas school bus fleet for the Pittsburgh region. However, programs like the Pittsburgh Healthy School Buss program, initially invested with $500,000 from the Heinz Endowments Program, show that Pittsburgh is making strides in making their school buses more environmentally friendly and well as more technologically advanced. This program is for pre-2007 school buses. The program replaces engine parts in the old school buses to make them emit less particulate matter and use less diesel fuel

Shuttle buses are used quite frequently in the Pittsburgh region. The Pittsburgh International Airport, local universities, and many large companies in the region use shuttle buses to transport customers, students, and employees. The bus group focused their research and analysis on UPMC employee shuttle buses. We found that UPMC is operating a shuttle bus fleet with 54 shuttle buses, 13 of these already are CNG powered, and 7 more CNG shuttle buses are due in June 2013. UPMC uses the Ford 6.8L engine retrofitted with the CNG package. This costs $22,000-$28,000. The new CNG shuttle bus costs $84,000 for a 22 -passenger shuttle bus. A 33 -passenger shuttle bus costs $104,000. The UPMC fleet does not face the same infrastructure problems that transit buses and school buses in the Pittsburgh region face. The UPMC fleet refuels once daily using the two local public stations. This allows them to run their daily routes without needing to refuel again until the next day. Economics is also not a problem for UPMC due to private funding. In an interview t with the UPMC Assistant Director of Transportation and Operations, Bart Wyss, we found that UPMC plans to convert their entire employee shuttle bus fleet to CNG.

There are multiple examples where these natural gas buses have been adopted in other metropolitan areas and school districts. However, due to lack of infrastructure and funds, currently it is not economically feasible for natural transit buses or school buses to be implemented in the Pittsburgh region.

Recommendations

The largest obstacle to implementing natural gas buses in the region is the lack of refueling infrastructure. Therefore, the most effective policy would be to provide an incentive for building infrastructure, possibly a grant program to spur infrastructure development.

3.3 Trains

Introduction

There are two major types of diesel locomotives: line-haul locomotives and switcher locomotives. Line-haul locomotives can either be long-haul or short-haul. Because short-haul locomotives do not travel enough miles to save substantially on fuel in the long term, they were not considered for the sake of this assessment. Similarly, because there was very little information on switcher locomotives, and because they also did not travel enough to provide adequate savings on fuel, they were also not considered.

That being said, about 65 long-haul locomotives travel through Pittsburgh daily, accumulating roughly 1.5 million miles traveled in the Pittsburgh Statistical Area each year. The average lifetime of a train is 6 years; at this point, the diesel engine and traction motors need to be overhauled and replaced. In the city of Pittsburgh, the major industry players are BNSF, Norfolk Southern, CSX, and Amtrak, where BNSF claims to be the largest user of diesel fuel in the United States, second to the US Navy.

Information Gathering

Technology

The options for replacing diesel powered line-haul locomotives include three types of natural gas engines: spark-ignited LNG engines, low pressure gas injection with diesel pilot ignition - called dual fuel - and high pressure gas injection with diesel pilot ignition. The third type of engine, involving high-pressure injection, has not undergone sufficient field research to have much in the way of discussion of its benefits and drawbacks. This engine would have comparable efficiency to the current diesel engines in use, but would reduce greenhouse gas emissions by 25% (Mumford, David, 2012).

The drawbacks of these engines are due in large part to lack of infrastructure, technical research, and field experience regarding the engines. The spark-ignition engine was tested in a switcher locomotive capacity and resulted in more mechanical breakdowns than a comparable diesel engine. (Caretto, 2007) There is less known about the common problems associated with these natural gas engines and so when there is a breakdown, it takes more time to rectify. The higher fuel consumption of these engines, coupled with a lack of readily available refueling stations makes it hard for the locomotives utilizing natural gas engines to travel very far (Couch, 2010). There is also the problem of lower power output from using spark ignition natural gas instead of diesel. This should be a consideration when deciding in what capacity to best use a certain type of engine. The benefits and drawbacks are summarized in the chart below (Table 12).

Table 12: Engine Comparison, (Caretto, 2007)

Method	Convert to spark-ignition engine	Low pressure gas injection	High pressure gas injection
Injection method	Gas is premixed with air and ignited by spark plug as in gasoline engines	Gas in injected at low pressure and diesel pilot fuel is used to ignite gas	Gas is injected at high pressure and diesel pilot fuel is used to ignite gas
Status	In use in four BNSF yard engines in Los Angeles	Method used in ECI conversion kits, demonstrated in over the road locomotives	Experimental promise, but no current over the road demonstrations
Emissions	Large reductions in NO_x and PM, increases total HC and CO; should meet Tier 2 locomotive standards	Reduces NO_x to Tier 2 levels with increases in other pollutants; does not meet Tier 2 locomotive standards	Experimental notch-8 demonstration of NO_x reductions from 14.1 to 7.3 g/bhp-hr with no loss in power or efficiency. Another study reduced NO_x from 12 g/bhp-hr to 3 g/bhp-hr with an 8% loss in efficiency
Problems	Significant loss of rated power and efficiency	Eight percent loss in efficiency from 1991 data computed on EPA duty cycle	Experimental work limited to laboratory assessment; not capable of being demonstrated in revenue service operation.

Another technical issue regarding the implementation of natural gas fuel for trains is where to store the liquefied natural gas as the train is traveling. One popular suggestion is reintroducing the tender car, a separate car that would be devoted to carrying natural gas. Tender cars were used to store coal for long journeys, where the coal would be transported from the tender car to the engine over the course of travel.

Environment and Emissions

Engines burning natural gas have the added benefit of having lower levels of emissions compared to current engines that burn diesel. The spark-ignition engine benefits from significant reductions in nitrogen oxides (NO_x) and particulate matter (PM), as well as meeting the Tier 2 of the EPA's regulatory standards for locomotives. The diesel ignition engine does reduce NO_x emissions, but increases in other pollutants meaning that the engine does not meet Tier 2 standards (Caretto, 2007).

In regards to emissions, a study in 2007 found that natural gas powered locomotives gained no benefit in being converted from diesel (Caretto, 2007). In fact, the nitrogen oxide emissions barely changed, while emissions of total hydrocarbons (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), and particulate matter (PM) were significantly higher (Caretto, 2007). It was also found that natural gas engines produced more greenhouse gas emissions than their diesel counterparts (Caretto, 2007). However, in a more recent statement released by the Canadian National Railway, tests indicated that converting diesel engines to engines that use 90% natural gas and 10% diesel actually have reduced carbon and nitrogen oxide emissions. Canadian National Railway believes it can reduce its carbon dioxide emissions by up to 30% and its nitrogen oxide emissions by 70%.

Actual emission production is an important factor for more than just reducing greenhouse gas emissions or being able to claim that your locomotive is clean burning. Over the past decade EPA regulations have been passed, and then strengthen further, which will severely limit the options for compliance that railway operators have enjoyed in the past. In an effort to adhere to these standards in the least cost fashion, companies across the industry have been pursuing alternative fuel engine technologies (including natural gas) in addition to diesel after-treatment systems such as particulate filters and urea injection. Which of these systems will ultimately prove cost effective for the industry is beyond the scope of this analysis. However, it is important to be aware of this regulatory dynamic in light of its potential interplay with readily available and affordable natural gas. For reference, we have included the EPA emissions schedule for line-haul locomotives in Table 13. Note the drastic emission reductions slated for 2015 and later locomotives.

Table 13: EPA Non-Road Emission Schedule, (U.S. Environmental Protection Agency, 2012)

EPA Tier System for Line-Haul Locomotives			
Tier	**Year**	**NO_x (g/bhp-hr)**	**PM (g/bhp-hr)**
Tier 0	1973-1992	9.5	0.22
Tier 1	1993-2004	7.4	0.22
Tier 2	2005-2011	5.5	0.10
Tier 3	2012-2014	5.5	0.10
Tier 4	2015+	1.3	0.03

This leads to another important factor when considering the implementation of natural gas trains in Pennsylvania: the direct and positive impacts the trains can have on the environmental quality of the city. While it is not an easy variable to quantify, increasing the use of natural gas vehicles should improve the overall air quality of the area, especially in urban environments.

Trains are powered by very large diesel engines, so the pollutants emitted by trains are very similar to those emitted by large trucks (Nijboer, Michiel, 2010); however, railway locomotives produce a relatively higher proportion of sulfur dioxide (SO_2) emissions, because diesel fuel used by locomotives has a higher sulfur content. Other regulated pollutants that affect urban air quality include nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs). Compared to gasoline or diesel engines, natural gas vehicles reduce CO emissions by 70-

90%, reduce NO_x emissions by 75-95%, reduce particulate matter emissions by 90%, and reduce VOC emissions by 89%.

Pennsylvania, specifically Pittsburgh, has struggled with its air quality since the early 1800s. While it has recently improved slightly in its ranking, Pennsylvania still emits 40.3 million pounds of total criteria air pollutants annually (Templeton, David, 2012). Additionally, a 2012 Department of Energy study by Argonne National Laboratory concludes that transportation accounts for 30% of total U.S. CO_2 emissions, that replacing petroleum-powered vehicles with natural gas will reduce CO_2 emissions, and claims that natural gas vehicles could reduce smog-producing pollutants by up to 95%. The study concluded that converting one waste truck from diesel to natural gas is the pollution-reduction equivalent of removing as many as 325 cars from the road (America's Champion of Natural Gas).

A local study about the feasibility of natural gas-powered buses note that "while converting to natural gas buses would likely have a minimal effect on a region's *overall* air quality, it could have a significant impact in particular locations, such as on a city's downtown streets" (Allegheny Conference on Community Development, 2012). Other factors related to local air quality that play a role in designing natural gas vehicle policies include where the air quality issues occur, what types of emissions are involved, and how severe the problems are (now and on the longer term – taking into account future developments like population growth, growth of transportation needs, etc.).

Survey Information

Seven companies were contacted to question about natural gas powered trains. The companies were chosen either because of their Pittsburgh-based location, or because of their public plans to go forward with natural gas powered locomotives.

The first company to respond to the survey was BNSF Railway. First, Steven Forsberg, the General Director of External Relations at BNSF, was spoken to. In regards to natural gas powered trains, Forsberg said that the LNG units for their recently announced natural gas pilot project have yet to be manufactured, and that there are still many technical and regulatory issues that need to be addressed. Overall, testing for their pilot project will not begin until next year.

However, Mr. Forsberg had a lot of information about BNSF's diesel fleet to share. The most helpful information was the lifetime of an average vehicle, which he said was 35 years. He also shared that the locomotive needs to be overhauled every 6 years, which includes replacing major parts of the train, including the diesel engine and traction motors. Forsberg also disclosed the typical distance a line-haul locomotive will travel annually as 3.4 million miles and 4.8 million miles, as well as the amount of fuel BNSF's 6900 train fleet burns per year as 1.3 billion gallons. These numbers were used to calculate some of the data listed in the assumptions chart.

Assumptions for Payback Analysis

The assumptions used in the payback period analysis involve ranges for Conversion Cost, Discount Rate, Miles Travelled, Miles per Gallon, and the Price Differential. For each of these parameters, a maximum, minimum, and best guess is determined in order to construct three different cases using net present value: the optimistic case, the pessimistic case, and the best guess case.

The conversion cost is taken directly from an article stating a range of $600,000 to $1,000,000. (Shauk, Zain, 2012) The average of this range, $800,000, is used as a best guess as no realistic approximation is stated.

The discount rate ranged from 3% to 12% with a best guess of 8%. The low guess of 3% is the rate that the government uses when making calculations involving discount rates. The high guess is the rate that the industry tends to use as an assumption in their calculations. Once again, the average of these two, 8%, was used as a best guess.

The number of miles travelled determined is based on a single year. The bounds are from communication with Steven Forsberg, General Director of External Relations for BNSF. The lower bound is 3.4 million miles per year and the upper bound is 4.8 million miles per year. The average miles travelled per year was used as a best guess: 4.1 million miles per year.

Miles per gallon is calculated using the range of annual gallons used and annual miles travelled. The range of annual gallon usage is 160 to 200 thousand gallons. Thus, the range of miles per gallon is 100/160 = 0.63 MPG and 135/200 = 0.68 MPG. The average was used as a best guess.

Finally, the price differential range is found from data displaying the difference in fuel price between diesel and LNG. This was discussed in a previous section, but the values will be stated here again. A minimum of $0.63, a maximum of $3.46, and a best guess of $1.91 is used in the payback period analysis. A summary of the numbers used for the analysis can be found in Table 14.

Table 14: Payback Period Analysis

	Conversion Cost ($)	Discount Rate (%)	Miles Travelled (miles/year)	Fuel Economy (miles/gal)	Price Differential ($)
Best Guess	800k	8	117,500	0.66	1.91
Minimum	600k	3	100,000	0.63	0.63
Maximum	1000k	12	135,000	0.68	3.46

Payback Period Analysis

A payback period analysis was performed as outlined in the Methodology section of this report, producing the net present value Figure 25 below.

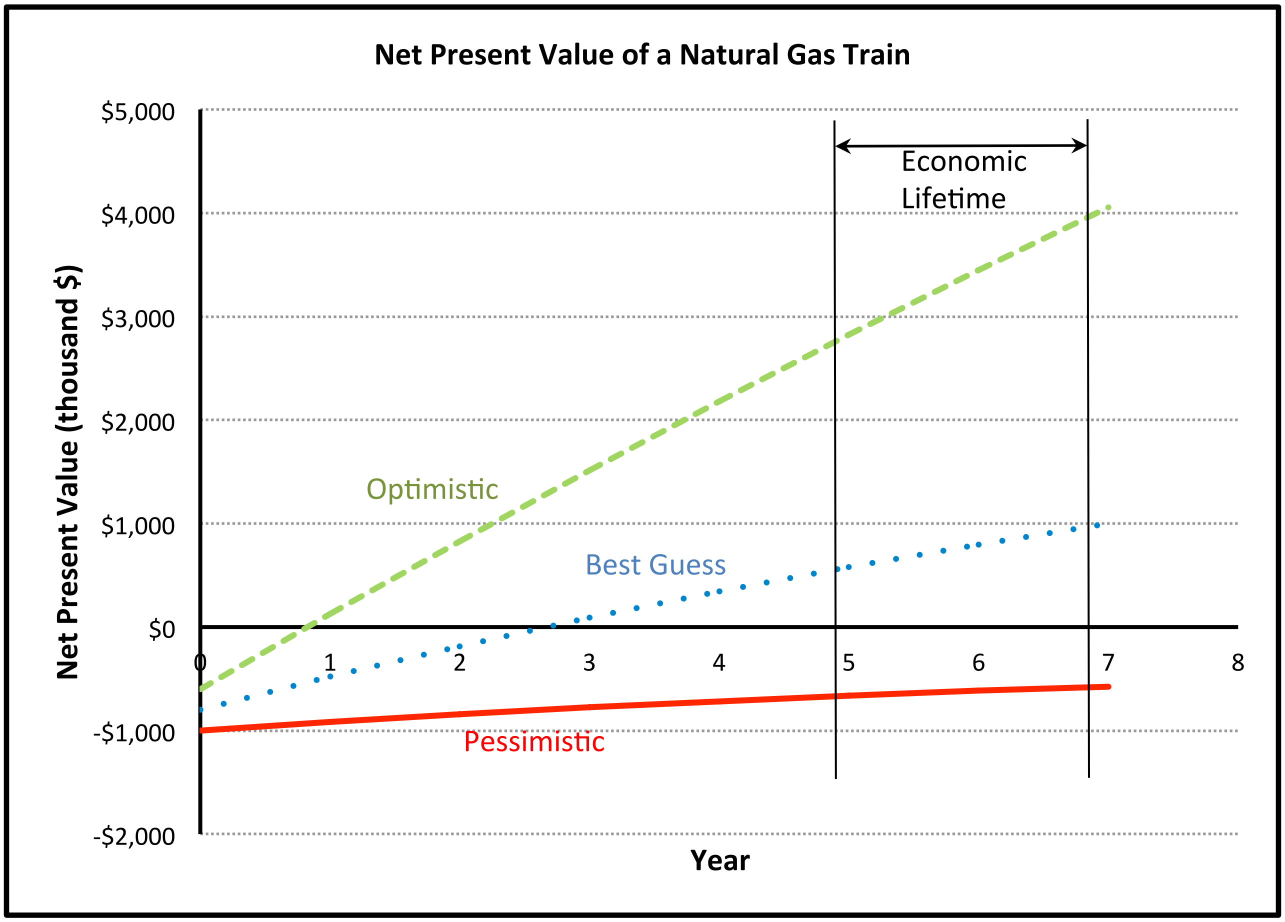

Figure 25: Net Present Value of a Natural Gas Train

Looking at the three cases of the net present value versus year graph, it is evident that the payback period for a train is likely to be close to or within the lifetime of an engine.

While the pessimistic case features an incredibly low slope, it is also under the assumption that the fuel price differential is less than $0.25. However, given the general trend of the fuel price differential, the conclusion that the payback period is close to the lifetime of the engine is reasonable. At best, under the assumption that the fuel price differential is $2.00, the payback period can be as low as just under two years, but it is still possible for payback period to be reduced by even greater gains in the fuel price differential, as the current difference is only $1.89. This explains why the best guess scenario finds a payback period of three years – much closer to the optimistic case than to the pessimistic case – and why it makes sense to use natural gas engines for trains from a private economic perspective.

When performing this payback period analysis, many assumptions have to be made about what variables to consider and what ranges to use for those parameters. Uncertainties in the market and unpredictable events have the potential to drastically alter the results of the analysis.

For this analysis, a sensitivity analysis was performed in supplement to the payback period analysis, in order to understand what variables the results and recommendations are subject to. A summary, in the form of a tornado chart, can be seen in Figure 26 below.

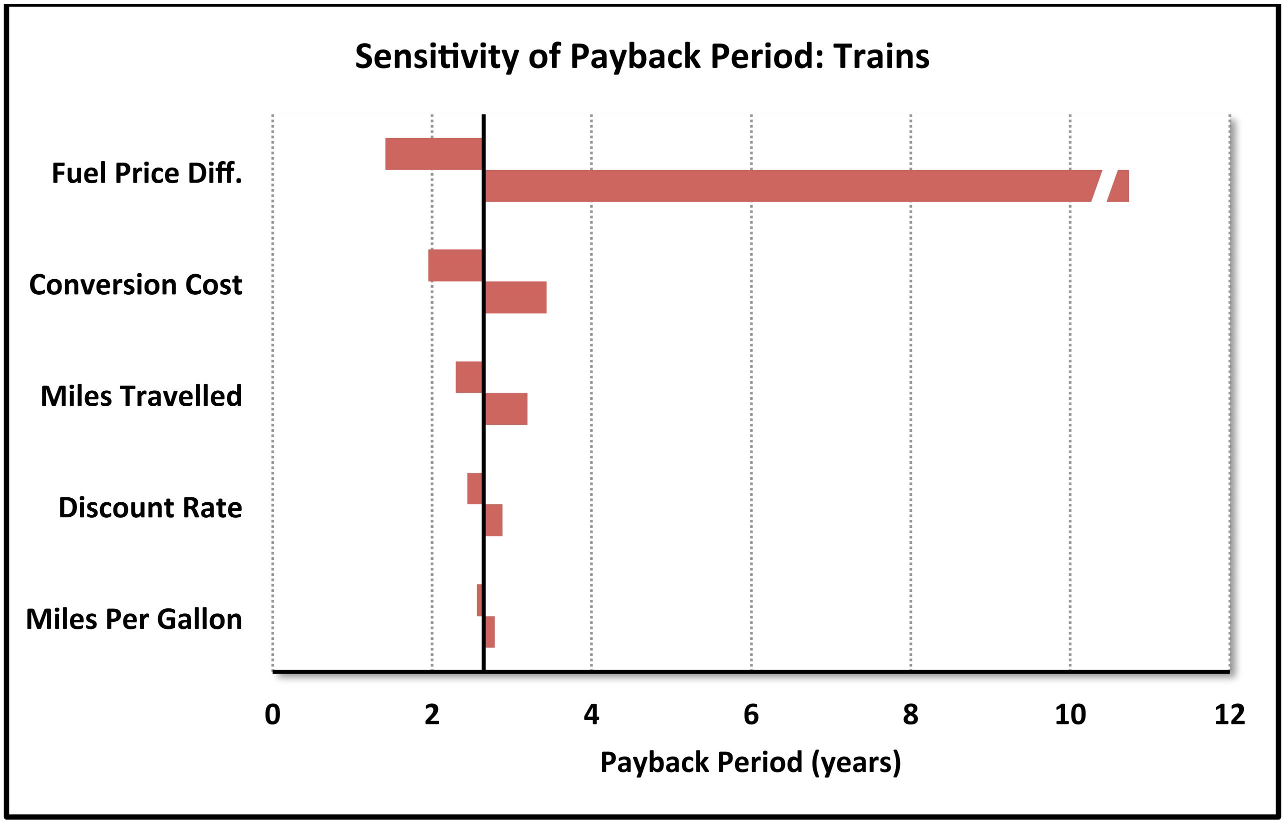

Figure 26: Sensitivity of Payback Period, Locomotives

As evidenced by this figure, the value of the fuel price differential between diesel and LNG is the single most influential factor in the outcome of the payback period analysis. What's more is that there is a great deal of uncertainty in this parameter. This price difference has fluctuated greatly within the past 12 years. A full discussion of the fuel price differential can be found in Section 2.5 Methodology – Fuel Price Differential.

Infrastructure

When considering the existing infrastructure in the Pittsburgh region, the major operating companies in the area include BNSF, Norfolk Southern, CSX, and Amtrak. Norfolk Southern operates the Pittsburgh Line, which is one of the largest rails passing through the area. The Pittsburgh Line passes east-west through the region (Gallitzin Tunnels and Parks Museum). Norfolk Southern also operates the Mon Line and the Conemaugh Line, which follow the Monongahela and Allegheny rivers respectively. No data could be found regarding the rail mileage or number of depot stations, however it's reasonable to assume that the mileage of the main thoroughfares is on the order of the river length through the area including the Ohio River, Monongahela River, and Allegheny River (Southwestern Pennsylvania Rails, 2010).

Findings

It's clear that strict EPA regulations on new locomotives are encouraging train companies to consider alternative engines. It is going to be more cost-effective for companies to develop new locomotives to meet these standards than pay to keep using outdated technology.

In response to the pressure from these policies, new engine development is currently in the works. BNSF and Canadian National have looked at dual fuel engines, though no companies are looking at pure natural gas engines at this time. Other companies are investigating dual fuel engines, as well, though not as predominantly as BNSF and Canadian National. There are currently no pilot projects demonstrating feasibility and scalability in Pittsburgh.

In the Pittsburgh region, though an extensive rail network is already in place, no fueling structure is available in Pittsburgh or Ohio. If natural gas powered trains were to be instituted, wide ranging fueling infrastructure would be needed as trains travel large distances out of the region.

Policy

Existing Policies

Natural gas is considered a clean and energy-efficient alternative to gasoline. Since it is a clean burning fuel, natural gas can help cities with growing traffic congestion (which is the primary cause of poor air quality) meet National Ambient Air Quality Standards (NAAQS) set by the Environmental Protection Agency. Natural gas vehicles can help improve air quality by displacing petroleum-powered vehicles, which contribute around 75% of the CO_2 pollution found in urban areas America's Natural Gas Alliance, 2012). New Jersey Natural Gas, the principal subsidiary of New Jersey Resources, created an incentive program called Fostering Environmental and Economic Development (FEED), which provides access to capital, incentives, and /or discounted rates for customers of natural gas vehicles; they also have several education initiatives to argue the positive economic and environmental effects of NGVs (New Jersey Natural Gas (NJNG), 2013). They argue that petroleum-powered engines emit soot particulates that negatively impact health, especially for those suffering from asthma and respiratory issues.

There is major legislation currently instituted in reference to natural gas locomotives. In regards to natural gas powered trains, this policy section concerns documents from several of the major train companies that operate in Pittsburgh, Amtrak and Norfolk Southern, and documentation from the state and federal governments. The first document comes from the Environmental Protection Agency and details current emission regulations for natural gas. The document contains scientific information relating to the amount of pollutant emitted by certain types of natural gas vehicles and the firing practices for natural gas powered engines. Specific ways to reduce the particulate matter from natural gas engines is examined in great detail (Environmental Protection Agency, 2002). The EPA also provides a document on the regulatory impact of the EPA's policies on the oil and natural gas industry. The EPA outlines specific regulations already in effect and how this impacts the natural gas wells in all 50 states. This contains much information about what specifically the EPA will permit in terms of drilling and emission standards. The document also contains a broad analysis of costs and benefits associated with natural gas drilling and implementation (Environmental Protection Agency, 2012). The Department of Transportation has a report from 2010 detailing ways in which improved transportation can reduce the risk of climate change. Several of the policies outlined relate to natural gas and the development of lower carbon fuel and increased vehicle efficiency. (US Department of Transportation, 2010)

Many train companies are considering using natural gas as a fuel source. Amtrak states natural gas may be a potential way to reduce costs, but no substantive information is given. As the federal government heavily subsidizes Amtrak, they seem to have little incentive to consider natural gas trains (US Department of Transportation, 2012). The other major rail company in the Pittsburgh area is Norfolk Southern, who primarily handles freight. A 2010 report by Blair Wimbush, the Norfolk Southern sustainability officer, outlines ways in which the company can reduce greenhouse gas emissions. The company pledges to reduce its carbon footprint by 10 percent by 2014. In regards to fuel, Norfolk Southern primarily plans to utilize more efficient diesel and biofuel, not natural gas. (Norfolk Southern, 2010)

Policy Analysis

When analyzing the three different natural gas policy options for trains, the group evaluated four different criteria: the effectiveness (denoted in the charts as O), which is defined as the extent to which goals will likely be met; economic efficiency (E), which is the output from an amount of input; responsiveness (R) which is a measure of how citizens' preferences are met; and equity (Q) which is whether the policy option is fair or equitable. If the goal would be met with the policy option, a "+" was denoted. Similarly, a "-" was denoted if the goal would not be met, and a "0" was denoted for a neutral effect.

The group analyzed three possible policies related to trains: (A) remaining at status quo, (B) additional vehicle economic incentives, and (C) an infrastructure service provision. The group's policy analysis findings are summarized in the chart below (Figure 27).

Option	O	E	R	Q
A: Status Quo - Payback period analysis indicates that it is beneficial for companies to transition to NG trains without any policies. - No money would need to be pent. - No consensus needed. - Benefits are accrued to first adopters.	+	+	0	+
B: Vehicle Economic Incentive - Giving money to companies already incentivized be economics of the industry will increase adoption time. - NO need to spend money when status quo would likely accomplish goal. - Spending unnecessary money will result in political backlash. - Spending tax dollars to fund private company profits.	+	-	-	-
C: Infrastructure Service Provision - Eliminating major barrier will accelerate rate of adoption. - Potential for creating nexus points across industries, though still is funding a project that might have been accomplished without policy intervention. - Many different interest groups would be involved. - Is a redistribution of funds, but dependent on value of related externalities.	+	0	+	0

Figure 27: Policy Analysis for trains.

When analyzing the effectiveness of option (A), status quo, the payback period analysis (discussed more thoroughly in Payback Period Analysis) was favorable, indicating that it is beneficial for companies to transition to natural gas trains even without any policies. The economic efficiency of remaining at status quo is also favorable, since no additional money would need to be spent. A measure of how citizens' preferences were met remains neutral, as there does not seem to be a push in either direction by citizens. Lastly, remaining at status quo seems to be fair and equitable; it is important to note that the benefits are accrued to the first adopters of natural gas trains. The second option, option (B), includes additional vehicle economic incentives for natural gas trains. While the effectiveness of this option helps to meet the goal (because giving money to companies will increase adoption time), the group believes that there is no need to spend money when it is likely that status quo will accomplish the goal, and spending unnecessary money may result in political backlash. Therefore, the efficiency of this option may be unfavorable in terms of both economic efficiency and responsiveness. In addition, the policy option may be seen as unfair or inequitable because these incentives may be seen as spending citizens' tax dollars to fund private company profits.

The last option considered was an infrastructure service provision for natural gas trains. The lack of infrastructure is the largest barrier, and it is believed that eliminating this barrier will accelerate the rate of adoption. Therefore, the effectiveness of this option is favorable. There is a possibility that this option can be used for other vehicles, too, which would boost the economic efficiency of additional infrastructure; however, since spending additional money on infrastructure when this goal may be met without policy intervention is not economically beneficial, economic efficiency is considered neutral. Since many interest groups would be involved in this decision, it is likely that the responsiveness of citizens would be favorable. Lastly, while this provision is a redistribution of funds, the equity depends on the value of related positive or negative externalities, so equity is denoted as neutral. Since option (A), remaining at status quo, had the most favorable scores when analyzed against the four criteria, it was deemed the best option for natural gas trains.

Recommendations

The potential for cleaner air and less emissions with NG locomotives seems promising. In part because of strict EPA regulations, an industry shift to natural gas is currently under strong consideration. Additionally, the payback period and high effectiveness ratings in calculated supply curves indicate that converting trains to natural gas is a feasible and economically-beneficial option. For these reasons, remaining at status quo for trains, and not increasing vehicle economic incentives or creating an infrastructure service provision, is the most feasible and economic policy option at this point.

However, the implementation of trains on a small scale – such as the city of Pittsburgh – would not be effective. Trains usually travel for much longer distances than simply through a city, so it would not make sense to simply convert one city to using natural gas trains when all other places the train would travel to would not have the technology.

That being said, major locomotive companies – such as Canadian National, BNSF, General Electric, and EMD – are all developing at least dual fuel technologies, meaning that the technology itself is feasible. Thus, it was concluded that the implementation of natural gas trains makes the most sense on a large scale. Because their destinations are fixed, natural gas infrastructure for trains could be very sparse, especially since natural gas trains would be built with tender cars (which would store LNG while the train travels). It is also important to note that there may be fueling infrastructure sharing opportunities. For example, boats and trains can likely use similar LNG infrastructure; coordinating with the same LNG pipelines. In addition, implementing natural gas trains on a large scale would also mean that the natural gas trains are traveling more miles than they would be if their travel was localized. If the trains are traveling more miles, they are using more fuel, and using more fuel means more financial benefit from a conversion to natural gas.

3.4 Trucks

Introduction

Heavy and medium duty vehicles are the second and third largest transportation market segments, following light duty vehicles, measured by energy consumption per day thus trucks are particularly attractive market for which to explore natural gas conversion (Clay, 2012). Specifically, class 8 vehicles account for the majority of this usage due to the high mileage accrued by semi-trucks during ground shipping. For this reason we have narrowed the scope of this project to only class 8 vehicles. Additionally, the long distances traveled and other logistics pertaining trucking make this class of vehicle particularly interesting to examine in the context of natural gas vehicles. Despite the large market potential, numerous technological, economic and infrastructure-related barriers prevent widespread use of natural gas trucks. In this literature review we will provide an overview of previous findings related to the feasibility of natural gas trucks in the Pittsburgh region, highlighting the aforementioned barriers as well as a review of current national, state, and local policy related to the use of natural gas trucks.

Information Gathering

Technology

Natural gas trucks have a variety of technical benefits and drawbacks. Natural gas is not as energy dense as diesel fuel, constituting a major technical obstacle in the field. The two fuel options available are compressed natural gas (CNG) and liquefied natural gas (LNG). In both cases the gas is injected at controlled pressure into cylinders that ignite with spark plugs.

CNG must be compressed to about 3600 psi for storage and use. This option is not suitable for heavy-duty trucks or long distance hauls because they require large power outputs for which CNG is not energy dense enough. CNG is more suitable for short haul fleets. In addition to new fuel storage tanks, to accommodate for the higher pressures engines must be modified with hardened parts and new fuel control systems. In a National Alternative Fuels Training Coalition (NAFTC) case study report, Giant Eagle reported miles per gasoline gallon equivalent (GGE) to be comparable to diesel trucks at four to six miles per GGE and fueling to take between six and eight minutes (NAFTC, 2012). CNG vehicles require highly pressurized and carefully sealed onboard fuel storage (Natural Gas Vehicles for America (NGVA), 2012).

LNG is the more feasible option for long-haul and heavy trucks. A typical "LNG truck equipped with two 119 gallon tanks has an operating range of approximately 775 miles" (Clean Energy). Each 119 gallon tank holds 108 gallons of LNG and the remaining space is for vapor, as the fuel evaporates at low temperatures. In order to liquefy natural gas it must be cooled to -260 degrees Fahrenheit, thus with any air leakage or temperature variation in the tank the fuel quickly evaporates. Release valves are necessary components to prevent explosions, however this causes the potential for a tank of gas to evaporate if left unused. Each 119 gallon tank can weigh about 500 pounds, which infringes on cargo space due to freight limits on natural gas trucks. LNG trucks are reportedly quieter and release less offensive odors than petroleum fueled truck.

In terms of the safety of natural gas powered fleets, many standards are in effect to insure maximum safety for drivers and vehicles. The tanks for storing both CNG and LNG are fairly robust. CNG tanks are aluminum wrapped in carbon fiber while LNG tanks are stainless steel. These tanks have an estimated lifespan of 20 years. The risk of a fuel leak is still present, but natural gas has a limited range of flammability and will not burn in concentrations under 15% when mixed with the air. Natural gas vehicles also have a significantly lower accident rate. A survey conducted among natural gas vehicle fleets showed that natural gas vehicles have a 38% lower rate of accidents than gasoline vehicle fleets. (U.S. DOE, 2013)Natural gas also burns at a lower temperature than petroleum fuel. Garages and other fueling stations would have to be renovated to safely handle high volumes of natural gas. Such renovations can cost an upwards of $100000. (CNG Now, 2013; CSX, 2012)

Environment and Emissions

One of the greatest driving factors for the adoption of natural gas vehicles in the Pittsburgh area is the prediction that natural gas vehicles will emit fewer harmful gases into the atmosphere, namely hydrocarbons, carbon dioxide, and particulate matter.

It is important to consider the potential implications of ultrafine particulate matter on the environment and air quality of our major cities. Currently, over-the-road transportation accounts for 43% of all ultrafine particulate matter in the atmosphere (California Environmental Protection Agency, 2003). These ultrafine particles have been correlated to respiratory and cardiovascular diseases and should be considered when evaluating the amount of particulate matter natural gas vehicles are emitting to the environment. Unfortunately, current research in ultrafine particulate matter is limited, and any additional action would require further investigation. Experimental data shows that the emission factors for PM 2.5 are 0.17 g/gal-eq for natural gas trucks and 0.18 g/gal-eq for diesel trucks. Such a small reduction does not yield any clear implications that natural gas is superior to diesel in particulate matter emissions (Carl Moyer Program Guidelines, 2008).

The amount of carbon emissions from a natural gas-powered engine is generally less than the equivalent diesel engine, creating a desire for that type of system. According to the American Trucking Association, "depending upon the source of the natural gas and the liquefaction efficiency rate, natural gas can reduce CO2 emissions by 15%- 23%" (Clean Energy). It is important to consider the dangers of methane as a greenhouse gas however, and employ appropriate safety precautions to prevent leaks. For example, if liquid natural gas inside of fuel tanks evaporates, it may leak out of the system and into the environment in order to prevent high pressure accidents. It is possible that if natural gas leaks out of trucks, storage, and refueling stations, it may actually add more greenhouse gases to the environment than the equivalent amount of gases released from diesel operation. To combat this effect, the EPA has certain regulations limiting the amount of natural gas than can be released during fueling and storage (Environmental Protection Agency, 2004). For example, it is required that no more than 0.20 grams of natural gas per gallon of dispensed fuel is released to the environment during the refueling process. Because natural gas rises instead of pooling to the ground like liquid gasoline, this can be a difficult challenge for fuel stations.

Survey Information

We contacted a representative from Pitt Ohio. He provided many key data points. Pitt Ohio maintains 1178 trucks, with 3 natural gas trucks in testing. The fleet consumed 11732680 gallons of gas in 2012 and traveled 77550717 miles in 2012. The average lifetime of a vehicle in the fleet is 5 years. The representative was unable to provide the payback period for the vehicle purchases or comment on number of natural gas vehicles Pitt Ohio plans to purchase over the next 10 years. In regards to government grants, the fleet manager believed they may be beneficial, but there are too many unknowns. Yet Pitt Ohio has fueling needs all across the mid-Atlantic, so access to fueling stations is very important, as is engine power and fuel efficiency.

Assumptions for Payback Analysis

We considered a best guess case as well as optimistic and pessimistic scenarios. The costs, discount rate, annual vehicle miles travelled, fuel economy, vehicle lifespan, and fuel price differentials are shown in the table of assumptions (Table 15: Natural Gas Truck Assumption Values) for each case.

Conversion costs were cited to be between $35,000 for a CNG conversion and $90,000 net price difference between a new LNG truck and a new diesel truck (INFORM Inc.). This price differential constitutes the initial capital cost considered in our net present value calculations, as explained in further detail in the payback period analysis. Annual vehicle miles traveled is calculated by considering the typical annual fuel consumption of a Class 8 truck and average fuel economy. These values, along with the annual vehicle lifetime, were obtained through our surveys with Pitt Ohio and presentations by Giant Eagle.

Table 15: Natural Gas Truck Assumption Values

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal -eq)	PM2.5 Reduction (tons/yr)	Lifetime (yr)	Price differential ($/gal-eq)	PM2.5 Reduction Benefit ($savings/ton)	Total vehicle number (#)
Best Guess	62,500	0.06	65,800	6.5	0.018	6	1.89	370,000	16,500
Minimum	35,000	0.03	60,000	5	0.014	5	0.24		16,450
Maximum	90,000	0.09	90,000	8	0.022	8	2		16,550

Payback Period Analysis

Pre-existing analysis (if applicable)

When deciding what fuel option to use companies need a solution to make economic sense. Kathryn Clay, Executive Director of the Drive Natural Gas Initiative, purports that the economics are already in favor of natural gas conversion. However, high capital costs of conversion or purchase as well as garage safety modifications, debate on the trajectory of natural gas prices, and industry acceptability of payback period fuel debates about the feasibility of natural gas. According to UPS a new natural gas truck has a 100% premium on the purchase of a new diesel truck. According to Pittsburgh Waste Management the purchase of a new LNG Mac MR-Refuse truck cost upwards of $40,000. Aftyn Giles, Sustainability Coordinator at the Office of Sustainability and Energy Efficiency in Pittsburgh, quoted a figure of $34,000 more than a new diesel truck (INFORM Inc., 2009).
The primary source of payback to investment in LNG or CNG technology is based on the differential in price between natural gas and diesel. In this analysis we focus on CNG due to data availability. The current price differential between CNG and diesel is about $1.47/gal (Diesel costs $3.75/gal while CNG costs $2.28/diesel gallon equivalent) but the future prices of both fuels remain unknown (Giles, 2013). Compared to diesel, which will presumably continue to increase in price, some experts think the price of CNG is stabilizing, due to significantly increased supply, while others predict the price of CNG will continue to increase. For vehicles travelling 100,000 miles per year the payback period can be within two years (Lockridge, 2012), and for large vehicle fleet sizes (greater than 30 trucks) the expected payback period is typically lest than seven years, which is slightly longer than the typical lifespan of a Class 8 truck. Higher life expectancy trucks, such as refuse vehicles, can have a payback period of up to 12 years (Johnson, 2010).

Pittsburgh Specific Analysis

To streamline the comparison analysis between vehicle types we assumed a set of values to be input in a quantitative analysis. These values included an optimistic, best guess, and worst-case scenario for each parameter.

In our analysis of the economic feasibility of natural gas trucking we generated the net present value chart as shown in Figure 28. We used the parameters indicated previously in the assumptions section to generate the net present value curves, which show the payback periods of a typical natural gas truck. We find that under the most optimistic scenario the return on investment begins after one year, in the average case it is in just below four, and in the worst case scenario there is not a return on investment during the life span of the vehicle.

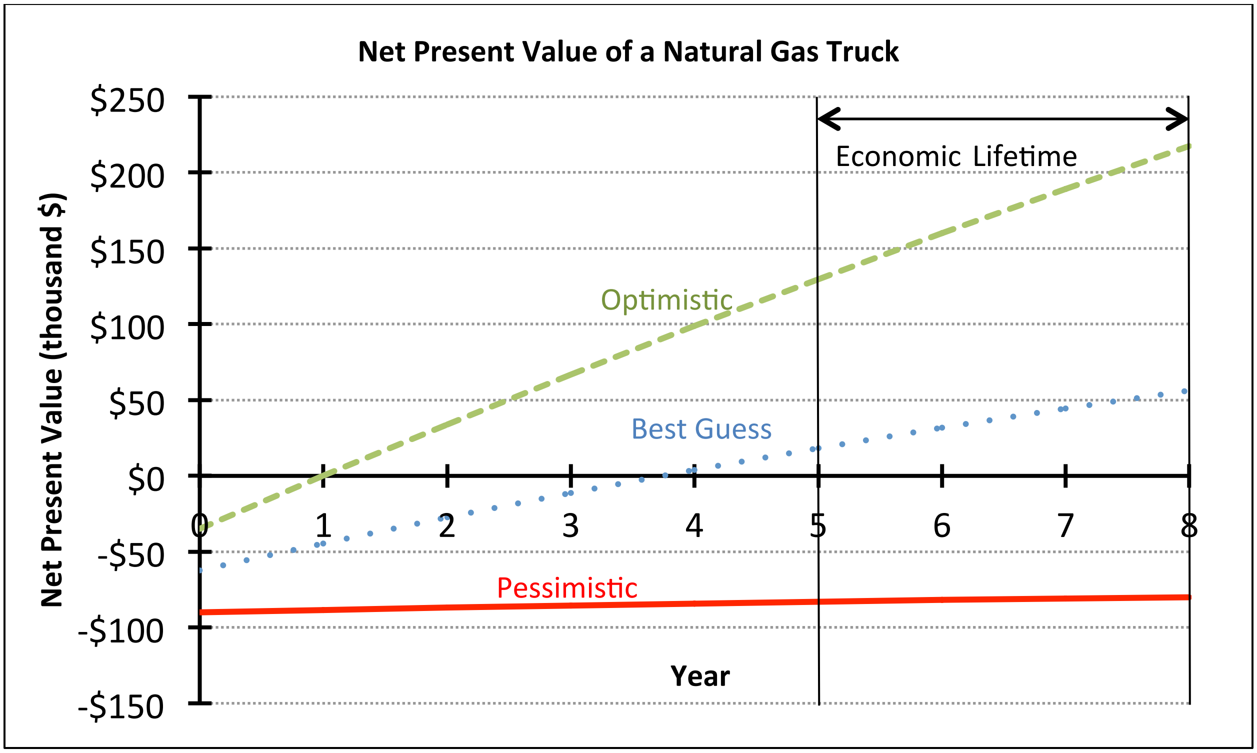

Figure 28: Net Present Value of a Natural Gas Truck

Using the same assumptions we developed a tornado plot to show the sensitivity of the payback period on a new Class 8 truck in order to show how each factor impacts the payback period. Ultimately it is clear that the fuel price differential, which is the most uncertain parameter, has the greatest potential to alter the amount of time before a return on investment is made. The chart is shown below in Figure 29.

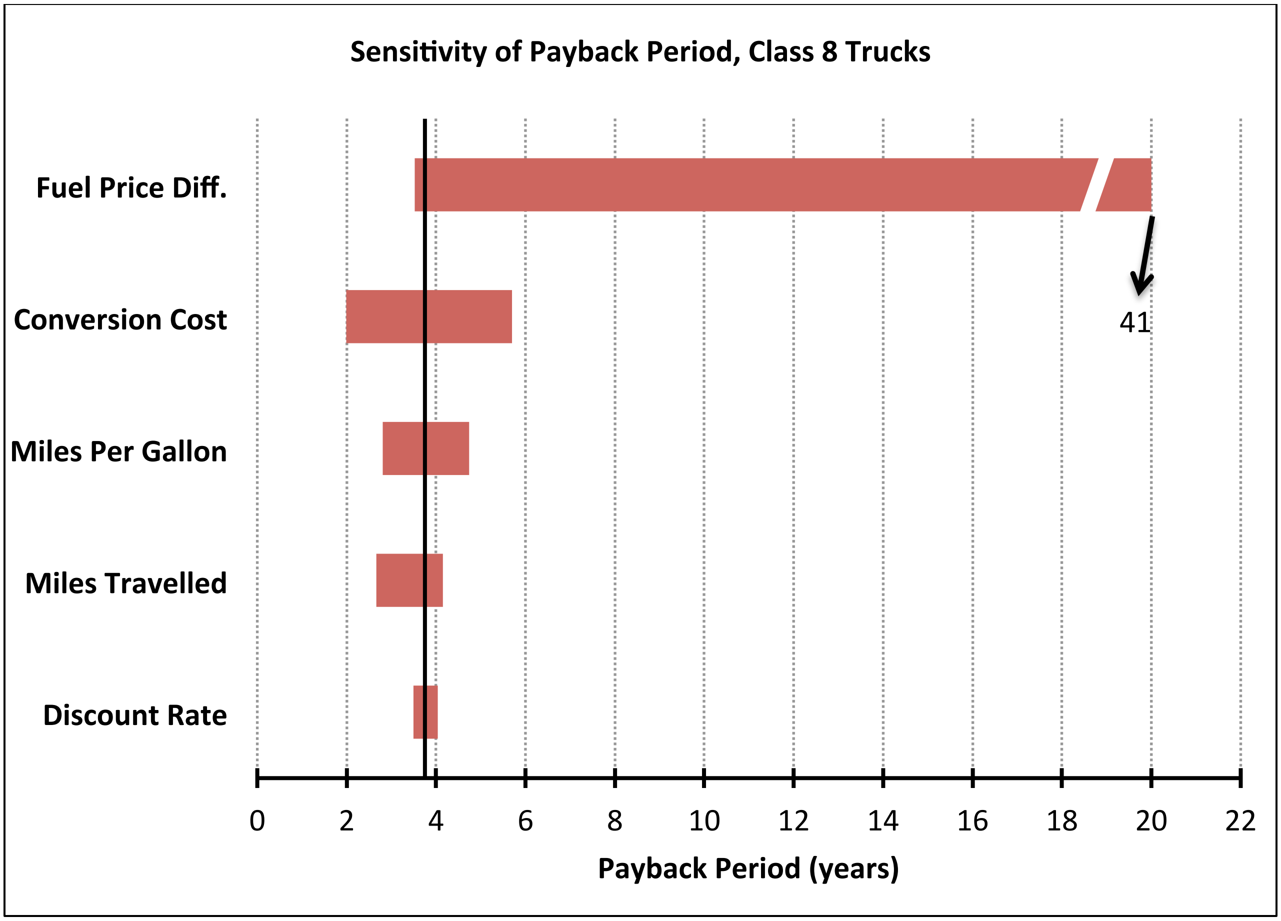

Figure 29: Sensitivity Analysis Tornado Plot for class 8 trucks.

Infrastructure

According to a survey conducted by Jeffries and Company through the *Fleet Owner* magazine, the number one perceived obstacle for fleet owners to the use of natural gas technology is fuel infrastructure (Alexander, 2012). According to statistics by UPS the construction of a fueling station costs more than one million dollars. Current statistics from the Department of Energy (DOE) estimate that there are 1190 CNG stations and 66 LNG stations in the United States, compared to 150,000 gasoline stations and 75,000 diesel stations nationwide. The combined number of CNG and LNG stations therefore represents less than 1% of the number of gasoline stations and 1.6% of diesel stations (Natural Gas Vehicles for America (NGVA), 2012). According to an article published by Yeh in *Energy Policy* "AFVs during transition from initial market development to mature market requires the number of alternative-fuel refueling stations to be a minimum of 10–20% that for conventional gasoline stations." If there are more than 20% then refueling stations will no longer be considered a major obstacle (Yeh, 2007).

Although CNG stations are expanding at current rate of 20 to 25 per month, it will take significantly higher growth for them to be on par with gasoline stations. It would require 16,000 to 32,000 CNG stations to be equivalent to approximately ten to twenty percent of the current gasoline infrastructure. (Natural Gas Vehicles for America (NGVA), 2012).

In considering strategies for the development of fueling infrastructure there are two dominant "types" of fleets: medium and short range fleets that have central refueling and long range trucks that travel across states, in distances greater than 500 miles, and thus require refueling infrastructure along transportation corridors. Developing local or regional hubs will help build confidence in NGV technology and increase consumer adoption. As demand increases, additional infrastructure can be built out to increase the number of viable NGV corridors for long-range trucking.

There are numerous fully operational CNG stations already in the Pittsburgh region. Within 50 miles of downtown there are approximately 20 fueling stations (shown in the Figure 30 below), all of which are CNG (FindTheData, 2013). Of those 20 stations, 18 are private access only, which is a potential problem in NGV growth. While the private stations work well for trucking companies with large fleets it limits the usage to only company trucks while those stations could be servicing cars and buses as well. In addition, trucks on long routes would benefit from being able to refuel at a public station when they are unable to return to their respective garages.

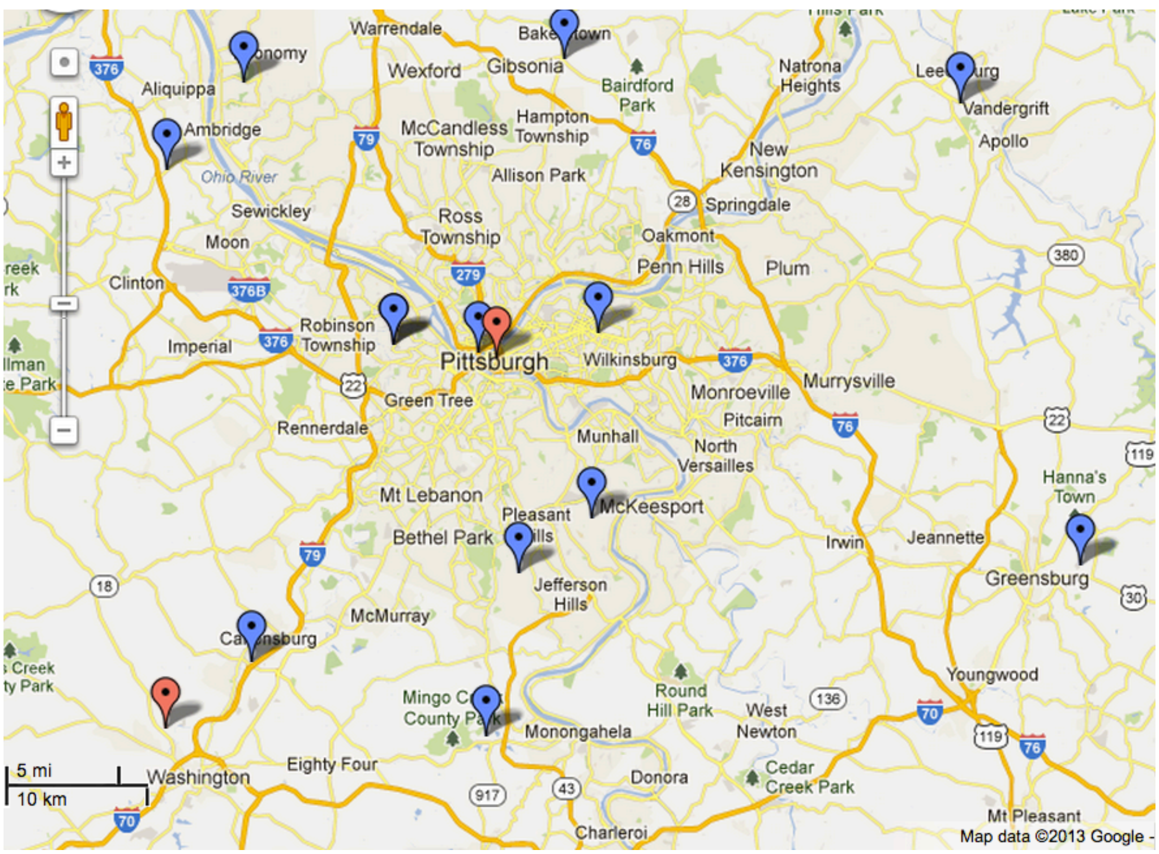

Figure 30: Map of CNG fueling stations with 50 miles of downtown Pittsburgh. Blue pins indicate private access stations and red indicate public.

Findings

Through our analysis it is determined that the economics of natural gas conversion for Class 8 trucks are currently favorable without government intervention. Pittsburgh currently has sufficient infrastructure to foster initial natural gas adoption, at least in quantity. The locations of refueling stations and garages may not be ideal for all trucking companies considering conversion.

Policy

Existing Policy

For natural gas trucks in the Pittsburgh area, there have been several examples of policies that have proven successful in promoting adoption. Most of these policies have been in the form of economic incentives, and they typically exist at the federal and state levels. The research done for the purpose of this report was unsuccessful in finding any substantial policies at the state level.
The Alternative Fuels Incentive Grant program, abbreviated AFIG, was a particularly influential policy promoting the adoption of natural gas trucks in the Pittsburgh area. The program was created in 1992 and was designed to promote the use of alternative fuels, especially in fleets (Pennsylvania Department of Environmental Protection (PADEP), 2013).

Giant Eagle is a Pittsburgh-based grocer and food distributor that has significant shipping requirements in both short and long haul realms. Through this program, Giant Eagle has become one of the companies spearheading the adoption of natural gas trucks in the Pittsburgh area. Specifically, in 2010, Giant Eagle, under its shipping and distribution unit Talon Logistics, received a $900,000 grant from the state of Pennsylvania through the Alternative Fuels Incentive Grant program. This grant funded the purchase of 10 CNG Class 8 trucks built by Volvo in addition to a private fueling station for the company (Shale Gas Innovation and Commercialization Center (SGICC), 2012).

Another company that has been proactive in the development and use of natural gas trucks is Waste Management. Waste Management has adopted natural gas trucks throughout its national fleet, but specifically, in the Pittsburgh area, where a large portion of the company is based, there have been advancements promoting the use of natural gas trucks. In fact, in 2011, Waste Management announced that they now own and operate 1000 natural gas refuse trucks in their national fleet (Andrew & Quiroa, 2011). Locally in the Pittsburgh region, Waste Management received $700,000 to build a CNG refueling station at their facility in Washington, PA. This purchase was made possible through the aid of the 2010 Alternative Fuels Incentive Grant program (Pennsylvania Department of Environmental Protection, 2010).

Additionally in the refuse truck industry, the city of Pittsburgh, alongside EQT, purchased four natural gas refuse trucks with a $500,000 grant from the Pennsylvania Energy Development Authority (. This conversion worked alongside EQT's own plan to build a public-access fueling station in downtown Pittsburgh. This purchase was part of the Pennsylvania Energy Development Authority's $3.7M plan to develop clean energy technology in the state (Government Fleet, 2011).

Another current policy that is having an effect on the adoption of natural gas vehicles is Act 13, a set of environmental standards and a three-year-long Natural Gas Energy Development Program, which was established in 2012 by the Pennsylvania Department of Environmental Protection (Pennsylvania Department of Environmental Protection, 2013). This policy will distribute $20M in grant funds to purchase or convert vehicles to natural gas. However, in order to qualify for grant money, there are specific criteria that a company must adhere to. Specifically, the grant can only cover up to 50% of the cost and the funding cannot be used to fund project development, refueling stations, or other infrastructure (Pennsylvania Department of Transportation (PDOT), 2012). Further, the applicant must pledge to convert at least 5 vehicles and they must identify plans to build a new refueling station or use an existing station.

Outside of government economic incentives, there have also been developments and policy creation to support the training and certification of mechanics to service and inspect the safety and general operation of natural gas trucks. For larger fleets, this has much more weight than vehicle purchase support because of the high number of trucks that must be serviced and repaired in order to achieve economical operation. Unfortunately, because the engines and fuel delivery systems are vastly different from a traditional diesel counterpart, mechanics must receive additional training in natural gas vehicles to provide optimal mechanical support. To assist this learning process, programs like the National Alternative Fuels Training Consortium and the Natural Gas Vehicle Institute offer training programs in natural gas vehicle and refueling station maintenance (NAFTC, 2012).

One example of a current training and certification program that is advancing the use of natural gas is the National Alternative Fuels Training Consortium, abbreviated NAFTC. The NAFTC is a training program hosted by West Virginia University that is supported by the United States Department of Energy. The goal of the NAFTC is to promote the training of certified mechanics to service alternative fuel vehicles, including those powered by natural gas. The NAFTC was originally established in 1992 under a contract with the Environmental Protection Agency. Currently, the NAFTC receives funding and is housed under the National Research Center for Coal and Energy (West Virginia University, 2013).

Another significant training program for natural gas trucks and refueling station mechanics and inspectors is the Natural Gas Vehicle Institute. The Natural Gas Vehicle Institute is the only natural gas training and certification program that has received recognition and certification from the National Institute of Automotive Service Excellence, abbreviated ASE (National Institute for Automobile Service Excellence, 2013). This certification was achieved in December 2010 after the National Automotive Technicians Education Foundation evaluated the headquarters and training program development. The importance of this certification lies in the reputation and industry standard that the ASE has in the automotive industry. Through ASE recognition, the Natural Gas Vehicle Institute has had great successes in training and certifying natural gas technicians. Potential training includes topics such as natural gas vehicle technician safety, CNG refueling station inspections, CNG refueling station operation and maintenance, and natural gas vehicle fleet management. The National Automotive Technician Education Foundation administers ASE certification, and only about 50 U.S. companies have achieved this high level of certification. However, ASE certification is voluntary, which may provide some insight as to why the number of certifications is low (National Institute for Automobile Service Excellence, 2013).

Policy Analysis

The important question to answer when developing policies for trucks is what the motivating factors are for a commercial fleet owner to adopt natural gas trucks. Following an interview with Pitt-Ohio, it was determined that the important factors in the decision were infrastructure and maintenance shortcomings, not high costs of individual vehicles (Pitt-Ohio, 2013). However, the general economic incentives through programs like the Alternative Fuel Incentive Grant and Act 13 still suggest that government is focusing on vehicle subsidies. To help answer this question, we can employ the evaluation criteria outlined in the policy methodology section to determine the effectiveness of different policy options.

In the context of trucks, we looked at the same three categories of policies: status quo, vehicle economic incentive, and infrastructure service provisions. The summary of our findings can be found in Figure 31 below:

Option	O	E	R	Q
A: Status Quo - Act 13 through Department of Environmental Protection provides \$20M for vehicle purchase and conversion, including up to 50% of incremental cost, which still leaves a larger cost for expensive truck conversion for the company. - Act 13 requires a pledge of at least 5 vehicles and an outline of the infrastructure that will be built or used.	0	+	+	-
B: Vehicle Economic Incentive - Conversion costs of Class 8 trucks are not specific concern to large trucking companies. - Alternative Fuel Incentive Grants (AFG) provide opportunities for companies to begin natural gas adoption, both Giant Eagle and Waste Management have seen success. AFG program is currently closed. - Effective in convincing on-the-fence companies to cross chasm into natural gas vehicle domain, especially for smaller companies (EQT/City of Pittsburgh Refuse Trucks)	+	-	-	0
C: Infrastructure Service Provision - Majority of refueling stations in the Pittsburgh area are private, which isolates benefit to those allowed to use them. - Cost of refueling stations, as well as modifying garages to current safety standards are high enough to deter trucking companies like Pitt Ohio from converting.	+	+	0	-

Figure 31: Policy Option Analysis Based on Overall Effectiveness (O), Economic Efficiency (E), Political Responsiveness (R), and Equity (Q)

Based on this table, Option B: Vehicle Economic Incentive appears to be the least favorable option for the promotion of natural gas trucks in Pittsburgh. This is due to the fact that the incremental cost for a natural gas class 8 truck is not a specific concern to most trucking companies, especially those with a large number of active trucks in their fleet. Therefore, the economic efficiencies of spending money on vehicle purchase and conversion incentive are low. The economic efficiency of this policy option is reduced even further when the average lifetime of a Class 8 truck is considered. Most Class 8 trucks rarely see more than 7 years of use on the road, which would limit the impact that a vehicle purchase has with respect to a fully-developed solution. Additionally, in the current economic climate, funding on the state and federal level is at more conservative levels, which means policy makers may be resistant to additional spending on vehicle purchases. This resistance, coupled with foci on other alternative fuels presents a set of disadvantages for this policy with respect to political responsiveness. On the other hand, programs like the Alternative Fuels Incentive Grant have provided motivation for smaller companies to cross the chasm into natural gas trucks, and would likely continue to support smaller, on-the-fence companies and fleets in their conversion. For example, it may be unlikely that the city of Pittsburgh would convert their refuse trucks without financial support from the state. This encouragement, coupled with the possibility of larger companies taking advantage of grant money that is not necessary for economic viability presents a generally neutral field for equity. Further, the Alternative Fuels Incentive Grant program has had success in promoting natural gas trucks in Pittsburgh, and therefore, it earns a positive overall effectiveness score.

Option A refers to the current policies in place, specifically Act 13. Act 13 is beneficial because it has definitive caps on the amount of money that can be spent on a vehicle, it ensures a certain number of vehicles to be converted, and it ensures that there is infrastructure support for the new vehicles coming into the region. With respect to equity, the status quo option is not entirely satisfactory. The policy prevents smaller fleets, like the city of Pittsburgh, from converting because they do not satisfy the minimum quantity requirements. It also puts unfair pressures on private stations that may need to support other fleets that cannot afford to build their own fueling infrastructure. In terms of overall effectiveness, Option A earned a neutral rating, mainly because it is such a new policy that there have not been enough cases to consider. Additionally, the focus of Option A still remains on vehicles rather than infrastructure, which furthers the neutrality of the effectiveness. In addition, the policy appears to achieve a neutral balance between effectiveness in advancing natural gas vehicles and cautionary measurements to ensure effective use of funding. Because of this balance, and the safeguards to ensure that investments will result in the best chances of integration, the political responsiveness of the policy is positive, and it has been well received by policy makers as a replacement to the Alternative Fuels Incentive Grant.

Option C: Infrastructure Service Provision appears to be on par with the current status quo in terms of overall ability to accomplish the policy goals. In some areas it outperforms the current policies, but it falls short in others. Specifically, Option C has greater overall effectiveness in achieving the goal of natural gas vehicles because it addresses the key issue that many trucking companies have: infrastructure is sparse and expensive to build. In addition, it is economically efficient because there is a need for more (ideally public) refueling stations in the Pittsburgh region to support new adoptions. With regard to political responsiveness, it is generally neutral, because policy makers and citizens alike will agree that there needs to be more infrastructure to support new natural gas vehicles. However, policy makers tend to put the focus on vehicle conversion with supplementary infrastructure development. This ideology suggests that they are relatively neutral on infrastructure, and as long as there is sufficient infrastructure to support new vehicles, as shown in the provisions of Act 13, then they are satisfied. Where Option C falls short is in the equity category. Providing infrastructure support is very beneficial to large companies that can economically use their own station. Historically, however, most new refueling stations, even those built with government funding, remain private. This may suggest that small companies that cannot logistically support their own infrastructure will suffer without the support of government.

Recommendations

First, it is important to note that Option B is not entirely unfavorable, but in order to gain success, some changes would need to be made to the focus of the policy. Due to the economics of long-haul trucking and the type of engines that are currently available, trucks are already in a favorable position to adopt natural gas engines. Therefore, the economics have the ability to drive conversion without too much government intervention and policy creation. However, economic incentive already exists for trucking companies and the Pittsburgh region has taken advantage of these grants to ease the costs of adoption.

Findings

Many large trucking companies have high expectations for the performance of the truck they are purchasing, and are not swayed by the cost of the vehicle itself.

Instead, they tend to focus on larger accrued costs such as fuel consumption, infrastructure, and maintenance costs. For example, a phone interview with PITT OHIO, a Pittsburgh-based shipping company, revealed that PITT OHIO has 578 Class 8 trucks with a turnover period of about 5 years.

For a company of this size and operating structure, government grants covering the cost of vehicle purchases and engine conversions are not as convincing as grants for fueling stations or garages. PITT OHIO, and other similar companies, desire assurance that there are fueling options along all of their major shipping routes and that the trucks they buy can be serviced the same way, and at a similar cost, as their diesel counterparts.

This roadblock, specifically, prevents investment by large companies with traditional operating budgets from taking a risk and changing the style of fuel and engine that they use for their trucks.

Policy Options

Programs like the Alternative Fuels Incentive Grant Program should shift focus from funding the purchase of vehicles and instead work on building public infrastructure.

There is a rational reason for why Giant Eagle, a company with 10-20 natural gas trucks is using federal money to buy new vehicles and a new public refueling station (NAFTC, 2012), while Waste Management, a company that recently announced 1000 natural gas trucks nation-wide in 2011

(Andrews and Quiroa, 2011), used grant money to purchase a fueling station dedicated to Waste Management.

This solution would assist in the resolution of any chicken-and-egg problem that fleets are facing. Designed mainly with larger fleets in mind, a shift of economic incentive from vehicle subsidy to public infrastructure subsidy will increase the number of natural gas vehicles in the area by encouraging large companies to convert their fleet to use the new infrastructure. This in turn will provide demand for natural gas providers to continue drilling and will encourage smaller companies to convert without worrying about not having fueling stations to cover their shipping lanes.

The two options that appear to be beneficial to trucks are Option A: Status Quo and Option C: Infrastructure Service Provision. Option B, although it has some historical context through the Alternative Fuels Incentive Grant program, fails to address some key aspects of the problem regarding natural gas trucks and without a strong infrastructure policy to support it, it will likely prove unsuccessful in accomplishing the policy goals. In order to determine which of these two policy options makes the most sense, it is important to understand what the willingness is to create new policy for natural gas trucks. Specifically, Act 13 is a relatively new policy, introduced in 2012, that is being implemented, and for policy makers, keeping status quo will be much more favorable than creating new legislation so soon after the emergence of the new policy. Additionally, our analysis has shown that the quantity of infrastructure in the Pittsburgh region is currently satisfying the demand and that this infrastructure can foster some additional growth in natural gas trucking. These combinations make Option A edge out Option C for the most beneficial policy, earning the recommendation as the best policy option at this time for natural gas trucks.
It is important to note, however, that Option C still has favorable outcomes and it would be beneficial for the stakeholders involved to further investigate and develop infrastructure service provisions to encourage the use of natural gas trucks.

3.5 Boats

Introduction

Pittsburgh marine shipping represents an industry that may stand much to gain from natural gas as an alternative fuel source. The Port of Pittsburgh is the second largest inland waterway in the United States, serving hundreds of vehicles, both land and aquatic. Tugboats and towboats are targeted for analysis, as they are owned in fleets and consume an amount of fuel similar to 23 semi trucks or 830 compact cars (American Clean Skies, 2012). Despite these advantageous qualities, the conversion of boats is not met without resistance. The remainder of this section explores the technologies, environmental concerns, economic feasibility, infrastructure, and policies associated with the marine industry's conversion to natural gas.

Information Gathering

Technology

Boats, like trains, require fuels with high energy density. As such, aquatic vehicles would require Liquefied Natural Gas (LNG) instead of Compressed Natural Gas (CNG). The energy density of LNG is roughly half of that of traditional diesel fuels whereas CNG's energy density is roughly a fifth of diesel fuel. LNG's storage poses possible safety concerns to potential investors, as the fuel must be cooled to a cryogenic -260F. The storage for the LNG, both on board and on land, is therefore more expensive and is heavier than traditional fuel storage (Balon, Thomas; Lowell, Dana; Curry, Tom; Van Attan, Christopher, 2012). Although the likelihood of an explosion is low, leakage in LNG storage tanks remains a safety concern. Rapid release of the fuel may result in a physical explosion or a cloud of flammable fuel. Although the probability of such events is low, their consequences may be dire. To account for these risks, ships must install vents and gas detectors, and double wall piping (Mohn, Henning, 2012).

Although LNG powered vessels have not been used in the Pittsburgh Area, they are employed by ferrying services in the Baltic Sea. The ferries in the Baltic serve as an example of successful deployment of LNG as an alternative fuel. Ship-owners there have found decreased maintenance costs, quieter operation, and cleaner boilers suits in the LNG vessels. Although only 27 boats are currently in service in the Baltic Sea, many more are being produced to meet the demands. Having logged more than 200,000 hours of operation logged, the LNG vessels have run without significant incident (Mohn, Henning, 2012).

Towboats and tugboats are powered by a variety of engines, which range across a spectrum of horsepower capabilities. Those in the Pittsburgh area range from 200 horsepower to 4,500 horsepower. The engines used by the Baltic Sea ferries are dual fuel engines, capable of producing more than 2,500 horsepower, are more than enough for many of the vessels in the Pittsburgh Area (Balon, Thomas; Lowell, Dana; Curry, Tom; Van Attan, Christopher, 2012).

Environment and Emissions

Emissions are a key topic when considering the conversion of boats in Pittsburgh to natural gas power. Air quality is of particular importance to Pittsburgh, given its past struggles with pollution, which go back to the steel production era.

Today, almost all boats along Pittsburgh's rivers operate with a diesel engine. Diesel is notorious for being high in hydrocarbon, nitrogen, sulfur, and particulate matter emissions. Upcoming Tier 3 and 4 regulations put in place by the EPA require reduced limits of NO_x, SO_x, and particulate matter emissions that these diesel engines are not all able to fulfill [EPA, 2013]. LNG is very low in sulfur and is therefore compliant with sulfur regulations for Tiers 3 and 4 (American Clean Skies, 2012). The alternatives to this, ultra and low sulfur diesel fuels, which contain 15 and 500 parts per million of sulfur respectively, can be very costly for Pittsburgh boats' high fuel consumption [EPA, 2013]. According to the Clean Skies Foundation, "a 150-ton tug can burn more than 400,000 gallons of fuel a year, while a 1,000-ton ferry can burn almost 700,000 gallons" (American Clean Skies, 2012). Given how LNG and diesel engines both get about 0.02 miles per gallon, these significant annual fuel expenditures would result in a significant annual emission reduction.

Another important consideration, when looking at the environmental implications of natural gas powered boats, is spill potential and consequences. If an LNG tank is to spill, it can form a vapor cloud that will ignite if sparked. As LNG is denser than air, this cloud would drop to water level and pose a major risk for those around it [Exponent, 2012]. Depending on the circumstances of a spill, it may be anywhere from harmless to very damaging. However, LNG storage technology has improved drastically and the likelihood of a spill is low enough to be considered negligible (Testa, 2004; Templeton, David, 2012).

Economic Feasibility

The costs associated with the conversion to an LNG-powered boat are mainly concentrated around updating the engine. The American Clean Skies Foundation produced a report that speculated on the viability of marine shipping vessels powered by LNG, specifically focused on large towing tugs, medium to large ferries, and Great Lakes Bulk Carriers (American Clean Skies, 2012). This report stated that the marine shipping industry fuel source is currently dominated by residual fuels; however, this fuel must soon be replaced by more expensive (but cleaner burning) distillate fuel due to increasingly stringent EPA emissions standards. Although the increased weight of a LNG tank will cause a larger quantity of fuel to be required in order to perform at the same level, the steady price increase of traditional fuel sources and imminent switch to distillate fuel may be enough to interest fleet owners in the possibility of using LNG as a future fuel solution.

Relying on projections made by the U.S. Energy Information Administration (EIA), the report published by the American Clean Skies Foundation examines the cost of investment, payback period, and possible implementation of natural gas vessel conversion. The EIA estimates that, within the next 10 years, liquid natural gas prices will remain as low as 47% of traditional fuels.

Outfitting a large vessel, like a Great Lakes bulk carrier costs roughly $4 million. The present value of fuel savings presented by the American Clean Skies Foundation is valued at more than $20 million. These numbers promise substantial savings by converting vessels to natural gas. The cost of conversion, however, lies not in the outfitting of the ship with an LNG engine, but in the facilities and infrastructure supporting the vessels. Outside of engine conversion costs, shipping firms must also purchase LNG fueling systems, which cost an estimated $20 million. The payback period of this investment is projected to be 12 years (American Clean Skies, 2012). As these figures will vary between engine types and vehicle purpose, decisions regarding the switch to LNG powered vessels should be specific to individual fleets or types of vehicles.

Payback Period Analysis

The payback period for a Natural Gas powered tugboat was calculated for the best guess, optimistic, and pessimistic cases. The data used in the necessary calculations of net present value is shown in Table 16.

Table 16: Key Base Data Assumptions for NG Boats Payback Period Analysis

	Conversion Cost ($)	Discount (%)	Miles Travelled (miles/yr)	MPG (miles/gal-eq)	PM2.5 Reduction (tons/yr)	Lifetime (yr)	Price differential ($/gal-eq)
Best Guess	$1,500,000	6%	8,000	0.020	0.000	10	$1.91
Minimum	$1,200,000	3%	6,000	0.015	0.000	7.5	$0.63
Maximum	$1,800,000	9%	10,000	0.025	0.000	12.5	$3.46

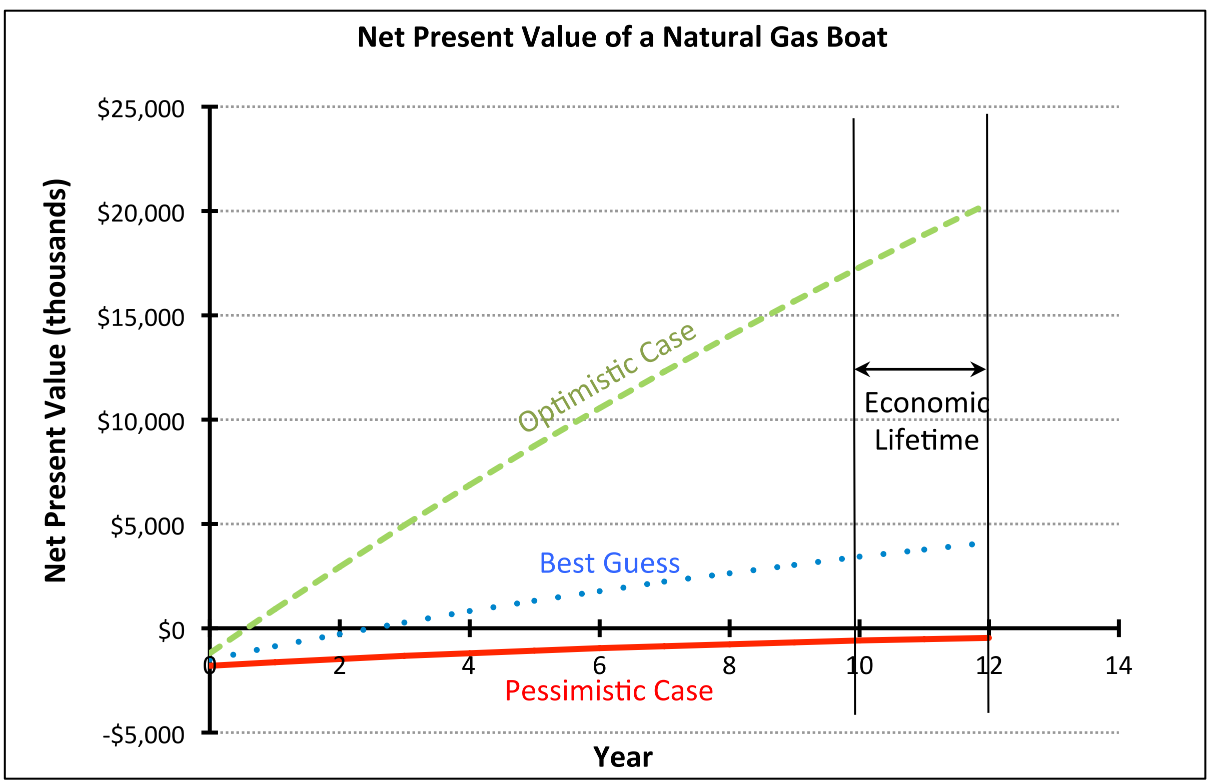

Figure 32: Results of the Payback Period Analysis of NG Boats.

As shown in Figure 32, boats would be shorter than the vehicle lifetime for both the best guess and optimistic cases. The optimistic case results in a payback period of approximately 1 year while the best guess case turns out a payback period of 2 years. The pessimistic case has a payback period that would be longer than the vehicle lifetime, which indicates that the investment would not be worthwhile. The large separation between the payback periods of the optimistic and best guess cases and the pessimistic case can easily be attributed to the fuel price differential used in the calculations. The best guess and optimistic cases used fuel price differentials of \$1.89 and \$2.00, respectively. The pessimistic case factored in a fuel price differential of only \$0.24, which significantly decreases the amount of money saved by the consumer on operational costs. Since it appears that the actual price differential in the immediate future will not fall by such a drastic amount, the payback period analysis concludes that LNG powered boats would be worth the investment.

Sensitivity Analysis

In order to determine the variable that most heavily affected the results of the payback period analysis, a sensitivity analysis was completed. This is an important supplement to the net present value analysis because it provides insight as to the effects of future changes in values of the key base data. The results of the sensitivity analysis are included in Figure.

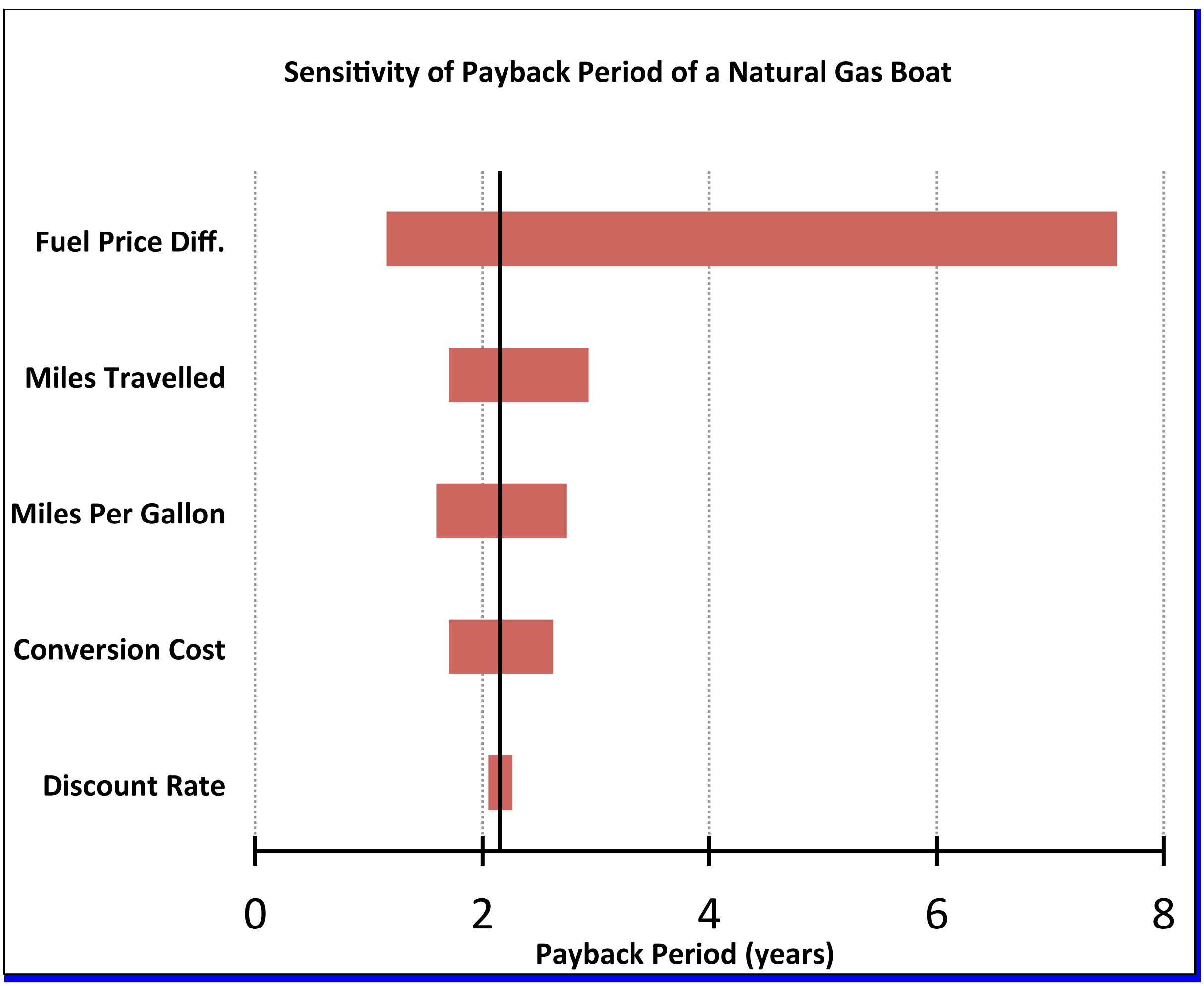

Figure 33: A tornado diagram displaying the sensitivity of the payback period of LNG tugboats.

The tornado diagram above (Figure 33) shows that the fuel price differential is the most influential factor in the determination of the payback period of an LNG powered boat. The value used in the calculation of the pessimistic case drastically increases the payback period far more than the variation of any other data point. The fuel price differential is by far the most unpredictable variable used in the calculation of payback period, meaning that an LNG powered boat could potentially be a risky investment.

Infrastructure

One of the main issues found with the implementation of LNG-powered vessels is the availability of related infrastructure. A report analyzing the market for marine natural gas vehicles, titled *Potential Market for LNG-Fueled Marine Vessels in the United States* and written by Bridget C. Brett, described the options for a refueling infrastructure. Methods provided include LNG terminals, tanks, tanker trucks, mobile tanks, and barges. LNG terminal refueling would allow marine vessels to refuel directly at stations that receive the fuel from overseas carriers, requiring no additional construction of infrastructure. A refueling tank would require construction of additional infrastructure at ports, at a quoted cost of roughly $1 million. The process of constructing a tank requires a site approval by the Federal Energy Regulatory Commission, followed by an Environmental Impact Statement. A tanker truck requires no infrastructure, as marine vessels are fueled directly from the trucks. This method, however, has a limited capacity, as it can require about six trucks to completely refuel a ferry. Mobile tanks are a similar option, and can be transported on site by trucks, trains, or ships, then stored at the port. The tanks require no dedicated housing. The last proposed refueling method was direct vessel-to-vessel refueling via barges. (Brett, Bridget, 2008)

There presently exists a shortage of shore-side LNG production facilities worldwide. Each new, dedicated facility is estimated to cost $50 million. American Clean Skies Foundation calculates the rate of return for a shoreline LNG facility to be 11% over 10 years (American Clean Skies, 2012). However, the report also questions if the demand for shore-side LNG production facilities is sufficient to sustain such an investment.

Another obstacle involves the conversion of CNG to LNG, which allows for fuel to be stored using much less space on the boat. CNG is easy to get but the infrastructure that allows it to be liquefied is not. Despite these difficulties, ferry managers remain optimistic about the conversion. What is holding companies back from switching to natural gas powered vessels? The Staten Island Ferry system in NY has set a good example it appears, as it has received $3 million in grants and finally motivated the switch (Farrell, A., Glick, M., 2000). Natural gas, however, has caught the attention of more than just those looking to improve passenger ferries.

The implementation of LNG-powered vehicles cannot be successful without the proper infrastructure. Current infrastructure uses 12 refueling stations to service the boat fleet of Pittsburgh, so we would estimate that an equal amount of LNG stations would be sufficient. If this fuel alternative is to be seriously considered, the state and federal governments may be able to help motivate the switch with the enactment of policies and/or incentives.

Findings

There are currently no natural gas refueling stations for boats along rivers within the Pittsburgh Metropolitan Statistical region. Many boat owners would need refueling stations not only within the Pittsburgh statistical region, but in the surrounding Pennsylvania region and Ohio to make refueling viable with their operating routes. It was determined that the group of shipping and towing companies that operate out of the Port of Pittsburgh are known to be very conservative and risk-averse, meaning that they may not necessarily be open to the idea of converting to natural gas-powered vehicles.

Existing Policies

There are no currently existing policies regulating natural gas boats explicitly in the Pittsburgh area. There are, however, national policies, which may help or hinder the adoption of natural gas boats.

It could be extremely challenging to build the infrastructure necessary for natural gas-fueled boats. Regulation by the Federal Energy Regulatory Commission (FERC) has the possibility to restrict the construction on LNG refueling stations for boats, disallowing construction in desirable locations. The FERC's website states the commission "issues certificates of public convenience and necessity for LNG facilities engaged in interstate natural gas transportation by pipeline… the FERC prepares environmental assessments or impact statements for proposed LNG facilities under its jurisdiction" (FERC, 2013). The FERC primarily ensures that terminals comply with the National Environmental Policy Act, but their regulations can extend beyond that if a location is not deemed suitable for an LNG facility.

Alternatively, regulations regarding boat emissions may be a push towards LNG, as operators already have to comply with regulations that require them to use a less-pollutant fuel. Under MARPOL, NO_x and SO_x emissions must be reduced, which is possible through the use of LNG (Pederson, 2011). Whether this influence of policy is enough to necessitate the use of LNG fuel must be analyzed, but it may be a factor that leads to the selection of LNG for fueling boats.

Findings

When considering the conversion of boat fleets operating in Pittsburgh to natural gas power, we must look a few critical points. First off, there are currently no policies in place to incentivize the switch. We also know that there is no refueling infrastructure for boats in Pittsburgh, although the port of Pittsburgh is performing a study on tentative locations of refueling stations for LNG boats. The conversion is viable on a per vehicle basis because the payback period is under 3 years. This payback period is most sensitive to the fuel price differential for LNG. Also, there is no economic incentive for ship owners to convert a boat to meet the new Tier 3 emission standards coming into effect in 2016 because these standards do not affect boat conversions, only newly manufactured boats (DieselNet, 2013).

Policy Options

Given the findings outlined above, we converge towards three main policy options, shown in Figure 34. Firstly, we could maintain status quo. Second, we could provide a vehicle economic incentive to further decrease the payback period and make it even more clear to fleet owners that LNG conversion is of economic benefit to them. Finally, we could suggest an infrastructure service provision that would provide ship owners with refueling stations along Pittsburgh's rivers. Based on our four-point methodology evaluation, we have concluded that the infrastructure provision is the best choice.

Boat Policy Option	O	E	R	Q
A: Status Quo - Little to no policies in place to incentive the switch. - Policy analysis is being conducted.	-	0	-	0
B: Vehicle Economic Incentive - Payback time without incentives or infrastructure costs is less than 3 years: already economically efficient. - Even if ship owners can make the switch, it is still difficult to implement change without infrastructure. - Ship owners are risk adverse.	+	+	+	-
C: Infrastructure Service Provision - Relieves ship-owners of risk in high infrastructure costs - Politically feasible. - Can service vehicles other than boats.	+	+	+	+

Figure 34: Final Policy Recommendations for Natural Gas-powered boats. Table 2. Final Policy Recommendations for Natural Gas-powered boats.

Recommendation

We would not recommend economic incentives for the conversion of boats to natural gas. The payback period for natural gas conversion, even without financial inventive, was found to be within an acceptable range due to the large consumption of fuel by towboats and tugboats. Rather, the major impediment to natural gas conversion is this infrastructure on which these vessels would rely. As such, boats benefit the most from government-assisted implementation of fueling infrastructure. This relieves ship-owners of the high capital costs and high risks associated from building this infrastructure. Provision of the infrastructure could be enough to motivate ship-owners to change to natural gas. Furthermore, this action could be perceived as politically feasible. Building infrastructure is also advantageous due to the opportunity to use the refueling structures for different vehicle types.

4.0 Cross-Cutting Quantitative Analysis

4.1 Introduction

The quantitative analyses were completed using the vehicle specific key base data and assumptions. The results of the payback period analysis were used to create charts displaying the payback periods of different cases and tornado diagrams showing the sensitivity to each individual variable. Supply curves were created in order to determine environmental benefits, energy independence, private economics, and aggregate social welfare. The products that resulted from these analyses were factored in when concluding on the feasibility of natural gas vehicles and the policies that would encourage the desired behavior of fleet owners.

4.2 Summary of Assumptions

Key Base Data and Assumption Summary

Each vehicle analysis group collected the key base data that was used for the quantitative analyses. This data came from a variety of sources that included surveys with fleet operators, relevant websites, and information gathered from guest presenters. The key base data for petroleum-fueled vehicles is shown in Table 17. All of the vehicle-specific groups were also responsible for providing key base data for Natural Gas-powered vehicles, which is provided in Table 18. These assumptions were either determined through specific NGV research or assumed to be the same as petroleum-powered vehicles, where appropriate. All references are listed in the footnotes that follow.

Using the key base data as a best guess estimate, the vehicle specific groups determined a pessimistic and optimistic value for each of the variables. This was done in order to compare the results of the quantitative analyses in each of the three cases. The ranges were most useful when determining possible payback periods and analyzing the sensitivity of the variables.

In addition to our assumptions on the social benefit of reducing $PM_{2.5}$, there is also a social benefit to reducing petroleum usage. A study concluded that the benefit ranged from $10.50 to $38 per barrel of crude oil, with a median, adjusted for 2012, of $25. For each barrel of crude oil, there is 11 gallons of diesel, 19 gallons of gasoline, and 12 gallons of others. This sums to a total of 42 gallons of fuel. Thus, an estimate can be made on the social benefit per gallon of fuel: $25/42 is approximately $0.60 benefit per gallon. This number is used in addition to the social benefits accrued by $PM_{2.5}$ reduction.

Methodology of $PM_{2.5}$ Reduction Benefit

In deciding whether or not the class should pursue the benefits of possible reduction in ultrafine particulate matter, scientific literature was consulted to determine its value. According to the Health Effects Institute, ultrafine particles (UFPs) are defined as being less than 100nanometers in diameter (HEI 2013). The fear of UFPs resulting in greater toxicity than larger particles stems from their ability to be inhaled through skin as well as their high surface area (HEI 2013). However, the effect of more fuel efficient vehicles and the use of natural gas as an energy source have an "undefined" affect on UFP production and thus it was not included in our analysis (HEI 2013).

One of the major aspects of the study of the benefits and feasibility of conversion to natural gas is the potential reduction of $PM_{2.5}$. The class researched what the economic benefit in a dollar amount of the $PM_{2.5}$ reduction that refers to "avoided human health impacts and the monetized benefits of air quality improvements" (Fann 2012). For the particular quantified amount of economic benefit, the methods used to resolve the particular number were to model the "$PM_{2.5}$ contribution from each of 17 different sectors… estimating the number of premature deaths and illness attributable to each of these sectors… and divided health impacts and monetized benefits by the emissions" (Fann 2012). For the specific number used to determine the quantitative benefit of $PM_{2.5}$, the estimate of "on-road mobile sources" of $240,000 saved per ton of reduction was chosen (Fann 2012).

Table 17: Key Base Assumptions by Vehicle Type for Petroleum-fueled Vehicles (gasoline for cars, diesel for all other vehicles)

Vehicle Type		Number of Vehicles in Pittsburgh MSA	Annual Gallons of Fuel Used per Vehicle (thousands)	Total Annual Gallons of Fuel Used Per Fleet (millions)	Average Vehicle Lifetime (years)	Turnover Rate (percent of fleet)	Conversion Cost or Cost of NG vehicle (thousand $)	Miles Travelled per Vehicle per year (thousands)	Miles per Gallon	g $PM_{2.5}$ per gal eq fuel
Cars	Taxi Fleet	500[i]	5.5[ii]	2.75[iii]	8[iv]	10 - 15[v]	40[vi]	20 – 146[vii]	13-18[viii]	0.391[ix]
	Passenger	719,000[x]	0.36[xi]	257[xii]	12[xiii]	N/A	18[xiv]	12[xv]	28-39[xvi]	0.176[xvii]
Buses	School	6794[xviii]	1.71[xix]	11.6[xx]	8-15[xxi]	7-12.5[xxvii]	120[lxxiii]	8-12[xxii]	3-7[xxiii]	.475[xxiv]
	Urban Transit	687[xxv]	9.98[xxvi]	8.0[xxvii]	4-5[xxviii]	20-25[xxix]	140[lxxxiii]-215[lxxviii]	66[xxx]	4-6[xxxi]	.3135[xxiv]
Trains		50-70[xxxii]	50-70[xxxiii]	160-200[xxxiv]	8-14[xxxv]	6[xxxvi]	3 - 18[xxxvii]	2000[xxxviii]	100-135[xxxix]	0.63-0.68[xl]
Trucks: Class 8		16,500	16,500[xli]	10-15[xlii]	165-247.5[xliii]	6[xliv]	16.7	116[xlv]	69[xlvi]	6.5[xlvii]
Boats		108	108[xlviii]	319-529[xlix]	34.5-57.1[l]	7.5-12.5[li]	2.0 -2.5[lii]	1200-1800[liii]	6-10[liv]	0.015-0.025[lv]

Sources for Table 17

[i] Personal Communication with Bob DeLucia, President of Star Transportation on Thursday, March 28th
[ii] Calculated from miles travelled and fuel economy
[iii] Calculated from fuel per vehicle and population size
[iv] Personal Communication with Bob DeLucia, President of Star Transportation on Thursday, March 28th
[v] Personal Communication with Bob DeLucia, President of Star Transportation on Thursday, March 28th
[vi] "VPG Has very big plans for its MV-1", Star Transportation Group, accessed from <http://www.startransportationgroup.com/itnvpg.html>. Note: This is cost for new vehicle.
[vii] Natural Gas Vehicles, Fueling Infrastructure and Economics, by NREL 2011
[viii] Information obtained from fueleconomy.gov. Using data about MV-1 <http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=33378>
[ix] Numbers calculated from gasoline car value from GREET using ratio of fuel economies.
[x] Report on Vehicle Registrations in Pennsylvania, 2012
[xi] Calculated from miles travelled and fuel economy
[xii] Calculated from fuel per vehicle and population size
[xiii] Report on Transportation and Energy Issues, by APS, accessed from <http://www.aps.org/policy/reports/popa-reports/energy/transportation.cfm>
[xiv] Value obtained for pricing from Honda Website < http://automobiles.honda.com/civic/>, Honda Sedan. Note: This is price for new vehicle.
[xv] Natural Gas Vehicles, Fueling Infrastructure and Economics, by NREL 2011
[xvi] Information obtained from fueleconomy.gov. Using data about Honda Civic < http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=33504>
[xvii] Numbers obtained from GREET Model 1.8.079, using gasoline car for model, accessed from <http://greet.es.anl.gov/greet/>
[xviii] Pennsylvania Department of Motor Vehicles. "Report on Registration." DMV, 2012. Accessed March 21, 2013.
[xix] "Environmental Benefits – School Buses". American School Bus Council. Accessed April 2, 2013
[xx] Calculated by multiplying the number of vehicles by the average fuel consumption per vehicle
[xxi] National Associate of State Directors of Pupil Transportation Services "Information Report School Bus Replacement Considerations" January 2002 http://www.nasdpts.org/Documents/Paper-BusReplacement.pdf

[xxii] "Environmental Benefits – School Buses". American School Bus Council. Accessed April 2, 2013
[xxiii] "Environmental Benefits – School Buses". American School Bus Council. Accessed April 2, 2013
[xxiv] Kado, Norman et al "Emissions of Toxic Pollutants from Compressed Natural Gas and Low Sulfur Diesel-Fueled Heavy-Duty Transit Buses Tested over Multiple Driving Cycles" California Air Resources Board http://www.aseanenvironment.info/Abstract/41013739.pdf
[xxv] National Transit Database. "Transit Agency Information". Accessed April 21, 2013.
[xxvi] National Transit Database. "Transit Agency Information". Accessed April 21, 2013.
[xxvii] National Transit Database. "Transit Agency Information". Accessed April 21, 2013.
[xxviii] Personal communication with Ken Robinson of Port Authority on March 20th, 2013
[xxix] Calculated from Vehicle life and total number of vehicles.
[xxx] National Transit Database. "Transit Agency Information". Accessed April 21, 2013.
[xxxi] Calculated from Miles traveled and number of vehicles.
[xxxii] No data available, assumed same as diesel trains
[xxxiii] "National Rail Freight Infrastructure Capacity and Investment Study." *Cambridge Systematics, Inc*. (September 2007): 36-7
"Appendix 5 – Freight Rail System." Pennsylvania Intercity Passenger and Freight Rail Plan. (2007): 4-3
Calculated from number of train cars that run through Pittsburgh annually (Cambridge Systematics) and the average number of train cars per train (Appendix -5) Best guess is 65 trains.
[xxxiv] *Fuel Efficiency* (CSX, 2012), *Railroad Equipment* (CSX, 2012)
[xxxv] Calculated range by multiplying lower and upper bounds for number of trains and annual fuel use
[xxxvi] Personal Communication with Steven Forsberg, General Director of External Relations, BNSF on March 21, 2013.
[xxxvii] Calculated from information obtained from Personal Communication with Steven Forsberg, General Director of External Relations, BNSF on March 21, 2013. Lower bound based on new vehicle conversion. Upper bound based on new and retrofitted conversion.
[xxxviii] "An Evaluation of Natural Gas-fueled Locomotives." BNSF. 2007. Accessed April 9, 2013.
[xxxix] Personal Communication with Steven Forsberg, General Director of External Relations, BNSF on March 21, 2013.
[xl] Calculated range from dividing annual miles traveled per vehicle and annual gallons of fuel used per vehicle.
[xli] Pennsylvania Department of Motor Vehicles. "Report on Registration." DMV, 2012. Accessed March 21, 2013.
[xlii] Lickert, Mike. "Giant Eagle: Delivering a cleaner future." Giant Eagle, 2011. Accessed April 2, 2013.
[xliii] Total class 8 trucks times annual diesel consumption per truck
[xliv] Transportation Energy Data Book. "Summary Statistics for Class 3-8 Single Unit Trucks, 1970-2010. US Department of Transportation, 2012. Accessed March 24, 2013.
[xlv] 2014 ISX ProStar Day Cab Cost
[xlvi] United States Energy Information Administration
[xlvii] http://www.cleanenergyfuels.com/pdf/KenGrnInitiatives-LNGCNG.pdf, slide 16
[xlviii] We looked up the regional carriers that use the port of Pittsburgh and tracked the # through their website
[xlix] http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf
[l] The total annual gallons of fuel used was calculated by multiplying the annual gallons used per vehicle by the number of vehicles.
[li] http://thekiva.org/ngv-files/public/234/Diesel%20Emissions%20Stds%20Marine%20Vessels.pdf
[lii] Transportation – Industrial Freight Transportation. Sustainable Development Technology Canada. 2009.
[liii] Engine cost for a Tug Boat and Ferry boat are $1.2M and $1.8M respectively. *Natural Gas For Marine Vessels: U.S. Market Opportunities*, American Clean Skies, April 2012.
[liv] Boating Safety. Life Lines. 2013.
[lv] The miles per gallon were calculated by dividing the miles traveled by the annual gallons per vehicle.

Table 18: Key Base Assumptions by Vehicle Type for Natural Gas-fueled Vehicles

Vehicle Type		Number of Vehicles in Pittsburgh MSA	Annual Gallons of Fuel Used per Vehicle (thousands)	Total Annual Gallons of Fuel Used Per Fleet (millions)	Average Vehicle Lifetime (years)	Turnover Rate (percent of fleet)	Conversion Cost or Cost of NG vehicle (thousand $)	Miles Travelled per Vehicle per year (thousands)	Miles per Gallon	g $PM_{2.5}$ per gal eq fuel
Cars	Taxi Fleet	500[lvi]	6.4[lvii]	3.2[lviii]	8[lix]	10-15[lx]	51[lxi]	20 – 146[lxii]	11-16[lxiii]	0.402 [lxiv]
	Passenger	719,000[lxv]	0.37[lxvi]	265[lxvii]	11[lxviii]	N/A	26[lxix]	12[lxx]	27-38[lxxi]	0.167 [lxxii]
Buses	School	6794	1.71[lxxiii]	11.6[lxxiv]	8-15[lxxv]	7-12.5[xxvii]	150[lxxvi]	8-12[xxi]	3.0[lxxvii]	.276[xxiv]
	Urban Transit	1440	9.45[lxxviii]	13.6[lxxix]	4-5[lxxx]	20-25[lxxxi]	270[lxxxii]	32[xxviii]	3.0[lxxvii]	.276[xxiv]
Trains		50-70[lxxxiii]	160-200[lxxxiv]	8-14[lxxxv]	6[lxxxvi]	3 - 18[lxxxvii]	2600-3000[lxxxviii]	100-135[lxxxix]	0.63-0.68[xc]	2.1[xci]
Trucks: Class 8		16,500	10-15[xcii]	165-247.5[xciii]	6[xciv]	16.7	35 (CNG) 90 (LNG)[xcv]	69[xcvi]	6.5[xcvii]	0.17 [xcviii]
Boats		108	319-529	34.5-57.1	7.5-12.5	2.0-2.5	1200-1800[xcix]	6-10[c]	.015-.025	1.5[ci]

Note: This table is for the scenario where all vehicles in Pittsburgh are converted to natural gas. Therefore, the number of vehicles and the miles travelled per vehicle are assumed to be the same as for the base case analysis.

Sources for Table 18

[lvi] Assumed same as gasoline vehicles.
[lvii] Calculated using fuel economy and miles travelled
[lviii] Calculated using fuel use per vehicle and fleet size
[lix] No data available, assumed same as gasoline vehicle
[lx] No data available, assumed same as gasoline vehicle
[lxi] "VPG Has very big plans for its MV-1", Star Transportation Group, accessed from <http://www.startransportationgroup.com/itnvpg.html>. Note: This is cost for new vehicle.
[lxii] No data available, assumed same as gasoline vehicle
[lxiii] Information obtained from fueleconomy.gov. Using data about MV-1 CNG < http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=32158>
[lxiv] Numbers calculated from dedicated natural gas car value from GREET using ratio of fuel economies.
[lxv] Assumed same as gasoline vehicles.
[lxvi] Calculated using fuel economy and miles travelled
[lxvii] Calculated using fuel use per vehicle and population size
[lxviii] No Data Available, assumed same as gasoline
[lxix] Value obtained for pricing from Honda Website < http://automobiles.honda.com/civic/>, Honda Natural Gas Civic. Note: This is price for new vehicle
[lxx] No data available, assumed same as gasoline vehicle
[lxxi] Information obtained from fueleconomy.gov. Using data about Honda NG Civic <http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=32336>
[lxxii] Numbers obtained from GREET Model 1.8.079, using dedicated natural gas car for model, accessed from <http://greet.es.anl.gov/greet/>
[lxxiii] "Environmental Benefits – School Buses". American School Bus Council. Accessed April 2, 2013
[lxxiv] Calculated by multiplying the number of vehicles by the average fuel consumption per vehicle
[lxxv] National Associate of State Directors of Pupil Transportation Services "Information Report School Bus Replacement Considerations" January 2002 http://www.nasdpts.org/Documents/Paper-BusReplacement.pdf
[lxxvi] "A Feasibility Study of Natural Gas Vehicle Conversion In Wyoming Public School Districts" November 2012 http://eadiv.state.wy.us/specialreports/NGV_School_Bus_2012.pdf

[lxxvii] Lowell, Dan "Clean diesel versus CNG Buses: Cost, Air Quality, and Climate Impacts" quoting Johnson quoting APTA.
[lxxviii] "PAAC's Natural Gas P3 Project" Presentation by Ellen M. McLean. Numbers were scaled.
[lxxix] PAAC's Natural Gas P3 Project" Presentation by Ellen M. McLean. Numbers were scaled.
[lxxx] Personal communication with Ken Robinson of Port Authority on March 20th, 2013
[lxxxi] Calculated from Vehicle life and total number of vehicles.
[lxxxii] "Alternative fuel transit bus evaluation program results" K Chandler Society of Automotive Engineer
[lxxxiii] No data available, assumed same as diesel trains
[lxxxiv] No data available, assumed same as diesel train.
[lxxxv] No data available, assumed same as diesel train.
[lxxxvi] No data available, assumed same as diesel train.
[lxxxvii] No data available, assumed same as diesel train.
[lxxxviii] Additional $600k-$1000k cost for NG engine conversion. Shauk, Zain."Natural gas eyed as fuel for trains." SFGate. 2013. Accessed April 9, 2013.
[lxxxix] Personal Communication with Steven Forsberg, General Director of External Relations, BNSF on March 21, 2013.
[xc] No data available, assumed same as diesel train.
[xci] "Nonroad Diesel Engines." EPA. 2013. Accessed April 9, 2013. And "The Carl Moyer Program Guidelines." CARB. 2013. Accessed April 9, 2013.
[xcii] Lickert, Mike. "Giant Eagle: Delivering a cleaner future." Giant Eagle, 2011. Accessed April 2, 2013.
[xciii] Total class 8 trucks times annual diesel consumption per truck
[xciv] Transportation Energy Data Book. "Summary Statistics for Class 3-8 Single Unit Trucks, 1970-2010. US Department of Transportation, 2012. Accessed March 24, 2013.
[xcv] http://www.forbes.com/sites/larrybell/2012/11/27/tough-trucking-for-natural-gas-vehicles-can-they-make-it-in-the-long-haul/ http://fuelfix.com/blog/2012/11/30/chesapeake-pushes-gas-conversion-kits-for-trucks/
[xcvi] Average value from the U.S. Energy Information Administration for a class 8 truck.
[xcvii] http://www.cleanenergyfuels.com/pdf/KenGrnInitiatives-LNGCNG.pdf, slide 16
[xcviii] http://www.aqmd.gov/trans/ab2766/ab2766_emission_factors.pdf
[xcix] Engine cost for a Tug Boat and Ferry boat are $1.2M and $1.8M respectively. *Natural Gas For Marine Vessels: U.S. Market Opportunities*, American Clean Skies, April 2012.
[c] Boating Safety. Life Lines. 2013.
[lxxx] No data available, assumed same as diesel train.
[lxxxiii] Nations Bus Corporation http://nationsbus.com/inventory.php

Payback Period Analysis Summary

The payback period by vehicle is listed in Table 19. These results are considered in the supply curve analysis to determine the most viable vehicles for conversion. Our analysis shows that by the best guess inputs taxis and boats have the fastest predicted return on investment, while school buses have the longest predicted return on investment during the vehicle lifetime. Natural gas passenger cars are not expected to generate a positive net value during the typical lifetime. The optimistic inputs yield much smaller payback periods, while the pessimistic inputs result in no return on investment being made during the vehicle lifetime.

Table 19: Payback Period by Vehicle

Vehicle Type	Best Guess	Optimistic	Pessimistic
Taxis	1	0.33	GVL*
Boats	2.5	1	GVL
Trains	3	1.5	GVL
Transit Buses	3	1	GVL
Class 8 Trucks	4	1	GVL
School Buses	11	3	GVL
Passenger Cars	GVL	11	GVL

* GVL = Greater than Vehicle Economic Lifetime

Supply Curve Analysis

The four supply curves illustrate all the corresponding product quantity in the Y-axis: $PM_{2.5}$ Reduction, total replaced petroleum; and cumulative private cost; as well as their corresponding unit cost. All the supply curves shown in the plot are step functions, all the vehicle types are in each segmented horizontal lines of the step functions. The supply curves provide information on how much it costs for each quantity supplied. The area under each horizontal line indicates the total cost or benefit upon supplying the products: $PM_{2.5}$ reduction, replaced petroleum, social and private benefits. The final decision on which vehicle has the highest feasibility for natural gas conversion will be based on not only the efficiency: unit quantity cost, but also base on magnitude: the total benefits or cost for the supply. In terms of conversion efficiency, taxi is the most viable vehicle for natural gas conversion according to the private economic and social benefit supply curves; boat has the highest feasibility for the conversion according to the environmental benefit and energy independence supply curve. In terms of total benefit magnitude, truck is the most feasible vehicle type for conversion from the three supply curves: private economics, $PM_{2.5}$ reduction and social benefits; passenger car is the most feasible vehicle from the energy independence supply curve.

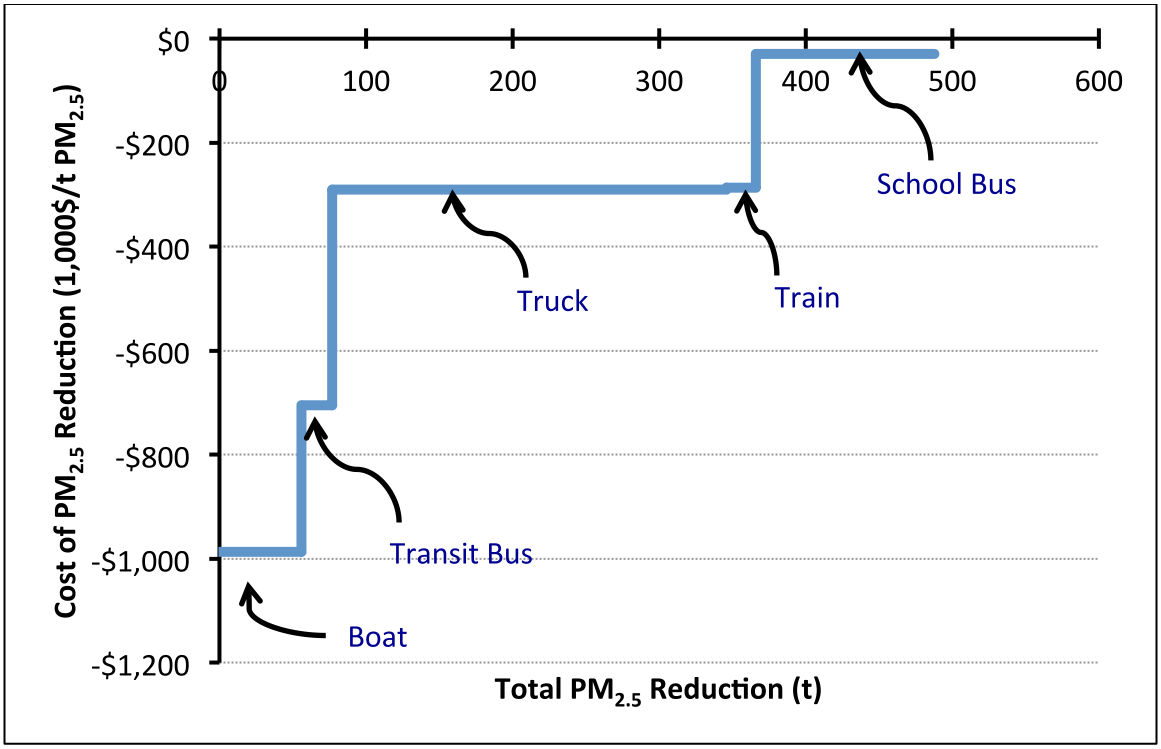

Figure 35: Supply Curve : Cost of PM2.5 reduction vs. Total PM2.5 Reduction

The first supply curve in Figure 35 shows that cost of unit $PM_{2.5}$ reduction increases from boat, transit bus, train, truck, and school bus; with boat has the minimum unit cost of $PM_{2.5}$ reduction: -$987000, and school bus has the maximum unit cost of -$29000. Hence, Boat is the best vehicle for natural gas conversion in this case because it has the highest unit benefits of $PM_{2.5}$ reduction; or in other words, boat has the highest efficiency in $PM_{2.5}$ reduction. On the other hand, truck has the largest amount of total $PM_{2.5}$ reduction: 366 tons; it is indicated in the curve that the horizontal line represent truck has the longest span. In addition, the area above the truck horizontal line represented the magnitude of total $PM_{2.5}$ reduction for all trucks. In this case, truck has the largest area, thus, in terms of $PM_{2.5}$ reduction magnitude; truck is more feasible for natural gas conversion than any other vehicles. It is also worth mentioning that neither natural gas taxi nor natural gas passenger cars is shown in the supply curve as we assume both of them has approximately no $PM_{2.5}$ reduction since gasoline and natural gas car have the similar $PM_{2.5}$ emission We assume that taxi and passenger cars has similar MPG which relates directly proportional to $PM_{2.5}$ reduction. According to the GREET model, the MPG difference between gas car and NG car was negligible, while natural gas car has slightly less MPG compare to gasoline cars.

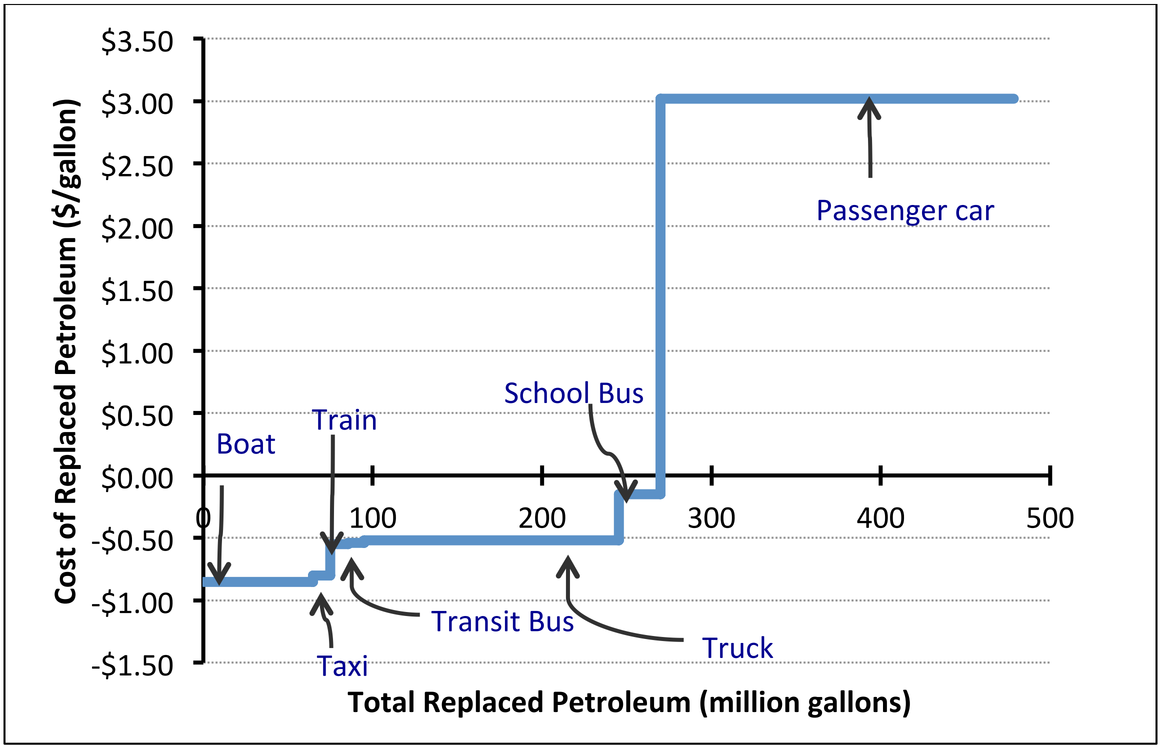

Figure 36: Supply curve: Cost of Replaced Petroleum vs. Total Replaced Petroleum

The second supply curve in Figure 36 shows that cost of unit replaced petroleum increases from boat, taxi, train, transit bus, truck, school bus and passenger car; with boat has the minimum unit cost: -$0.9/gal, and passenger car has the maximum unit cost of $3.0/gal. Please note again that all vehicle types have negative cost for petroleum replacement except passenger car. Hence, Boat is the best vehicle for natural gas conversion in this case because it has the highest unit benefits for petroleum replacement; or in other words, boat has the highest efficiency. On the other hand, truck has the largest amount of total petroleum replacement: 208 million gallons; it is shown in the curve that the horizontal line representing truck has the longest span among all the lines on the negative Y-axis. In addition, the area above the passenger car horizontal line represented the magnitude of total replaced petroleum for 15% passenger cars in Pittsburgh since 15% is the assumed natural gas vehicle adoption rate. In this case, passenger car has the largest area, thus, in terms of total replaced Petroleum; passenger car is more feasible for natural gas conversion than any other vehicles. The reasoning behind is that the number of passenger cars (179K) is significantly greater than any other vehicle types, thus, the amount of total replaced petroleum by all the passenger cars is much more than that of all other vehicle types.

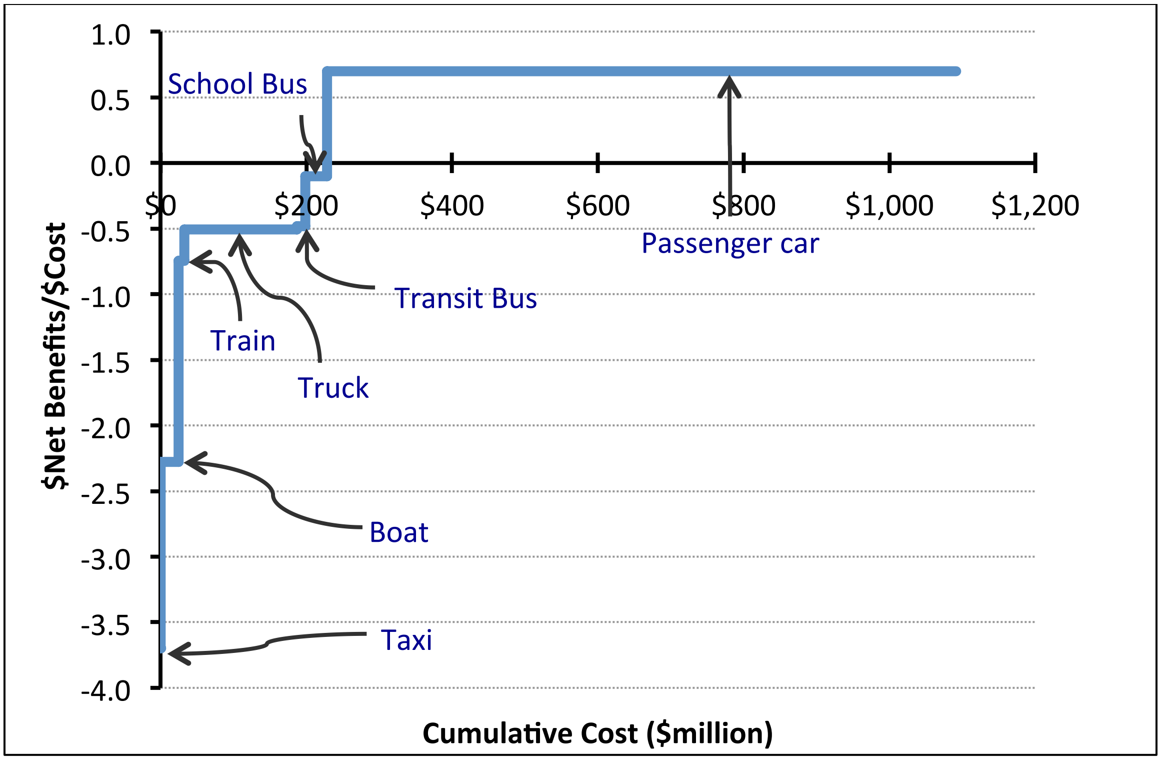

Figure 37: Private net cost for benefit over cost vs. Cumulative cost

The third supply curve shows (Figure 37) that net cost for private benefits over cost from natural gas vehicle conversion, which increases from taxi, boat, train, truck, transit bus, school bus and passenger car. Taxi has the minimum unit benefit over cost: -3.7$, and passenger car has the maximum cost per benefit over cost of $0.7. Please note again that all vehicle types have negative benefit over cost except passenger car. Hence, taxi is the best vehicle for natural gas conversion in this case because it has the highest negative cost (or benefit) per unit benefit over cost; in other words, taxi has the highest efficiency. On the other hand, passenger car has the largest cumulative cost: $862 million; it is shown in the curve that the horizontal line represent passenger car has the longest span. However, passenger car does not have the highest magnitude of benefits, since it has positive cost of net benefit over cost, it means it has positive cost for getting unit private benefit over cost. So the area above the truck horizontal line represented the greatest magnitude of benefits for total benefit over cost., the total cumulative cost for truck is $15 million. Thus truck is more feasible for natural gas conversion than any other vehicles.

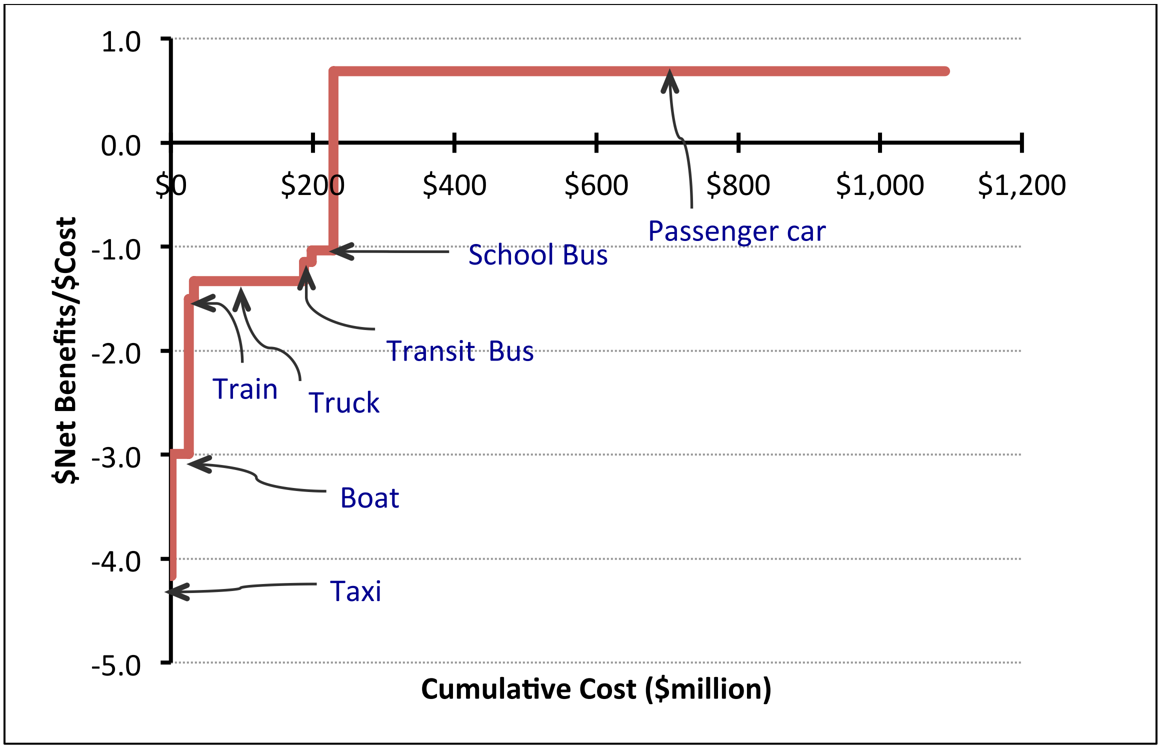

Figure 38: Supply curve: Social net cost for benefit over cost vs. Cumulative cost

Similar to the third supply curve (Figure 38), the fourth supply curve shows that net cost for social benefits over cost from natural gas vehicle conversion; the social benefits take into account of both benefits from PM2.5 reduction and energy independence. The Y-axis net cost increases from taxi, boat, train, truck, transit bus, school bus and passenger car. Taxi has the minimum unit benefit over cost: -3.7$, and passenger car has the maximum cost per benefit over cost of $0.7. All vehicle types have negative benefit over cost except passenger car. Hence, taxi is the best vehicle for natural gas conversion in this case because it has the highest negative cost (or benefit) per unit benefits over cost; in other words, taxi has the highest efficiency. On the other hand, passenger car has the largest cumulative cost: $1,091 million; it is shown in the curve that the horizontal line represent passenger car has the longest span. However, similar to the third supply curve, passenger car does not have the highest magnitude of benefits since it has positive cost of net benefit over cost, it means it has positive cost for getting unit social benefit over cost. So the area above the truck horizontal line represented the greatest magnitude of total social benefits for benefit over cost, the total cumulative cost for truck is $187 million. Thus truck is more feasible for natural gas conversion in terms of magnitude of total social benefits than any other vehicles.

Conclusively, taxi and truck has the highest unit conversion benefit, or efficiency, while truck has the highest accumulative conversion benefits.

5.0 INFRASTRUCTURE

5.1 Historical Precedent

The lack of natural gas infrastructure is a challenge to the market development of natural gas vehicles (NGV) in cities throughout the United States; however, it remains unclear whether incentivizing the development of natural gas infrastructure is an effective way of increasing the use of NGVs in the Pittsburgh metropolitan area. The question of which will occur first – the adoption of NGV or the construction of NG refueling infrastructure – is an important one to the discussion of NGVs. On the one hand, companies considering NGVs need some assurance that the fueling infrastructure will be there. On the other hand, fueling companies need assurances that there will be sufficient demand for NGVs before investing in new capital-intensive infrastructure projects. This dilemma is referred to as the 'chicken and egg problem' with natural gas. To assess whether this current dilemma represents a market impasse, the history of gasoline and gasoline infrastructure is analyzed and compared to present day natural gas fueling.

In 1907, Standard Oil of California opened a filling station in Seattle Washington adjacent from the Standard Oil main depot (Wilma, 2001). By 1915, Standard Oil was having difficulty meeting the demand in the gasoline market; it was becoming clear that the development of gas stations was becoming necessary(Jakle & Sculle, 1994). As a result, Standard Oil of California opened up several new gasoline stations. Following this example, Standard Oil of Indiana and Atlantic Refining Company of Pittsburgh both opened drive through gas stations in hopes of meeting increased gasoline demand. By 1920, it was clear that gas stations were becoming necessary, and station growth increased rapidly from then until 1929 The history of gas station development suggests that the development of NG refueling infrastructure will follow an increased demand for natural gas by the market.

To encourage independent companies to continue selling gasoline and developing gas stations, the National Petroleum News was founded by Warren Platt in 1909 (Platts Energy History). The publication was dedicated to promoting open competition among independent companies and Standard Oil. Later, in the 1920s and 1930s, it also served as a source for gasoline prices, as well as information about refining, production of gasoline, and gas station innovation. Not only did the National Petroleum News promote competition and thus, increasing the growth of gasoline stations, it also educated the public on matters relating to gasoline (Jakle & Sculle, 1994).

In the 1950s, independent service stations comprised of three groups: company owned and operated stations, lessee-dealer stations, and contractor stations. Company owned stations were in the minority, with Standard Oil of Ohio being responsible for many of them. Lessee-dealer relationships involved independent businessmen making profit off of the number of gallons sold. The most popular arrangement in the 1950s was the contractor station, in which a dealer owned and operated the station (Beckman). While this may show that natural gas infrastructure could be funded independently after some initial support, it is a reminder that the initial establishment of infrastructure was primarily from private gasoline companies.

Currently, in regards to natural gas in Pittsburgh, EQT owns two CNG stations. As a response to an increase in natural gas transactions, EQT intends to expand its Smallman Street station. In January

2012, 200 transactions were made, selling 2000 gallons of CNG natural gas. In December 2012, the number of transactions increased to 1000, with 15000 gallons of CNG natural gas sold. This scenario suggests that that the expansion of natural gas fueling stations is following a similar path as the expansion gas station (EQT Expands Downtown Natural Gas Fueling Station, 2013).

There are also incentives being offered to companies considering natural gas vehicles. The state of Pennsylvania passed the Act 13 Shale Legislation in 2012, which reserves $20 million for the conversion and purchase of natural gas vehicles (Schwartzel, 2013). The Pittsburgh city received around $7000 for natural gas vehicles as the result of the legislation (Shale Gas/Act 13 Analysis and Resources). Jim Arthurs, president of natural gas engine company Cummins Westport, believes that if the federal government offered incentives to build natural gas stations, their availability would increase the numbers of natural gas vehicles on the roads (US government incentives needed for natural gas fueling stations, 2012).

There are a number of differences between how gasoline infrastructure developed in the past and how natural gas infrastructure is being developed currently. First of all, fueling infrastructure for gasoline is already present today, making it easier to either add natural gas fueling or to not change at all. In addition, while there was no environmental drive behind the implementation of gasoline infrastructure, EPA regulations on emissions may push people to switch to natural gas, making the implementation of natural gas infrastructure even more pressing.

Overall, natural gas fueling infrastructure will initially follow behind natural gas vehicles. In addition, while government incentives may speed up infrastructure creation, it may not be necessary to successfully implement natural gas infrastructure.

5.2 Current Infrastructure

Cars Infrastructure

The Energy Policy Act of 1992 helped hasten the development of compressed natural gas (CNG) refueling stations in the United States at the start of the 1990s by creating incentives and development strategies (United States Enrichment Corporation (USEC), 1998). The strategy was approved by the Natural Gas Vehicle Coalition (NGVC), which represents 280 companies in the natural gas industry who favor the industry's advancement. The strategy led to four main approaches for the development of CNG infrastructure: onsite private fueling for captive fleets and with public dispensing, offsite private fueling, and public fueling (TIAX, 2008). The demand for natural gas tripled to 27.7 million gasoline gallon equivalents from 1997 to 2009. Following a peak in the number of CNG refueling stations in 1997, the current number of refueling stations remains at less than one thousand as of 2012 (Smith, 2012). There are approximately 120,000 retail gasoline stations – or about 120 gas refueling stations for every 1 CNG refueling stations – in the United States (TIAX, 2008). In the United States, 566 CNG refueling stations are accessible by the public according to the Department of Energy (U.S. DOE, 2013).

There are several factors that impact the design and cost of CNG fueling station. CNG refueling stations require safety mechanisms unique to natural gas vehicles. For example, gas dryers and high-pressure storage systems are necessary in CNG refueling stations under codes for high-pressure gas. Additionally, the size and design of the station depends on the expected demand and usage patterns.

According to studies by America's Natural Gas Alliance, the average cost for installing a CNG refueling station ranges from $10 thousand to $2 million depending on application and size (U.S. DOE, 2013). The same studies recognize infrastructure developers to be compressor manufacturers, suppliers, packagers, engineering and construction companies, and CNG retailers. There was a demand for sixty and eighty new CNG stations in 2010 (TIAX, 2008).

CNG refueling stations can be either fast-fill or time-fill, with the difference between the two being the amount storage capacity available and compressor size. Taxi fleets and other light duty vehicles use fast-fill refueling stations. These types of stations use a compressor to compress the low-pressure natural gas received from a local utility line to a higher pressure of about 4300 psi (U.S. DOE, 2013). Storage vessels at the fueling station store the compressed natural gas until a dispenser is used to transfer CNG gasoline gallon equivalents or (GCEs) to the vehicle tank. A 20-gallon equivalent tank of natural gas can usually be filled in less than five minutes (U.S. DOE, 2013). The following image (Figure 39) depicts a typical fast-fill CNG refueling station.

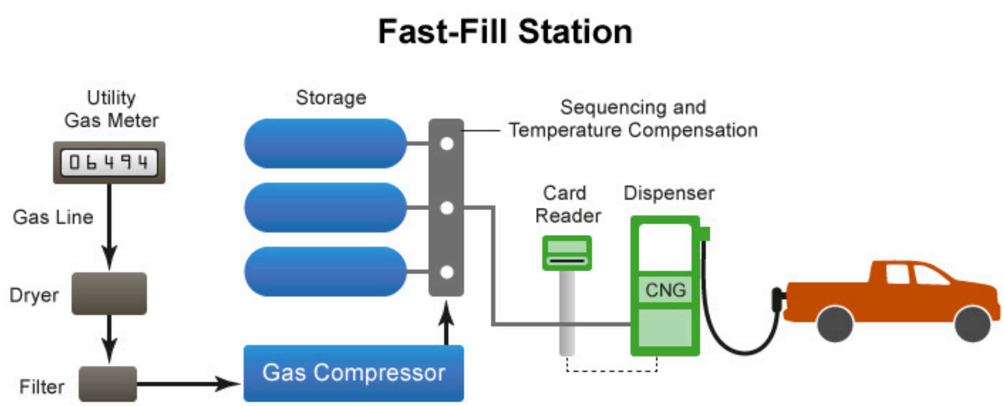

Figure 39: Illustration of a CNG fast-fill refueling station typically used for taxi fleets (ADFC)

Buses Infrastructure

Currently in Pittsburgh there is no defined natural gas fueling infrastructure for buses. However, the same refueling technology is used to dispense natural gas for cars and trucks may be used for buses. Therefore as long as the dimensions of the station can accommodate a bus, the station could be used to fill natural gas buses.

The National Fire Protection Agency (NFPA) defines a set of safety requirements that address the unique properties of natural gas. Thus, vehicle maintenance facilities used to store CNG vehicles, such as buses, must be designed or modified to meet NFPA safety requirements. For example, because natural gas is lighter than air, NFPA requires storage facilities to have an 18 inch area extending from the ceiling where special care must be taken to prevent sparks. Whereas NFPA defines an 18-inch area extending from the floor for storage facilities designed for vehicles using liquid fuels (TIAX, 2008). Similarly, there are unique ventilation requirements for where air can be pumped and exhausted with respect to CNG storage facilities. These requirements can cause problems when dealing with tall vehicles such as buses; the Port Authority's garages have reported that this could be an issue and would require major renovations (Mclean, 2013).

Trucks Infrastructure

Class 8 natural gas trucks have several common engines powered by either CNG or by LNG. Virtually all natural gas cars run on CNG, which presents the opportunity for crossover in fueling stations. In the Pittsburgh region there are several CNG fueling stations that currently service class 8 trucks, however nearly all of them are private access only – where stations are owned and run by the trucking companies to service their own fleets. NG cars are primarily owned and operated by the public, so drivers do not have access to the same stations as truck drivers.

Cars use natural gas compressed at a pressure between 3000 and 6000 psi and CNG semi-trucks operate with CNG at approximately the same pressure range so any station with access to a CNG pipeline should be capable of refueling all land vehicles that run on CNG. In general, it is cheaper to convert an existing gas station into one capable of serving CNG than it is to build a new one.

Between fast- and time-fill fueling, the fast-fill system is more similar to refueling with diesel or gasoline, in terms of the flow rate from the station to the vehicles tank. While fast-fill is more convenient for consumers, there are additional costs. Station that support fast-fill refueling require large tanks on-site that compress natural gas directly from the pipeline and subsequently store it.

The other system is time-fill fueling, which like the name suggests, requires more time to fuel a vehicle. With time-fill there is no intermediate compression and the gas becomes CNG inside the vehicles tank. This system has an approximate flow rate of one to six diesel gallon equivalents per hour. The extra time to refuel makes this system ideal for fleet based trucks that can be refueled all night; however, for a station to be effectively utilized by the public a fast-fill system is required.

To accommodate class 8 vehicles that would be refueled using fast-fill, CNG stations would require large garages that can house the cab of the truck overnight. In addition to standard refueling safety regulations, natural gas stations must have an emergency shutdown device within 10 feet of the dispensing area and at the compressor. Additionally both of those locations are required to have fire extinguishers. Ventilation systems for CNG stations are opposite of gasoline stations, since gasoline pools on the ground and natural gas floats to the ceiling. Air must be introduced at the ground and vented at the ceiling. No ignition systems or anything that could create a spark can be installed within 18 inches of the ceiling (TIAX, 2008).

There are already many CNG fueling stations in the region but creating or converting more along frequent trucking routes close to the city would be ideal. This way trucks on long shipments, short route fleets, and cars could have access. Possible locations are along highway 376 that runs east to west through city or on the north side across the Allegheny River that would gain access to the north south routes 279 and 28.

Trains Infrastructure

Trains and boats both use LNG engines, and as such have the opportunity to share infrastructure. It's thus important to outline the existing infrastructure for each. An extensive train rail system already exists, though little of this is natural gas specific. In fact, research did not yield any natural gas fueling stations in the Pittsburgh region. Similarly, no existing refueling stations exist in the region to service natural gas boats. Crossover in fueling station infrastructure, then, could be established near a river, at a point where railroad tracks are sufficiently close that natural gas boat and train sharing of fueling resources becomes feasible.

Other concerns unique to natural gas properties also affect where a fueling station may be located in the future. The station would need to be near a pipeline, as well as have powerful enough pumps to deliver the fuel at the pressure needed. Because the fuel would be used in its liquefied form, resources would also be needed to cool the natural gas below the boiling point of natural gas. According to research done by Canadian National, a large LNG tank car can hold 25.5k gallon of LNG, at a pressure in the range 0-150 psi and at a temperature of -263°F. This size tank car, costing $0.9 million, would power 2 locomotives and enable a locomotive to travel 2,200 miles before refueling, under the assumption of using 85% NG and 15% diesel. The tank would require 35 minutes to fill, at a rate of 700 gallons per minute (Pellerin, 2012). It's important to note these figures in order to later be able to make a statement about what fueling rate will be needed in a natural gas fueling station as well as calculate the number of vessels able to be fueled daily. The percentage of trains to be converted to using a natural gas engine must be established in order to predict the infrastructure needed to support a transition to natural gas. This would also address the issue of what number of fueling stations would be necessary to avoid a backup of boats and trains at a station.

Boats Infrastructure

An option to provide LNG for refueling boats would be to construct an LNG Production Facility to produce, store, and supply LNG. This facility would require close proximity to a natural gas pipeline, but could convert the fuel from a gas to a liquid. The American Clean Skies Foundation (ACSF) estimates that such a facility would cost $50M, and could supply 100,000 gallons per day of LNG, with 500,000 gallons of storage on-site. (2012) Constructing a new facility allows for a location to be chosen that can service both boats and trains. The facilities would be scalable to meet local demands, which would be advantageous for the initial investment, allowing growth in production as demand increases. It is noted by the ACSF, however, that such a facility would require annual revenue of $11.1M by their models, and would nearly double the price of the LNG for vehicles (American Clean Skies, 2012).

Broader Scope

The current infrastructure described per vehicle type mentioned above applies nationally across the United States, not just in the state of Pennsylvania. Nearby states are also investing in their natural gas fueling infrastructure. A national infrastructure is necessary to support long-haul truck routes, and personal vehicle travel. Generally, boats and trains (and now LNG long-haul Trucks) are used for long distance transport and thus require a larger, coordinated refueling network. New Jersey Natural Gas is investing in 3 new CNG stations in, which should be completed by 2013

(Business Wire). North Carolina has around 40 CNG stations either already operational, or currently under construction (Murawski, John). IGS Energy has announced plans to invest $10 million into a CNG station corridor along Interstate-79 in West Virginia (Ressler, Don). This would be a vital corridor for truckers in the area. There are investments being made into LNG stations as well. Clean Energy has plans to develop LNG stations nationwide, including three stations in Ohio, three in Pennsylvania, and two in New York State (Clean Energy). While it is necessary for this region to invest in infrastructure to support natural gas vehicles, it is also vital that the surrounding regions invest in infrastructure as well. The capital cost are such that it doesn't make sense to work on point by point infrastructure projects, but rather infrastructure on the state/regional/national levels.

Thought Experiment

Although history suggests that fueling infrastructure will be developed by fueling companies provided there is sufficient initial demand, we consider how the payback is impacted for the case where a fleet owner assume the cost of fueling infrastructure. Table 20 lists estimated costs of building a single refueling station for each vehicle type. Passenger cars, taxis, school busses, and transit buses consider compressed natural gas (CNG) refueling stations. Boats, trains, and trucks all consider liquid natural gas (LNG) refueling stations. The cost estimate for trains uses the same price as a boat station, under the assumption that these vehicles can use similar infrastructure due to similar technology.

Table 20: Estimated Costs of Single Refueling Stations by Vehicle Type

Vehicle	Infrastructure Cost
Boats	$6M[a]
School Buses	$18M[b]
Transit Buses	$18M
Taxis	$0.6M-1.2M[c]
Passenger Cars	$0.6M-1.2M
Trains	$6M
Trucks	$1.5M-$2M[d]

[a]American Clean Skies. (2012). *Natural Gas for Marine Vessels*. Retrieved from http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf
[b]Schmitz, Jon. (2012, November 22). *Port Authority of Allegheny County looks at fuel conversion.* Retrieved April 30, 2013, from http://www.post-gazette.com/stories/news/transportation/port-authority-of-allegheny-county-looks-at-fuel-conversion-663237/
[c]TIAX. (2008). *U.S. and Canadian Natural Gas Vehicle Market Analysis: Compressed Natural Gas Infrastructure.*
[d]http://www.forbes.com/sites/larrybell/2012/11/27/tough-trucking-for-natural-gas-vehicles-can-they-make-it-in-the-long-haul/

In order to understand the investment necessary for infrastructure, a model experiment was created. As we have noted, at times infrastructure is supported by the public (in the case of transit buses) and other times by the private sector (either as a business selling fuel or for their own use). This makes calculating payback time challenging. As a thought experiment, we examined the implications of providing 12 stations for natural gas at each of the existing boat fueling stations in the Pittsburgh Metropolitan area. This is a particularly interesting case for the region since these fueling stations could potentially be used as a crossover fueling hub for long-haul trucks as well as trains (e.g., fueling can take place when trucks bring products to a barge for transportation elsewhere).

In this case experiment, the implications of implementing 12 LNG stations for boats was studied. A model was used to calculate the year at which the investor would break even through such a policy. This model took into account the infrastructure cost, the cost of conversion of the fleet, and the fuel savings the fleet conversion would provide. The results of the model are recorded in Table 21.

Table 21: Results of Model Predicting Payback for Boat Infrastructure Investment

Percent of Boat Fleet Converted to NG	Infrastructure Investment	Break Even Year
15%	$72M	9
100%	$72M	4

Based on this analysis, if an infrastructure investment of $72 million was made at these 12 fueling stations, the break-even time would be 9 years if 15% of the boats converted to natural gas and 4 years if 100% converted. Although this is based on fuel savings by the boat owner, it also provides some notion of the revenue that would be gained by the fueling station owner. Based on the goal of a break-even of 3 years, both estimates exceed as of now, the likelihood of a capital investment. More analysis is needed, but it is clear that a substantial adoption rate would be needed from the perspective of the fuel station owner for it to be a viable investment.
As shown by the model, a larger fleet conversion would result in an earlier breakeven year, despite the larger cost of converting the fleet. However, neither circumstance achieves the desirable three year breakeven point.

Findings

Considering the evolution of the gasoline fueling infrastructure outlined previously, it is assumed that the development of natural gas fueling infrastructure will follow a similar process. There is no market failure currently present that would merit government intervention. Suppliers will enter the market to meet demand for natural gas. Thus, the cost of building the fueling stations and implementing them with proper safety protocol will fall on the suppliers rather than the consumers. It is for these reasons that cost of infrastructure is neglected in this report when calculating the payback period for vehicles.

Cars, buses, and short-haul trucks all use CNG, and as such show the potential to share fueling infrastructure. Just as gasoline fueling stations are structured now, future public CNG stations could be equipped to fuel all three types of vehicles. Private stations might only need to be able to fuel one type of vehicle, depending on the fleet in use. That's not to say that private stations could not also be capable of fueling multiple vehicle types.

Another finding concerns the future installation of LNG fueling infrastructure. Trains and boats both use LNG engines, and as such have the opportunity to share infrastructure. It's thus important to outline existing infrastructure for each. An extensive train rail system already exists, though little of this is natural gas specific. In fact, research did not yield any liquid natural gas fueling stations in the Pittsburgh region. Similarly, no existing refueling stations exist in the region to service natural gas boats. Crossover in fueling station infrastructure, then, would have to be established by a river, at a point where railroad tracks are sufficiently close that boat and train sharing of fueling resources becomes feasible. Other concerns also affect where a fueling station might be located in the future. The station would need to be near a pipeline, as well as have powerful enough pumps to deliver the fuel at the pressure needed. Because the fuel would be used in its liquefied form, resources would also be needed to cool the natural gas below its boiling point.

The percentage of trains to be converted to using a natural gas engine must be established in order to predict the infrastructure needed to support a transition to natural gas. This would also address the issue of what number of fueling stations would be necessary to avoid a backup of boats and trains waiting to fuel at a station.

When examining a map of current docks and railways, there exist a few locations where overlap between boats and trains might be possible. The Kiski Junction Railroad is located right on the bank of the Allegheny River, representing a prime opportunity for fueling stations overlap. No other location shares the same opportunity as the Kiski Junction. A concern that then arises; however, is what safety or health risks do building a fueling station near a major waterway present? This would need to be analyzed before any policy recommendations could be made.

Looking forward, it is clear that long-haul truck, boats, and trains show the potential to share fueling infrastructure. Both vehicles use similar engines, and run off of LNG. Additionally, both vehicles operate in a determined path way, that is, each vehicle will deliver cargo along fixed route. This regimented operation schedule allows for simple analysis of the hubs of transportation, and thus the optimal points at which to install fueling stations.

5.3 Safety

When considering developing the infrastructure for natural gas vehicles it is necessary to bear in mind the safety implications of both compressed and liquefied natural gas. Safety restrictions and codes can require additional funding or precautionary measures that must be followed in order to ensure the safety of the consumer.

CNG Refueling Stations

In specific, CNG refueling stations have three safety requirements unique to natural gas fire prevention. The first requirement is that two emergency shutdown devices (ESDs) are required per CNG station. The first device must be located no greater than 10 feet from the dispensing area. The second device must be located 25 feet to 75 feet from the same dispensing area. The second requirement also asks for an ESD to be installed at the compressor location itself. The third unique requirement asks for fire extinguishers to be located at both the dispensing area and close to the compressor enclosure (TIAX, 2008).

The National Fire Protection Association (NFPA) also has a Vehicular Gaseous Fuel Systems Code entitled the NFPA 52. This set of codes for storage and production in addition to building and fire code requirements. One code in specific, requires CNG refueling stations to include an 18-inch special care area from the ceiling to prevent sparks (TIAX, 2008). The International Code Council has an International Building Code that applied to CNG stations as well (U.S. DOE, 2011). For example, specific ventilation requirements are required for pumping air for ventilation. High-pressure storage systems are necessary under codes for high pressure gas. In addition, the expected demand and usage patterns for the refueling station will affect its size and design. Certain vehicle types can share CNG refueling stations. For example, cars and busses can both use the same station if the dimensions are able to facilitate a bus.

LNG Refueling Stations

There are several unique safety considerations that must be made for the infrastructure related to LNG vehicles. To liquefy natural gas, the temperature must be reduced significantly. It is stored at temperatures as low a -260 F and maintaining this cryogenic state is potentially hazardous. If the temperature of the LNG were to rise the pressure would increase and escape the container. Thus, specially insulated tanks are required to ensure that it does not leak into the surroundings. If a tank were to leak then the LNG would immediately turn into vapor due to its low boiling point. This vapor is primarily methane, a greenhouse gas, which does not biodegrade and thus will remain in the atmosphere (EPA, 2002). Additionally, the gas is highly flammable and poses a fire hazard when in an enclosed space such as garage or fueling station. Beside the risk of igniting leaked LNG, the vapor is toxic and potentially fatal if inhaled. Federal standards require every LNG fueling station and maintenance garage to be equipped with a methane detection system, fire protection system, temperature detection system, emergency shutdown device, fire suppression system, and eye wash station. Tanks, pumps, and vaporizers are high risk and are required to have secondary enclosures built around them to further contain incidents (EPA, 2002).

Other safety concerns arise from the handling the fuel. Cryogenic burns and frostbite can occur if LNG or LNG vapor comes into contact with the skin (NPC, 2012). Also, any spill will result in the same hazards as leakage since the fuel will immediately turn into vapor instead of pool on the ground. Anyone handling LNG is required to have training and be equipped with properly insulated gloves, boots, apron, and a face shield (ANGA, 2010).

There are few safety issues, related to specific vehicle types. Storage and handling is basically the same but is however more dangerous for smaller vehicles such as cars, buses, and trucks. These land vehicles have smaller fueling stations and garages so any leaked LNG will have a higher concentration within these enclosures. Also, such structures have smaller storage tanks that are more likely to be damaged in the event of a fire. Vehicles with exposed onboard fuel tanks, such as trucks, have a higher risk of tank failure due to corrosion, vibration, and collisions (NPC, 2012).

6.0 Cross-Cutting Policy Analysis

6.1 Education

There are currently multiple resources that provide public information regarding NGV that require little funding to promote. Pennsylvania has one formal educational program set up through their NGV grant, while other educational means are provided through websites and promotion of NGVAmerica, the DOE's Clean Cities Program, and the Allegheny Conference.

Pennsylvania's educational program is funded through Pennsylvania's Natural Gas Energy Development Program. One aspect of this program is NGV seminars that are held across the state. The intention of this seminar is to educate fleet owners on grant opportunities, vehicle and fuel technology, liquefied natural gas versus compressed natural gas, and how best to assess if these opportunities are best for a particular fleet (PaDEP, 2013).

NGVAmerica is an organization dedicated to the growth of NGVs. Their website is a great resource for fleet owners to find government policies and incentives, as well as fueling locations and how to convert a vehicle.

Clean Cities is similar to NGVAmerica because their website is a great resource for public NG information. The Clean Cities program is funded by the DOE to reduce petroleum use, by promoting economical and environmental alternatives. Clean Cities provides publications for the basic technologies for NG but more importantly Clean Cities provides technical assistance, called Tiger Teams, to help overcome vehicle or infrastructure obstacles, such as safety, maintenance, training, etc. According to John Gonzales, NREL Senior Engineer, Tiger Teams see about five to ten projects a year with an approximate cost of $10,000 each. The scope of these projects range from facility/infrastructure upgrades to issues the vehicle may be having.

Findings:

- Public web information, personal service on an as-needed basis, and state-wide educational seminars are currently being provided
- The majority of technical requests Clean Cities Tiger Teams receive can be answered by phone and do not require a site visit. In their view, the demand for education does not exceed their capabilities of supplying site visits and further information.

Policy Options:

A. Status Quo: Publicly accessible information on the Internet and further education can be provided to those that seek it.
B. Always pair educational seminars with grant funding, to fully educate those applying for the grant. Therefore, no grants are provided without full knowledge of technology and economic opportunity.
C. Only provide educational assistance on an as-needed basis, like Tiger Teams currently does.

Analysis and Recommendation:

The group's policy analysis findings related to education funding are summarized in the chart below (Figure 40).

Option	O	E	R	Q
A: Status Quo: Public information on web and further information if needed. - Public web information provides general information with little cost and maintenance. - Based on Clean Cities interview, demand for education does not exceed supply.	+	0	+	+
B: Additional education: seminars paired with grants - No grants are provided without full knowledge of technology and economic opportunity.	+	0	0	+
C: Education on as-needed basis - Only provide information on demand. - Reduce education spending costs.	-	+	+	-

Figure 40: Education Policy Analysis

Option A, retaining status quo, would maintain the current education programs being provided. This is a balance between public information on the Internet, Tiger Teams providing technical services on an as-needed basis, and state seminars paired up with grants on an as-needed basis. The effectiveness of reaching this goal is positive because sites like NGVAmerica, Clean Cities, and PaDEP provide thorough information for those who seek it. Based on an interview with Tiger Teams, the current demand for education does not the supply. The status quo is neutral in economic efficiency because it is difficult to measure the effectiveness of some educational initiatives because they are non-measurable public web forums. The political responsiveness and equity were both ranked as being positive because little funding is needed for current educational policies and funded educational programs are more on an as-needed basis.

Option B increases education about natural gas vehicles by requiring educational seminars to be paired with federal or state grants. This would be to insure no grants are provided without full knowledge of technology and economic opportunity. The effectiveness of this policy would be positive because it would sure full knowledge to those receiving funding. The economic efficiency and political responsiveness are both neutral because it would require additional resources to increase education and there might not necessarily be a demand for this information. The equity is positive because education is going to specifically those who need it.

Option C would be to decrease education by only provided services on an as-needed basis. This would reduce educational spending costs, especially in areas that are not being utilized. This is negative in achieve education policy goals because without easy educational access the public is not being properly informed on the topic. Economic efficiency and political responsiveness would both be positive because this policy option would reduce spending. The equity is also negative because the general public is not receiving any benefits unless the search further within.

Our final recommendation in regards to policy options for education is to maintain the status quo. We feel there are currently ample resources for the general public and for those seeking further information regarding NGV more seriously. Perhaps the marketing and promotion of these resources is hindering the public from being well educated on the NGV topic, but we believe the resources to facilitate education are currently available.

6.2 Maintenance and Training

As natural gas vehicles become more common, there will be an increasing need for mechanics and inspectors to ensure the safety of these vehicles, as well as to service them during operation. Due to the differences between a conventional engine and a natural gas engine, additional training and certification may be required to ensure high quality craftsmanship and to provide natural gas vehicle users with adequate options to service their vehicles. To promote the feasibility of natural gas vehicles in the Pittsburgh area, an effective policy may be to make it easier for mechanics to receive natural gas training, and several training institutes have already encouraged this addition to their training offerings.

Findings:

- Currently, training courses are not required in order to gain certification in natural gas vehicle service.

  This is a good system for allowing a large number of mechanics to be certified in natural gas engines, but as natural gas vehicle fleets proliferate, a simple test might not be sufficient to ensure that mechanics are knowledgeable in the field and able to efficiently and safely service natural gas vehicles for an entire fleet.

- With the exception of the Natural Gas Vehicle Institute, the National Institute of Automobile Service Excellence (ASE) (NGVI, 2012) has not certified any natural gas vehicle training programs.

  The ASE is an industry-standard certification institute that provides certifications to the majority of mechanics in the transportation industry (ASE, 2013). This allows mechanics to simply take a test, and if they pass, they will gain a certification. They have a solid reputation for only providing certification to qualified mechanics, and a natural gas vehicle mechanic with ASE accreditation would provide companies with an idea of the level of knowledge that the mechanic has.

- Several companies (Waste Management, Giant Eagle) that have tested natural gas vehicles in their fleet have reported a significant learning curve for mechanics servicing natural gas engines.

  This learning period causes maintenance costs to increase to levels that may not be suitable for the economics of a fleet.

- Currently, training courses are offered in different geographic areas at different times throughout the year.

  It may be that there are companies that wish to receive training, but cannot logistically travel to a location where a training class is offered. For these cases, it may be constructive to offer fleet-specific training on an on-demand basis. This style of training class is currently offered by the Natural Gas Vehicle Institute, but has the potential to be offered by more training programs. Further, increasing the advertising of this option may encourage larger fleets to participate in a class.

- The United States Department of Transportation has a law in place that states that all natural gas vehicles with compressed natural gas cylinders should be inspected for safety every 36 months or 36,000 miles (US Department of Transportation, 2010). However, due to the small number of natural gas vehicles, this rule is not stringently enforced.

  Economically, it is simply not worth the time of law enforcement to pursue violators of this law because of their little impact on the overall community. In the future, should natural gas vehicles become more prevalent, this mentality may change and enforcement of the rule become more prevalent.

Policy Options:

1. An organization such as the ASE requires a natural gas segment in current vehicle maintenance training programs in order to earn certification.

   In order to be certified for vehicle training, specifically for an industry standard like the ASE, it may be beneficial to require a natural gas vehicle training segment in the training course. If the level of difficulty is high enough for the certification test that passing is only possible with significant training or exposure, then mechanics would be encouraged to learn about natural gas vehicles. This is beneficial because if a mechanic is trained and then works for a fleet, and that fleet decides to adopt natural gas vehicles, there is no re-training or inefficient maintenance work because the mechanic has already been trained in the area. This allows for streamlined transitions between traditional petroleum-based fuels and natural gas without downtime or time spent out of the garage and in a classroom. For companies with tight training budgets, it may make sense for only lead mechanics to participate in the natural gas training. This knowledge will then be passed down to younger mechanics so that the entire staff has the resources and knowledge to service natural gas vehicles safely without the large maintenance costs potentially caused by the learning curve.

   With respect to individual mechanics, this policy option is also favorable because adding a natural gas vehicle component to their training experience increases their employment flexibility. Current trends suggest that there are some vehicle types, specifically trucks and buses, which will continue to increase in the near future. These vehicles need servicing options, and adding natural gas training to a traditional fuel mechanics repertoire increases marketability and encourages natural gas vehicle adoption by providing natural gas vehicle users with options for service technicians.

2. Make training classes more affordable and convenient by subsidizing the cost, increasing frequency, and providing training at more locations.

   Currently, these training classes cost around $500 for technician training and around $800 for CNG refueling station inspector training (NGVI, 2012). The technician training is aimed at any mechanic working on natural gas vehicles while the refueling station inspector training would be appropriate for companies wishing to operate their own public/private refueling station. Adding frequent, cheap training courses may encourage mechanics to gain training to effectively service natural gas vehicles. These training courses would reduce the amount of on-the-job learning that mechanics must go through, provide natural gas vehicle users with more mechanic flexibility, and give fleets with their own private mechanic staff the ability to ensure that any natural gas vehicle purchases would be serviced to the same standard that gasoline or diesel vehicles receive. Further, training classes tend to serve specific regions at different times of the year. This structure is helpful for spreading the training to a lot of people, but makes the dates inflexible and forces mechanics into a specific schedule that may not be suitable for their personal or work schedules. By increasing the number of training classes, mechanics in a variety of areas can still be trained, but there is more than one opportunity per year to get the training.

3. Enforcing the United States Department of Transportation's inspection requirements on CNG cylinders more strictly

   Due to the low number of natural gas vehicles in use, the United States DOT law requiring inspection of CNG cylinders every 36 months or 36,000 miles is not followed or enforced very strictly. However, due to safety concerns on natural gas vehicles, these inspections may be necessary and could put to rest some of the concerns about natural gas vehicles. Additionally, enforcing these policies would increase the demand of inspectors, which would encourage others to earn certification. There would be some disadvantage to natural gas vehicle owners, who would now need to spend additional money on more frequent service trips. However, overall, having safer roads with more opportunities for economic growth in the automobile service sector would be a benefit to the Pittsburgh community.

Analysis and Recommendations

Having identified policy options to evaluate, the next step is to evaluate them against the criteria previously identified. The results of this analysis have been tabulated below in Figure 41 as an overall summarizing reference.

Option	O	E	R	Q
A: Status Quo - Currently, there are several institutions that offer certification and training in Natural Gas Vehicle maintenance and inspiration, including a West Virginia University department close to the Pittsburgh area. - There exist laws, though minimally enforced, that support frequent inspection for natural gas vehicles.	+	0	0	+
B: Vehicle Economic Incentive - The number of natural gas vehicles on the road is increasing in the Pittsburgh area, and there should be a need for more mechanics. - There already exists policy supporting frequent inspections, and these inspections may remove safety concerns associated with natural gas vehicles.	+	0	+	-
C: Infrastructure Service Provision - Training classes may be expensive, especially for large teams of mechanics that may need a dedicated training session for their fleet. - Training currently exists in different locations at different times in the year, which may not be convenient to a rural fleet or a fleet with tight scheduling opportunities.	+	-	0	+

Figure 41: Maintenance and Training Policy Analysis

Option A consists of remaining at status quo and continuing the current policies that are in place regarding training and maintenance. There are several institutions and programs that offer training in natural gas vehicle maintenance. The most important institution for the Pittsburgh region is the National Alternative Fuels Training Consortium at West Virginia University due to its extensive programming and geographical proximity to the Pittsburgh area. The NAFTC currently works closely with fleet mechanics to assist them in translating their training in diesel and gasoline engines to natural gas engines. Following an interview with NAFTC, it is important to note that the institute offers a wide range of alternative fuel training, but the most recently prevalent alternative fuel has been natural gas. They are currently training around 25 mechanics each month, and this has been evidence to the institution that the current supply of training meets the demand. Based on this measurement, it is suggested that there should not be any changes to the current policies because they are proving to be effective. Status quo received neutral ratings in economic efficiency and political responsiveness because both categories only apply to those utilizing the program. As part of an educational institution, the credibility of the education is strong and there appears to be no real political incentive attached to the program. Overall, the NAFTC serves as a method to promote alternative fuels, a generally acceptable task, and to educate the public and individual employees on the operation.

Option B refers to policies on the vehicle level, which may be inspired by the increasing number of natural gas vehicles on the road each day in the Pittsburgh area. This increase in vehicles should directly correlate to the need for additional mechanics, suggesting that maintenance and training programs are effective methods for supporting natural gas vehicles in the Pittsburgh area.

Additionally, there already exists a policy created by the United States Department of Transportation that mandates CNG vehicle inspection every 36 months or 36,000 miles. If this policy was more actively enforced, the need for mechanics would rise, and additional training would be required. Therefore, training programs would support vehicle development by supporting the increased frequency with which inspections take place. Unfortunately, the overall equity of Option B is not quite sufficient, because there is a clear set of winners and losers regarding these policies. Specifically, natural gas vehicle owners are forced to spend more money on inspections, and natural gas mechanics receive substantial benefit for increased and consistent levels of clientele.

Option C refers to policies regarding infrastructure. This is an important realm for maintenance and training because natural gas refueling stations require a certain level of maintenance in order to be operational and safe. Currently, the NAFTC does not offer a course regarding refueling station, however the Natural Gas Vehicle Institute does. The biggest drawback for this option is that the training courses are expensive, especially for large fleets trying to convert their entire mechanic base. Because of this, the economic efficiency of this policy might not be good enough to encourage adoption of natural gas vehicles in fleets. Companies with large fleets like Pitt Ohio express a strong bias against natural gas because of the increased maintenance costs, and a training provision in the infrastructure realm would impose a cost onto the company due to the increased complexity and safety requirements for infrastructure as compared to a vehicle. In terms of equity, the infrastructure service provision actually scores well. This option ensures safety by having qualified and experienced mechanics inspecting and operating natural gas infrastructure. Additionally, it causes companies to have reduced operational costs by conquering the learning curve of new natural gas technology.

After comparing the scores of the three options, it does appear that the status quo option is the most beneficial to the Pittsburgh region at this time. The demand for natural gas vehicle training is being met by the current supply and the fleets using natural gas are successfully integrating new mechanic knowledge into their fleet operations without incurring significant costs. Further, should the need for natural gas vehicle inspectors and mechanics increase unexpectedly, the NAFTC has a community of member schools that would be able to assist in the new influx until a more permanent solution was developed.

6.3 Research and Development

With regards to natural gas, research grants for the research and development of technology at both the federal and the state levels are an important and effective component of the overall strategy to expand use of natural gas vehicles.

The State Energy Program (SEP) is a federal program that provides grants to states to assist in designing, developing, and implementing renewable energy and energy efficiency programs. Each state's energy office receives SEP funding and manages the SEP-funded projects. Additionally, states may receive project funding from technology programs in the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy for SEP projects. (SEP, 2012)

In Pennsylvania, the Pennsylvania Energy Development Authority (PEDA) provides grants of up to $1,000,000 for alternative energy projects and research related to deployment projects or manufacturing. The grants are available for projects involving biomass, fuel cells, and clean and alternative fuels for transportation. The funding may be used for construction, engineering designs (necessary for construction or installation), contractor expenses, equipment purchases. The PEDA grant program was closed November 2012, but the program may be re-opened in the future (PEDA, 2012). David A. Althoff from the Department of Environmental Protection says that the reopening of PEDA is something that must be considered by the PEDA Board, and they are hopeful that a board meeting will occur in 2013 whereby the future plans and direction of the PEDA program will be discussed. There is also a project grant by the Pennsylvania Energy Harvest Grant seeking to deploy cleaner energy sources by funding projects that address both energy and environmental concerns for alternative energy projects. While this program closed in October 2011, it also may be re-opened.

The focus of any policy initiatives in research and development should be to advocate science and technology policies that will promote natural gas vehicle research, e.g., by sustaining or increasing funding at state and federal agencies during the FY 2014 budget process. Since state-wide research funding has been decreased in the past two years (PEDA and PEHG funding programs have been closed), there should be an increase in funding at the state level. Natural gas vehicle advocates should generate support for the federal engineering research and development budget by supporting the annual SAE International Engineering R&D Symposium (and other research symposiums) and generating support for increased NGV funding. The Symposium brings together leaders from the engineering community to gain firsthand knowledge of the administration's R&D priorities and the potential impact of the President's fiscal year budget request on the science, engineering and technology community (SAE, 2013). A good way to ensure future policy initiatives in this type of research and development is to bring natural gas vehicles to the agenda.

Findings:

- Currently, there are various Department of Energy federal research and development programs that fund $50 to 100 million annually (Department of Energy 2012)
- The State Energy Program (SEP 2012) is a federal program that provides research and development grants to renewable energy and energy efficiency programs
- The Pennsylvania Energy Development Authority provided grants of up to $1,000,000 for alternative energy projects (closed November 2012, may be re-opened)
- The Pennsylvania Energy Harvest Grant funded projects that deploy cleaner energy sources (closed October 2011, may be re-opened)

Policy Options:

The group analyzed three possible policies related to research and development:

A. Remain status quo with regards to funding for federal programs that provide grants specifically to natural gas research and development
B. Increase/re-open state-wide funding(such as the Pennsylvania Energy Development Authority's alternative energy programs) that promote natural gas vehicle research

C. Open research programs (or divert existing programs) to focus research and development funding on the infrastructure supporting natural gas vehicles

Analysis and Recommendations:
The group's policy analysis findings related to research and development funding are summarized in the chart below (Figure 42).

Option	O	E	R	Q
A: Status Quo - Currently, there are sufficient federal research and development programs and funding (Department of Energy) - Some state-wide research and development programs are closed, but may be re-opened.	+	+	0	+
B: Vehicle Economic Incentive - Alternative fuel research grants provide opportunities for companies to begin natural gas adoption. - Because in the Pittsburgh area, there should be more state-funded research and development for natural gas vehicles to become less expensive and more feasible.	+	0	0	-
C: Infrastructure Service Provision - Eliminating this major barrier will accelerate rate of adoption, this research and development programs for natural gas vehicles will expand.	+	0	0	0

Figure 42: Research and Development Policy Analysis

When analyzing the effectiveness of option (A), status quo, it was noted that there are sufficient federal research and development programs and funding, some state-wide research and development programs may be re-opened, and natural gas vehicles seem to be becoming more common in the Pittsburgh region, indicating that it is beneficial to remain at status quo. The economic efficiency of remaining at status quo is also favorable, since no additional money would need to be spent. A measure of how citizens' preferences were met remains neutral, as there does not seem to be a push in either direction by citizens (more or less money allocated to research and development). Lastly, remaining at status quo seems to be fair and equitable. However, it is important to note that the benefits are accrued to those who utilize the research and development grants.

The second option includes additional vehicle grants for natural gas vehicles. The effectiveness of this option helps to meet the goal (because giving money to research and development will likely decrease adoption time), but the group believes that there may be no need to spend money when it is likely that status quo will accomplish the goal, and spending unnecessary money may result in negative feedback from citizens. Therefore, the efficiency of this option may be unfavorable in terms of both economic efficiency and responsiveness; however, if there were more research and development funds, natural gas vehicles may become less expensive and more feasible, which would make economic efficiency and responsiveness favorable. The chart reflects "neutral" for both of these criteria. Lastly, the policy option may be seen as unfair or inequitable because these incentives may be seen as spending citizens' tax dollars to fund private company profits.

The last option considered was allocating research and development funds to infrastructure development for natural gas vehicles. The lack of infrastructure is a very large barrier, and it is believed that eliminating this barrier will accelerate the rate of adoption of natural gas vehicles. Therefore, the effectiveness of this option is favorable. There is a possibility that an increase in research and development for infrastructure may increase research on using infrastructure for multiple types of natural gas vehicles (trains, boats, and cars sharing fueling stations), which would boost the economic efficiency of additional infrastructure; however, spending additional money on infrastructure when this goal may be met without this policy proves it may not be economically beneficial. Economic efficiency is therefore considered neutral. It is likely that the responsiveness of citizens would be neither favorable nor unfavorable, and the equity of this policy (although it is a redistribution of funds), was also denoted as neutral.

Since status quo had the most favorable scores when analyzed against the four criteria, the policy group decided to remain at status quo for policy options related to research and development funding.

6.4 Regulations

Regulations on both the federal and local levels are essential when considering what motivates vehicle owners to switch to natural gas power. On a federal level, there are currently several regulatory incentives for the adoption of natural gas powered vehicles. One incentive is the Alternative Fuels Tax. The main premise is that the user is taxed based on the gasoline gallon equivalent. This tax can be measured according to the amount pumped by a single consumer at a gas station or, if a company has its own refueling facility, paid by the amount of gas arriving at the facility (PA Dept. of Revenue, 2012). There is also the Alternative Fuel Tax Exemption available to those who use natural gas for uses including "farming purposes, certain intercity and local buses; in a school bus; exclusive use by a nonprofit educational organization" and others. We must also consider federal emission standards set by the Environmental Protection Agency. There are 3 categories of engines to consider. Category 1 includes "land-based non-road diesel". Category 2 includes all locomotive engines. Category 3 covers marine engines. The standards that are concerning for purposes of present-day conversion to natural gas are known as Tiers 3 and 4. Natural gas is very attractive for the transition into Tier 3, and even more so Tier 4 standards because it releases significantly fewer emissions than diesel fuel, which does not meet Tier 4 standards. These standards do not apply, however, to any vehicle manufactured before the year in which the regulations were implemented (2008 for Tier 3 and 4) (Dieselnet, 2013).

Findings:

1. The Alternative Fuels Tax covers natural gas and is based on its gasoline gallon equivalent.

2. The Alternative Fuel Tax Exemption is available to those who use natural gas for certain farming and city bus applications.

3. EPA emission standards only apply to vehicles manufactured after the standards are put in place. Therefore only new vehicles are under considerable regulatory pressure to lower emissions.

Policy Options:

The group analyzed two possible policies related to regulation:

A. Remain status quo with regards to current regulations and emission standards.
B. Retain the Alternative Fuels Tax and EPA emission regulations in addition to creating a mechanism for long term price guarantees for companies interested in converting their fleet operations to natural gas.

Analysis and Recommendations:

The group's policy analysis findings related to research and development funding are summarized in the chart below (Figure 43):

Option	O	E	R	Q
A: Status Quo - Maintain current EPA emissions regulations - Maintaining status quo on the Alternative Fuels Excise Tax credit as it currently provides a valuable economic incentive for the switch.	+	+	+	+
B: Provisions to Stabilize the Price of Natural Gas - Creating new regulations that allow for long-term price guarantees for LNG	+	0	-	0

Figure 43: Regulation Policy Analysis

Using our consistent policy analysis framework we examined maintaining the status quo on all current regulations and emission standards. We rated this option positive in terms of overall effectiveness because taxes, like the Alternative Fuels Tax, provide a tangible incentive for conversion to NGVs. In terms of efficiency, we rated it positive because these will cost a relatively small portion of tax revenue while possibly motivating a large change of direction to natural gas power. We rated this option positive with regard to political responsiveness because there is a strong backing in Pennsylvania to increase natural gas utilization due to the prevalence of natural gas production in the state. Finally, the equity is positive because it benefits natural gas providers and consumers without taking from petroleum consumers.

The other option still keeps status quo on the Alternative Fuels Tax and EPA standards, but also introduces new regulations that allow for long-term pricing guarantees for natural gas to fuel NGVs. We found this option to be positive for overall effectiveness because the payback period of conversion is, in almost every case, most sensitive to fuel price differential. This kind of regulation would make that sensitivity negligible. For efficiency, we rated this option neutral because it is difficult to gauge the cost of fuel price stabilization contracts and related policies. For political responsiveness, we rated this negative because the potentially large cost of a price guarantee may be frowned upon by the public, given how few natural gas vehicles there are in Pittsburgh today. Lastly, for equity we rated this neutral because the natural gas providers would benefit while petroleum providers would suffer.

6.5 Economic Incentives

Economic incentives exist at both federal and state levels to help promote the use of natural gas vehicles. These policies exists to help subsidize the conversion of vehicles to NGV and to assist in the development of fueling infrastructure. Economic incentives do vary based on vehicle types, as each type has different attributes that drive the economics of the vehicle.

The policies that provide tax breaks or grants to potential natural gas vehicle users generally focus more on on-road vehicles than off road. For example, there are two federal tax credits that have been extended to 2013 to help support natural gas vehicles.

The Energy Policy Act (EPAct) of 2005 is an income tax credit for alternative fuel infrastructure. This provides income tax credit equal to 30% of the cost of natural gas refueling equipment, up to $30,000 for large stations. This act was extended to the end of 2013 and is retroactive for 2012. A second tax credit is the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). This incentive provides a 50-cent tax credit per gasoline gallon equivalent (GGE) of compressed natural gas (CNG) and per liquid gallon of liquefied natural gas (LNG) sold for use as a motor vehicle fuel. Both of these acts provide incentive for potential fueling stations to be built and provide natural gas as fuel to consumers. These incentives are made to address the lack of infrastructure for natural gas vehicles, which will need to be built to compete with traditional fuel sources.

At the state level, Pennsylvania has a good number of state incentives and grants to support natural gas vehicles. They have programs such as the Alternative Fuels Incentive Grant (AFIG) Program. This program provides financial assistance, information on alternative fuels, alternate fuel vehicles, advanced vehicle technology R&D. The program focuses on projects that result in commercialization and the expansion of Pennsylvanian companies. For the economic incentives, rebates are offered to assist with the purchase of natural gas vehicles at approximately $1000. Another state incentive comes from the Pennsylvania Department of Environmental Protection. This department administers the Natural Gas Vehicle Grant Program, which provides funding to eligible municipal and commercial fleets for the purchase or conversion of dedicated or bi-fuel NGVs. This economic incentive is meant to help subsidize the costs of natural gas vehicles, in some cases providing up to 50% of the conversion costs (up to $25,000) per vehicle.

Findings:

- There are currently various federal and state (Pennsylvania) economic incentives available to fleet operators, individual vehicle owners, and fuel providers to help subsidize the conversion costs to natural gas.
- There were no local economic incentives found during this project

Policy Options:

A. Remain at the status quo, providing incentives for both vehicles and infrastructure with a combination of federal and state programs
B. Focus incentives solely on vehicles, subsiding new purchases and conversion of vehicles.

C. Focus incentives on fueling infrastructure, providing funding for fueling locations and, in some cases, places for vehicles to be stored.

Analysis and Recommendations:

The results of the policy analysis for economic incentives is below, in tabular form (Figure 44):

Option	O	E	R	Q
A: Status Quo - Currently there are various grant program and tax credits/incentives. - Tax credits are being extended into 2013 currently, so interest still remains.	+	+	+	0
B: Vehicle Economic Incentive - Focus on vehicles will help increase the number of NGVs in the region - People may still be reluctant to buy if there isn't sufficient infrastructure.	+	0	+	0
C: Infrastructure Service Provision - More fueling stations will help alleviate the problems of fueling NGVs in the Pittsburgh Area - May not be feasible to invest a lot of money into infrastructure and get "good returns" on the investment.	+	0	+	0

Figure 44: Economic Incentives Policy Analysis

Option A, retaining the status quo, would maintain the current economic incentives that exist at both federal and state levels. These incentives focus on both subsidizing vehicle costs and providing funds for fueling infrastructure. The effectiveness of reaching this goal is positive because one of the greatest barriers to vehicle conversion is the cost and the current economic incentives, when used, help alleviate those costs. The economic efficiency is positive because the money put into economic incentives produces opportunities for natural gas vehicles. The political responsiveness is positive because there are various politicians who support natural gas vehicles in the Pittsburgh area. Finally, the equity is neutral because there are winners in the natural gas industry and losers in the traditional fueling industries (gasoline, diesel).

Option B, focusing on vehicle incentives, would shift funding to providing subsidies, tax credits, grants, etc. to those looking to purchase new NGVs or converting to NGVs. The effectiveness of reaching this goal is positive because with these incentives, and possibly more funding just for vehicles, more operators would be willing to switch to NGVs. The economic efficiency is neutral because, although there would be incentives to purchase vehicles, there is not enough incentive to encourage fuel providers to build natural gas fueling stations/infrastructure for these vehicles. Without fueling opportunities, the NGVs do not compete as well economically with traditionally fueling vehicles. The political responsiveness is positive because there are various politicians who support natural gas vehicles in the Pittsburgh area. Finally, the equity is neutral because there are winners in the natural gas industry and losers in the traditional fueling industries (gasoline, diesel).

Option C, focusing on fueling infrastructure, would shift funding to providing subsidies, tax credits, grants, etc. to those looking to build new natural gas fueling infrastructure. The effectiveness of this option is positive because if there is more fueling infrastructure available in the Pittsburgh area, NGVs could be seen as a more viable competitor to traditionally fueled vehicles as there are more locations and opportunities to refuel. The economic efficiency of this option is neutral because, similar to policy option B, this option only addresses one of two major financial obstacles to NGV conversion, providing funding for fueling infrastructure but not for the vehicles themselves. Without funding to subsidize vehicle purchases/conversion, parties may not buy the NGVs and money may not have been used effectively. The political responsiveness is positive because there are various politicians who support natural gas vehicles in the Pittsburgh area. Finally, the equity is neutral because there are winners in the natural gas industry and losers in the traditional fueling industries (gasoline, diesel).

Our final recommendation for policy options for overall economic incentives is to maintain the status quo. There are many programs in place for vehicle/fleet operators and for fuel providers to find funding to help subsidize conversion costs to natural gas. These programs could be advertised more and additional funding could be placed in these programs to give interested parties in the Pittsburgh area opportunities to receive funding.

7.0 Project Summary and Recommendations

Throughout this project ten policy areas were explored and analyzed pertaining to the advancement of natural gas vehicles in the Pittsburgh Metropolitan Statistical Area (PMSA). Five of these areas covered the particular vehicle types in question while the remainder focused on cross-cutting policies, which transcended vehicle specific boundaries. Table 22 summarizes the results of these analysis efforts and presents the groups' policy recommendations for NGVs in the PMSA.

Table 22: Policy Analysis Recommendations by vehicle type

Maintain the Status Quo	Consider Infrastructure Incentives
Trains	Boats
Trucks	
Buses	
Cars	
Maintenance and Training	
Education	
Regulation	
Research and Development	
Economic Incentives	

The predominant policy recommendation is to maintain the status quo for all of the cross-cutting topics and for all vehicle types, with the exception of boats. This result may appear striking given the stated objective of advancing NGVs in the PMSA and that to date there is only minimal penetration of natural gas into any of the vehicle segments in the PMSA. However, for all of the vehicle types, except passenger cars, our payback analysis demonstrates that for both our optimistic and best guess scenarios the private economics are favorable within the expected economic lifetime of the vehicle and should not necessitate further government subsidization. The status quo is not equivalent to advocating no action. As identified in the various vehicle sections throughout this report, many economic incentives (vehicle grant and fuel subsidy programs) are currently in existence to incite private adoption of NGVs.

As part of the status quo, there currently exist publicly available education outlets for those interested in learning about NGVs; with training and certification programs available for those companies and individuals wishing to gain proper maintenance training for the care of NGVs. We caution that these resources may become strained if NGV growth is prolific, but the current demand for these services is being met. Long term research and development funding for NGVs has primarily been handled at the federal level through agencies such as the Department of Energy, and this practice will continue. The current price differential between NG and petroleum in North America has engendered a flurry of research activity and spending in the private sector. These companies should soon (or presently) bring to market products, both new vehicle and conversion oriented, to take advantage of these favorable economic conditions.

Bolstering this level of investment by the private sector into NG engine technology is the role played by status quo environmental regulation. For all of these vehicles, but especially trucks, trains and boats, the continuingly increasing stringency of previously enacted EPA engine emission limits is forcing companies to seek cost effective means of compliance. Several alternative fuel approaches are being investigated, along with the use of extensive diesel exhaust after-treatment systems, with no clear winner having yet been identified. However, for the PMSA we feel that using natural gas to help boat owners meet emission requirements through the creation of an infrastructure provision simultaneously meets several of our policy objectives.

Our analysis did not provide a favorable outlook for the conversion of passenger cars to natural gas in the PMSA but we recommended that the status quo be maintained. This is in part because many of the previously passed economic incentives for passenger cars have, or are scheduled to, expire in the near future. In the past, passenger cars have been the focus of NGV legislation due to their large numbers and contribution to petroleum consumption. That precedent has continued, with CNG passenger cars being awarded a fuel economy multiplier of 1.6 for the 2017 model year that will ease to 1.3 for model year 2021 under the most recent Corporate Average Fuel Economy legislation. We feel this provides vehicle manufactures adequate incentive for continued NG engine development, despite unfavorable private economics, all in a politically favorable manner. The identification and balancing of tradeoffs, such as these for passenger cars, was the goal of this analysis and allows us to provide insight to the original questions we posed such as:

What is the priority of conversion when assessing economic, environmental, and energy security?

The answer to this question can be summarized in a variety of ways depending on the values of the particular policymaker.

The motivation behind the development of natural gas vehicles usually falls into a series of categories. For the purposes of the analysis of this report, the following areas were considered as potential benefits for natural gas vehicles: Private Economics, Environmental Benefits, Energy Independence, and Social Welfare.

Table 23 summarizes the findings of the overall magnitude of these benefits for each vehicle type and ranks each vehicle choice in its total ability to promote economic, environmental, and energy security needs. These rankings were derived from the supply curve analysis.

Table 23: Ranking of vehicle types in according to the magnitude of their impact on four measures of benefits from natural gas conversion, in descending order

Private Economics	Environmental Benefits	Energy Security	Social Welfare
Trucks	Trucks	Passenger Cars	Trucks
School Buses	School Buses	Trucks	School Buses
Boats	Boats	Boats	Boats
Transit Buses	Transit Buses	School Buses	Transit Buses
Trains	Trains	Transit Buses	Trains
Taxis		Trains	Taxis
Passenger Cars		Taxis	Passenger Cars

For example, according to this table, a policymaker principally concerned with reducing environmental impact would be advised to focus on the conversion of Class 8 trucks before considering the other vehicle types.

The overall result of the supply curve magnitude analysis suggests that trucks have the best private economics, environmental benefits, and social welfare benefits. The one category that trucks fail to provide the best option is for energy security. There, passenger cars provide the greatest potential for improving energy security, due to their large numbers. This analysis favors the conversion of passenger cars and trucks, but the results do not provide a complete depiction of the situation regarding conversion. Cars and trucks have a large presence in the Pittsburgh region and these favorable outcomes are contingent on a large number of conversions, which are probably not an accurate reflection of the current industry adoption rates and public opinions.

Though the magnitude of these benefits is useful information, additional consideration must be given to certain vehicle types and their reported performance in these categories. An energy-focused policymaker might look at passenger cars as the best option to reduce the largest amount of imported foreign oil. This benefit is achieved because of the sheer size of the passenger car fleet and consequently the amount of petroleum, which could be offset in aggregate, is substantial. The aggregation however is across roughly three-quarters of a million personal vehicles, which is an unrealistic number of vehicles to convert to natural gas.

To help resolve these potential pitfalls in the analysis of this report, a second table has been constructed. Table 24 reports the overall efficiency (benefit per dollar spent) of each of the vehicle types in its ability to accomplish the same set of policy goals. This analysis provides additional insight by showing how the benefit relates to the cost of the conversion.

Table 24: Ranking of vehicle types in according to the efficiency with which they accrue four measures of benefits from conversion to natural gas, in descending order

Private Economics	Environmental Benefits	Energy Security	Social Welfare
Taxis	Boats	Boats	Taxis
Boats	Transit Buses	Taxis	Boats
Trains	Trains	Trains	Trains
Trucks	Trucks	Transit Buses	Trucks
Transit Buses	School Buses	Trucks	Transit Buses
School Buses		School Buses	School Buses
Passenger Cars			Passenger Cars

In terms of efficiency, a different hierarchy of vehicles emerges than was created from the magnitude supply curve. Boats exhibit the highest efficiency in promoting environmental benefits and energy security. This shift occurs because although there are substantially fewer boats in the Pittsburgh Metropolitan Statistical Area than passenger cars, each boat converted does far more to promote these goals than an individual passenger car.

Boats provide the best environmental benefit because of the large amount of fuel they consume and the lax emissions regulations to which boats currently adhere. Additionally, boats provide the greatest efficiency in energy security because of their ability to displace a large amount of foreign oil through natural gas fueling.

The other vehicle type that shines through this analysis is taxis. The private economics and social welfare of natural gas taxi fleets makes them a viable option for conversion to natural gas. Specifically, the great number of annual miles travelled and low operating fuel economy make taxis a prime candidate for favorable private economics.

Trucks, the vehicle that was most favorable in the magnitude supply curve performed slightly worse in the efficiency analysis. This suggests that although trucks are a strong candidate to accomplish these policy goals, there are better vehicle conversions, namely boats and taxis, which could provide the benefits more efficiency than trucks.

Both performance metrics should be taken into account when deciding which conversions make the most sense. A proper balance between magnitude and efficiency will ensure that the desired outcome is achieved, and will also prevent overspending or ineffective policies from focusing on the wrong transportation sector. When these balances are considered, boats stand out as a vehicle type that achieves a favorable magnitude of benefits across a variety of benefit categories in a very efficient manner. Based on this conclusion, policymakers should consider facilitating the natural gas conversion of boats, as potential targets for natural gas development.

Will it be cost-effective to change our fleet to natural gas as a fuel source?

The answer to this question for the PMSA is not a straight-forward yes or no. Although the private economic payback period calculated for all the vehicles, except passenger cars, was favorable under both the optimistic and best guess scenarios; the accompanying sensitivity analysis revealed a strong dependency on the fuel price differential between petroleum and natural gas. The assumptions we used for fuel price differential are examined extensively in an earlier section of this report but the conclusion of our analysis is that if the price differential were to remain relatively constant at current levels, then it is cost-effective to change most fleets to natural gas from a private perspective.

It is important to note that our private economic analysis excluded the cost of the infrastructure required to support and refuel the NGVs in question. Clearly from a societal perspective there exists considerable infrastructure inertia surrounding the use of liquid petroleum fuels, which will be challenging both economically and behaviorally to overcome. Taking this into consideration, along with the results from our private payback analysis, we do not feel we can make prescriptive policies but rather offer descriptions for the general types of fleet conversion situations that should be pursued.

A favorable situation for a cost-effective conversion to natural gas is one in which each individual vehicle uses a large quantity of fuel over its economic lifetime. This provides opportunity to reap the rewards of any available fuel price disparity, which is the sole source of positive economic value identified. Vehicles that use a large quantity of fuel also tend to be large, expensive commercial or industrial vehicles whose purchasers are not as sensitive to the added capital cost from the conversion to natural gas. Lastly, the cost-effectiveness of conversion can be further improved if the vehicles operate over fixed routes, which minimizes the need for dedicated natural gas refueling infrastructure. Examples of vehicles meeting these criteria are boats, trains, and trucks following established shipping corridors.

What are the prospects for natural gas vehicles in Pittsburgh?

The Greater Pittsburgh Area possesses a litany of economic and geographic factors, which make the city a prime location for the introduction and growth of natural gas vehicles. Its industrial history, rife with the legacy issues of pollution, has stimulated the social consciousness required to take collective action to address the negative externalities associated with modern living. Combined with the recent expansion of natural gas production in the Marcellus Shale, and the corresponding decline in natural gas prices, it is easy to understand why advocates of natural gas vehicles view Pittsburgh as a city primed for action. We have shown throughout the course of this analysis that, in most cases under current conditions, the private economics of conversion are favorable and that converting vehicles to natural gas would yield positive impacts for environmental benefits, energy security, and net social welfare. Each type of vehicle possess its own unique set of challenges which may slow or prevent immediate adoption, but we feel confident that the long term prospects for natural gas vehicles in Pittsburgh are viable.

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