The Problem of Fixed Costs and the Adoption of Vehicles Fueled by Natural Gas

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The technical refinement of natural gas fueling equipment for vehicles has illustrated that the concept is feasible and can indeed decrease vehicle pollution emittance. Some governments have developed a quantitative method to put a price on pollution and this is currently a concern to most businesses operating fleets of vehicles, large or small, as regulations mandate allowable emission release rates. It remains to be shown if a fleet's conversion to, or purchase of, vehicles running on natural gas is an economically wise maneuver. This paper presents an economic analysis that can be applied to individual fleet situations to help evaluate this problem. Vehicle characteristics and use data are input with capital costs and an appropriate interest rate to generate a dollar figure representing the estimated actual cost of vehicle use and the corresponding value of "non-emitted" pollution. Previous calculations naively ignore capital costs and encourage a biased solution. The method presented would be applicable to any "alternative" fuel type. Results can help guide the decision making process concerning all alternative fueled vehicles.

Introduction

The "chicken or the egg" problem has slowed the adoption of vehicles powered by natural gas. Entrepreneurs do not want to build fill stations until they are assured of a market. Managers do not want to pay for training compressed natural gas (CNG) technicians until there is a market for their skills. On the other hand potential purchasers of vehicles, or conversion systems, do not wish to convert to CNG until they know an infrastructure of fill stations and technicians exists. Sometimes this problem is described as one where an "immature" industry must "mature."

This is a problem where an individual, company or a government, must invest a substantial amount in initial fixed costs in order to convert to CNG where a limited, or non-existent, market exists. The degree to which these costs can be spread out over units of operation is in some cases unknown, while in other cases an appropriate cost/benefit methodology is missing.[1][2] The purpose of this study is to develop a cost/benefit methodology which can guide investment. Second, the methodology is applied to a series of real world and hypothetical situations. Specifically, a university maintenance fleet is used to illustrate a method of calculating cost and benefits for alternative fuel vehicles which spreads fixed costs over the energy consumed. Hypothetical cases are used to illustrate both small and large fleet scenarios. A discussion is included about the conversion of the federal fleet to alternative fuels. We use the fleets in our examples because they help illustrate the problem of the development of market for CNG vehicles. Furthermore, the conversion of large fleets like units within the federal fleet can help overcome the problem of fixed costs in the development of this market.

AFV Adoption Challenges

The problem for the industry is analogous to the one a fleet manager faces when deciding to convert to CNG. Figure 1, below, can help explain the choices a fleet manager must make when deciding to convert. Whether the manager's fleet uses CNG or gasoline, it consumes energy, or BTU's, to operate. Consequently, equivelant total fleet gallons are on the horizontal axis of Figure 1. The vertical axis, rising from zero, is the amount the manager must spend in order to operate the fleet (Labeled $). The curve labeled GAS, represents the marginal cost of operating gasoline powered vehicles. It is a horizontal line because fixed costs have already been spread out over so many units that it no longer declines. Primarily, the marginal cost of operating gasoline vehicles is the cost of fuel.

The curve labeled CNG, represents the marginal cost of operating the manager's fleet with converted or purchased CNG vehicles. Cost is higher initially because the manager must convert vehicles to CNG, or purchase a dedicated vehicle which is more expensive, possibly install a fill station, train technicians, etc. As the fleet consumes more BTUs these fixed costs drop because the cost of CNG fuel is (currently) lower per BTU than gasoline. CNG becomes cost effective relative to gasoline as the fixed costs are spread over more energy units. Point A represents the break- even point for CNG vehicles.

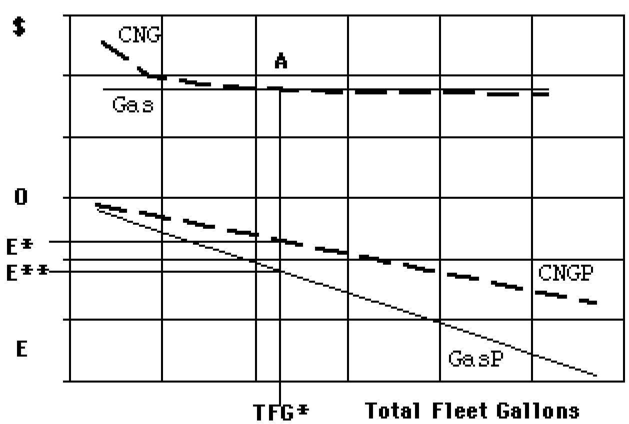

Figure 1. Marginal costs compared to emissions for gasoline and CNG vehicles.

The vertical line running down from zero represents tons of emissions at varying levels of CNG. Gasoline and CNG vehicles emit pollutants as they consume energy. According to the best engineering data available, a properly installed and tuned CNG vehicle is much cleaner than its counterpart running gasoline, even reformulated gasoline. Data available from the Alternative Fuel Data Center of NREL for 1991-94 Dodge RAM vans is presented in the following Table.[3] The actual amount depends upon many factors and several test fleets are now being operated to better define the potential emittance. This high value was reported in an early NGV demonstration study. The line labeled CNGP represents tons of pollutants emitted by CNG vehicles. The line labeled GASP represents tons of pollutants emitted by gasoline vehicles. This figure is a standard type used by U.S. EPA and is derived from engineering results.

Table 1. Averaged AFDC data for gasoline and CNG Dodge RAM vans, 1991-94.

	CO(gm/mi)	CO2(gm/mi)	HC(gm/mi)	NOx(gm/mi)	CH4(gm/mi)	NMHC(gm/mi)
average refm-gas	5.0013	648.41	0.3458	0.7214	0.0639	0.2906
average on CNG	2.3189	542.22	0.9458	0.5314	0.8335	0.1123
% reduction	53.6%	16.4%	-173.5%	26.3%	-1204.4%	61.3%

At point A in Figure 1, the break- even point, CNG vehicles produce (E** -E*) less emissions. This is the "social benefit" of converting to CNG vehicles at that point. The area between the two curves to the left of A represents the costs of converting to CNG up to that point. Beyond the break- even point the benefits of converting to CNG are the shaded area between the lower costs of CNG and the higher costs of gasoline. Furthermore, beyond that point (point A) the "social benefit" of conversion is indicated by the vertical distance between the GASP line and CNGP line.

For a fleet manager, the CNG industry, and society as a whole, point A represents the point at which CNG becomes cost effective without any consideration of the social benefits of pollution reduction or abatement. In other words, at that point the CNG industry matures.

This statement of the problem simplifies the discussion of a methodology for calculating costs and benefits. First, policy makers need a simple statistic which will allow them to measure the costs of pollution abatement. If the value of the social benefits in reduced pollution is greater than the costs of achieving point A, then a system of subsidies and taxes can be worked out. Second, fleet managers, the CNG industry, and policy makers need to know something about these cost curves and how to calculate them to accurately discuss fleet demographics.

Below, we first provide a formula for measuring costs and then discuss how costs have been calculated in the past. Second, Department of Energy data is used to calculate costs and benefits for the federal fleet. Third, we use the formula to calculate the costs of conversion for a specific sample fleet. The fleet chosen for study has 140 vehicles, less than half of which have been converted to run on CNG. (Vehicle characteristics will be described below.) Fourth, we change the values of the parameters in order to shift the cost curves and assess the impact of these changes. Finally, we summarize the implications of this decision making methodology to public and private fleet vehicles in general.

It should be noted that the formula presented here produces the marginal costs of emissions reduction over a range of energy use. In other words, it is the supply curve of clean air. The demand curve for clean air will vary according to location. Individuals in some sites, especially known dirty and unhealthy spots, may be willing to pay a higher price for pollution reduction than people in cleaner, rural settings.

The Actual Cost of Emissions Reduction

A commonly used measure of the costs of pollution abatement is the cost per ton of reactive hydrocarbons reduced, see Fraass and McFarland. The following formula is proposed which can be used to determine this cost of abatement and is:

(Annual Change in Cost of Fuel + Annualized Capital Costs) / Gallons per Year

(Emissions Reduced per Year)

This becomes the following formula in practice:

$$M(x) * G/M * \{[(MG*P(CNG) + Cv\{i*(1+i)n/[(1+i)n-1]/GAL\} + Cf\{i*(1+i)n/[(1+i)n-1]/GAL\}- P(GAS)]\}$$

$$M(x) * g/m(gasoline\ car) * t/g * (percent\ reduced)$$

Where:
M(x)=The average number of miles driven by a vehicle in a year
G/M=Gallons of gasoline used to drive 1 mile.
M(x)*G/M=GAL= Gallons of gasoline used by a vehicle in a year
MG=CNG used to achieve the same amount of miles as one gallon of gasoline.
P(CNG)=Price of CNG on a per gallon basis.
P(GAS)=price of gasoline per gallon

Cv=Costs of converting vehicle to CNG. (conversion kit)
Cf=Other fixed costs of conversion. (fill station, training etc.)
i=the interest rate
n=Years of useful life equipment
g/m(gasoline car)=Grams/mile emitted of reactive hydrocarbons for a gasoline car.
t/g= tons per gram, a conversion factor.
percent reduced=Percentage of emissions reduced by using the AFV.

Annual capital costs are fixed costs relative to the conversion of CNG vehicles, and "annualized" by an interest rate calculation. Capital costs include the cost of CNG conversion, fill stations, training and other fixed costs. In each case fixed costs are divided by gallons. Where the fixed costs concern a single vehicle then average yearly gallons consumed per vehicle are used. For example, when a single vehicle is converted it costs approximately $3,900. This fixed cost is divided by gallons used by that vehicle, rather than total fleet gallons, in order to avoid double-counting. Consider the following; a fleet with 10 vehicles is converted to CNG at a cost of $39,000 and the fleet uses 10,000 gallons a year. Without using the interest rate the fixed cost in one year would be $3.90 per gallon ($39,000 / 10,000 gal.). This is the same as dividing the cost of conversion by the average gallons used by a single vehicle ($3,900 / 1,000). If each vehicles cost of conversion were divided by total fleet gallons this would count all other vehicles in the fleet as using the same conversion kit.

On the other hand, when fixed costs are spread out over the entire fleet then total fleet gallons are used. The change in the annual cost of fuel is the difference between the cost per gallon of gasoline versus CNG equivalent per gallon (or other alternative fuel's). Emissions reduced per year is the difference between emissions from gasoline vehicles and emissions from CNG vehicles. The numerator in this formula is the change in the annual cost of operating a CNG vehicle. Each capital cost term is calculated using the following formula, one of the terms in the equation above.

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Capital cost per gallon = Cost { irate *(1+i) life / [(1+ irate ) life - 1 ] / Gallons
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This formula is different from the one used by Fraas and McFarland (1990) to estimate the cost effectiveness of methanol, CNG, and oxygenated fuels.[4] They added the annualized increased capital costs *per vehicle* to fuel savings. In other words marginal costs were calculated on a per vehicle basis rather than a per gallon basis. A commonly used computer software package used by the CNG industry calculates these fixed costs by subtracting "investment," interest expenses and operating and maintenance expenses from annual fuel savings.[5] Standard accounting procedure produces a break even point over a number of years. The method used in this paper calculates the break even point from the first year on the basis of fuel use. It is also based on standard microeconomic theory.

A U.S. Department of Energy report calculates the cost of reducing oil consumption by converting to alternative fuel vehicles.[6] All of the results in that report represent undiscounted amounts (e.g. costs weren't "annualized" using an appropriate interest rate). Once again, the marginal cost of refueling facilities for methanol and CNG vehicles is defined on a dollars/vehicle basis ($177.00). Again, fixed costs were not calculated over the appropriate units; a more appropriate definition would be one based on gallons of gasoline equivalent consumed (e.g. dollars/vehicle/gallon). .

Calculating costs in this way can overestimate, or underestimate, the cost of conversion (under certain conditions) because fixed costs do not fall as they are spread over more energy units. A methodolgy which does not spread fixed costs over the appropriate units (e.g. gallons of gasoline) will not provide a break even point based on fleet size. A fleet which uses large amounts of gasoline could find it immediately beneficial to switch if it operates a certain number of vehicles. (Below we suggest this number can be quite low.)

Intuitively, with a cheaper fuel, the greatest savings will come from vehicles which consume the most energy. Converting these vehicles means costs will be spread out over more energy units. The formula above explicitly includes gallons of gasoline in order to more accurately calculate the costs of conversion. The difference between the formula above and other formulas which calculate the costs of CNG vehicles is that this formula uses equivalent gallons of gasoline. Other methods use vehicles as the unit of output. In this formula over a certain range costs will decline as energy consumption increases.

The Costs and Benefits of Converting the Federal Fleet

We recalculate the costs and benefits of converting the federal fleet using the proposed methodology. The basis for our calculations is the Department of Energy's report Assessment of Costs and Benefits of Flexible and Alternative Fuel Use.[5] Wherever possible we have updated data on costs based on actual experience. The costs are all reported in 1988 dollars so a direct comparison can be made between our results and the original reports cited. We start with the federal fleet because it is our belief that conversion of the federal fleet would greatly reduce the problem of fixed costs in the conversion to NGV vehicles. For example, arrangements with privately owned gas stations could help develop the infrastucture of fill stations needed by this market. Orders by the fedral government could also greatly reduce the cost of OEM vehicles. Table 2, below incorporates our methodology and all of the fixed costs involved. Table 3, estimates the costs with a full developed infrastructure.

It is possible to take the data contained in the DOE's Assessment and use it in the formula above to derive the cost per ton reduction for federal and state government fleets. The DOE assumed the incremental cost of an alternative fuel vehicle would fall between 1994 and 1998 as economies of scale were realized in their production. The DOE also assumed the marginal cost of refueling facilities was $177 for each vehicle (e.g. calculated $/vehicle). In the calculation below the annual mileage per vehicle is 12,000; miles per gallon 23.8; incremental vehicle cost 2,500 and marginal cost of fill station $177/gallons. These figures come from the DOE's Assessment Report.[7] Fuel costs are from Frass and McFarland, 35 cents to 54 cents for CNG and $1.04 for gasoline in 1990. The size of local fleets is assumed to be small, ten vehicles. The same interest rate is used, 6.1 percent. The study compared the cost of reducing oil consumption based on different bills before Congress at the time. They found each of the bills would lead to positive costs in displacing oil. (These costs ranged from $11.27 to $17.19 per barrel.)

This report also presented and utilized vehicle emissions values that are misleading. Table 1 above reports that most accurate data currently available. Gasoline auto emissions have been dropping rapidly as performance and environmental concerns force the manufacturing process. Data in the referenced report is evidently quite dated as the emission values are very high for the gasoline control vehicles. This generates an inaccurate reading of HC and CO cost benefits. The tables below summarizing DOE data using figures quoted in those reports, but the examples presented later in this paper, illustrating the proposed revisions, contemporary data is applied.

These results are probably low, since the DOE did not include training and other potential costs. On the other hand the value given for the "marginal cost of refueling stations" was an undiscounted one. Spreading costs out over a number of years would have led to a smaller value. These results indicate that even on small fleets of passenger cars, CNG, or methanol, dedicated vehicles could be cost effective. Of course, the crucial determinant of these savings is the difference between the cost of the alternative fuel and gasoline. If the retail cost of CNG for 1991 ($0.70 per equivelent gasoline gallon) was used then the results are slightly positive. In this case, the net cost is $15 per vehicle per year.

Table 2. Economic analysis of an NGV fleet using DOE data.

I. Cost of CNG:
A. Cost of CNG (gasoline gallon equivalent) $0.35 - $0.54
B. Conversion cost per gallon ($4,000 total cost)[1] $0.62
C. Fill station cost per gallon ($177/10,084) $0.02
D. Cost of gasoline - $1.04
E. Difference in costs (per gallon) - $0.05 to $0.14

Net cost per vehicle per year[4] - $25.20 to $70.56

II. Costs per ton of emissions

CO (Net cost per vehicle per year/CO) - $ 97.68 to $273.58
HC (Net cost per vehicle per year/HC) - $1,145.46 to $3207.27

[1] Conversion cost per gallon = Cv{i*(1+i)n/[(1+i)n-1]/GAL} = $4,000{0.07*(1+0.07)*10/[(1+0.07)*9]/504 = $0.62 per gallon

[4] Difference in costs (per gallon) x yearly gallons per vehicle

[5] Reduction in emmissions come from Frass and McFarland

Note: Variable deffinitions and formula are in Appendix 1.

Source: U.S. Department of Energy, Assessment of Costs and Benefits of Flexible and Alternative Fuel Use, May 1992, p. 28. Prices in 1988 dollars.

As Table 2 indicates the primary fixed cost is the cost of conversion. The fixed cost per fill station (using DOE) figures would quickly go to zero as more vehicles use the station. There are two immediate solutions to this problem. First, by ordering enough OEM cars the fixed costs of production would drop to the point where their price was the same as a petroleum based vehicles. Second, commercial fill stations, or centrally located fleet stations servicing large numbers of vehicles, would quickly reduce those fixed costs to zero. The difference between vehicles would then be difference between the costs of the two fuels. These results are reported in Table 3, indicating the potential benefits from a fully developed market and infrastructure. If the federal government, with its huge fleet, could purchase enough vehicles to reduce the difference between OEM and petroleum car costs to zero then great benefits could be derived.

Table 3. Estimate of cost benefit with fully developed infrastructure.

I. Cost of CNG:
A. Cost of CNG (gasoline gallon equivalent) $0.70
B. Conversion cost per gallon 0
C. Fill station cost per gallon 0
D. Cost of gasoline - $1.04
E. Difference in costs (per gallon) - $0.34

Net cost per vehicle per year - $171.36
(267 gallons/yr for average vehicle)

III. Costs per ton of emissions
CO (Net cost per vehicle per year/CO) - $664.19
HC (Net cost per vehicle per year/HC) - $7789.09

Source: U.S. Department of Energy, Assessment of Costs and Benefits of Flexible and Alternative Fuel Use, May 1992, p. 28. Prices in 1988 dollars.

Sample Calculations

Actual Mid-Size Fleet

A natural gas company provided a $300,000 grant to a prominant university's physical plant to train mechanics, install a fast fill station, and convert forty-five vehicles to CNG. Vehicles in this fleet do not travel very far (on average 4000 miles per year), average about fifteen miles per gallon, and generally continue to operate for about ten years. Use data was compiled from maintenance records, most of which were available for more than a one year period. As a demonstration fleet, the subsidized equipment drastically reduced the initial investment. This type of relationship is not uncommon in this evolving market as participants pursue long range infrastructure development.

The interest rate used to calculate "annualized capital costs" is 6.1 percent. This is the interest rate for Triple AAA state bonds.[8] It was chosen because this interest rate reflects what it would have cost the institution to fund the conversion on its own. We chose a seven year life span for both training and conversion systems. The bulk of the conversion cost comes from the fuel tank; these tanks usually have a long life and can be reused in a replacement vehicle. The benefits of training, and skills developed as part of the training, are also likely to last several years because the basic installation process has remained the same despite technological change.

Conversion costs are calculated on a per gallon basis. These costs are then added to the cost of CNG and then the cost of gasoline is subtracted from the total, this difference is multiplied by the average gallons used by a fleet vehicle. The numerator is divided by the emission reduction per year (in tons). The values for per ton reduction in emissions are from Frass and McFarland. Emission reductions of 60% have been reported as based upon the reputable engineering evidence at the time. More recent testing and statistical averaging may show that this could be a stretched estimate of actual gain. As data is validated and accepted the formula should be changed accordingly.

A solution based upon approximate fleet data is shown in Table 4. This fleet has a couple of unique features that should be emphasized because they may not be standard practice. This sample fleet is run by an organization of tradesman (plumbers, carpenters, grounds, HVAC, etc.) that travel very short distances and usually only once or twice a day, as indicated by the low vehicle mileage listed. Capital costs for this fleet were drastically reduced as the local gas utility donated a fast-fill station adequate for their needs for the next few years. Small expense was incurred to put up a protective building but this has been ignored in the calculation.

Table 4. Solution to economic model run with actual mid-sized fleet data - model accounts only for cost associated with fuel and specialized fueling requirements (i.e. insurance, drivers, vehicle purchase cost are not included).

Number of vehicles	45
Ave vehicle fuel efficiency (mpg)	15.0
Ave vehicle miles driven (mpyear)	4000
Ave vehicle fuel use (gal per year)	266.7
Fleet gasoline use (gal per year)	12000
Conversion system cost (unit cost)	$ 2483
Conversion kit life (yrs)	7
Fuel station cost (donated fast-fill for demonstration)	$ 0
Fuel station life (yrs)	20
Standard interest rate	6.1 %
Technician training cost - fleet (2 technicians)	$ 5872
Useful life of training (yrs)	7
Price gasoline (per gal)	$ 1.170
Price NG (per eq gal)	$ 0.420

Gasoline fleet cost (per year)		$ 14040
NG fleet cost (per year)		$ 13330
Cost differential (per vehicle)		- $ 15.77
Savings		5.1 %
Fleet's cost differential ($/yr reduction)	neg =	- $ 710
CO cost differential		- $ 1,470
HC cost differential		- $ 22,134

Source: West Virginia University's Physical Plant vehicle maintenance records, 1990-1994 ; and fuel data compiled from natural gas vendor.

Important aspects of this case are that the fueling station was donated in its entirety and that the entire conversion kit cost was born by the fleet. If the fleet could receive a grant or donation to cover 75% of the conversion equipment cost a savings of $147 per vehicle for the year could be realized; a 47% savings in fueling would be realized. {Note: the authors make no statement of bias toward one fuel or another, each situation must be evaluated independently.} For the 45 vehicles this means fleet savings over similar vehicles running on gasoline of $6617. Note the very low average mileage of vehicles in this sample fleet; most of the vehicles carry tradesman and run one or two short trips a day. The conversion cost was totally born by fleet ($2483 per kit, includes tank) and savings are still realized, but only to $15.77 per vehicle per year or $710 for the fleet for the year. This is on the correct side of the scale but may not be substantial enough to appease the critics. Obviously, some of the parameters used as inputs will vary (some of which change often) and that is taken up in the next section where some of the important trends of this NGV fleet's operation will be examined.

The following figure examines the impact of varying daily vehicle mileage for this sample vehicle fleet presented in the Table above. Note that this fleet paid vehicle conversion costs (relatively low in 1987 when done) and pays very little for natural gas. A demonstration fast fill station is available free of cost. This fleet has a very low daily milage load on the vehicles, this chart illustrates the effect of increasing daily use. The significance of this example is that each fleet must be analyzed separately to accurately capture that fleet's unique features. For this case, 3700 miles/year is breakover point.

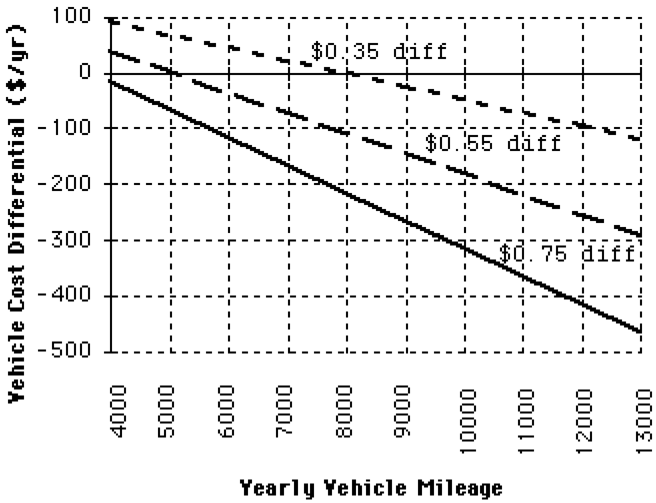

Figure 2. Vehicle usage in the mid-sized fleet dramatically affects the return upon investment.and projected fleet savings, as does the fuel price differential shown.

Hypothetical Large Fleet Case

Evaluating the economic issues of a large fleet may be quite enlightening and dramatic and that is attempted here. Take a large fleet, such as a Walt Disney World, Federal Express, United Postal Service, Rental Uniform Service, RPS or a tractor fleet from a major airport and predict the impacts of changing the entire fleet to natural gas. Table 5 below presents such a scenario. The fleet is presumed to have 100 vehicles traveling 90 miles every working day (250 days/yr). Delivery fleets contacted report that vans put on as few as 40 miles/day for an urban route (better than 75% of fleet) and as many as 250 for a rural route.[9] Four technicians would be trained to maintain the vehicles and a fueling station costing $350,000 is purchased and installed by the operator. The efficiency of the vehicles are low as these tend to be working vans or tractors with average loads running stop and go routes. It is assumed that these are converted gasoline engines and no diesel units are addressed.

The dramatic results realized are mostly due to the high mileage driven every day and the poor economy of a step van, tractor or delivery vehicle, accenting the high fuel use and multiplying the cost per energy unit advantage of natural gas as a vehicle fuel.

Table 5. Solution to economic model run with hypothetical large fleet data - model accounts only for cost associated with fuel and specialized fueling requirements (i.e. insurance, drivers, vehicle purchase cost are not included).

Number of vehicles		100
Ave vehicle fuel efficiency (mpg)		9.0
Ave vehicle miles driven (mpyear)		22,500
Ave vehicle fuel use (gal per year)		2,500
Fleet gasoline use (gal per year)		250,000
Conversion system cost (per unit)		$ 3983
Conversion kit life (yrs)		7
Fuel station cost (fast fill station)		$ 350,000
Fuel station life (yrs)		10
Standard interest rate		7.0 %
Technician training cost - fleet (4 technicians)		$ 23,488
Useful life of training (yrs)		7
Price gasoline (per gal)		$ 1.170
Price NG (per eq gal)		$ 0.500
Gasoline fleet cost (per year)		$ 292,500
NG fleet cost (per year)		$ 186,100
Cost differential (per vehicle)		- $ 1,064
Savings		36.4 %
Fleet's cost differential ($/yr reduction)	neg =	- $ 106,400
CO cost differential		- $ 17,640
HC cost differential		- $ 265,462

If the company risks fines for non-compliance with alternative fuel vehicle mandates this margin would be increased. This type of fleet may need to purchase a larger tank or add a second fuel tank to the conversion cost to allow these vehicles to travel the day's route without refueling. Large fleets like this vary tremendously depending upon location and service as indicated earlier. Each case must be analyzed on its characteristics and merits. For this large fleet example it is interesting to determine the break-even point, where running on natural gas makes economic sense. Taking all costs and investments to be identical to those in the above table and varying only driven miles it is found that the magic number is 33 miles per day on the average vehicle. This would change if any of the input parameters are altered.

Hypothetical Small Fleet Example

Local utilities and energy companies face government mandates as do larger firms. The data for this case is provided by a small, local natural gas pumping and distribution company in the central appalachians.[10] The entire fleet is 25 vehicles and the company employs approximately 50 people. Government mandates dictate that they must be running on alternative fuel in the near future or face fines for non-compliance. The questions in this case are, "Which option is the least expensive, converting or accepting the fines? Can running a small fleet on natural gas be cost effective?" The cost benefit method is applied to help answer these questions. Note that gas utility could fuel their own vehicles without the overhead of a commercial station - if this option makes economic sense. For such a small fleet the cost of fill equipment may be prohibitive. Table 6 presents the data and results for this case.

Table 6. Economic model run with hypothetical small utility company fleet data .

Number of vehicles (16% of fleet)	4
Ave vehicle fuel efficiency (mpg)	12
Ave vehicle miles driven (mpyear)	12,000
Ave vehicle fuel use (gal per year)	1,000
Fleet gasoline use (gal per year)	4,000
Conversion system cost (per unit)	$ 3600
Conversion kit life (yrs)	7
Fuel station cost (2 slow fill units)	$ 12,000
Fuel station life (yrs)	10
Standard interest rate	7.0 %
Technician training cost - fleet (no inhouse repair)	$ 0
Useful life of training (yrs)	7
Price gasoline (per gal)	$ 1.299
Price NG (per eq gal) - well head price	$ 0.450
Gasoline fleet cost (per year)	$ 5,196
NG fleet cost (per year)	$ 3,890
Cost differential (per vehicle)	- $ 327
Savings	25.1 %
Fleet's cost differential ($/yr neg = reduction)	- $ 1,306
CO cost differential	- $ 10,150
HC cost differential	- $ 152,748

This analysis shows that converting this fleet might make sense. The margin is close so actual costs must be confirmed to assure savings. Savings approximately equal the cost of gasoline for one vehicle for the year. The variability in some parameters may risk this application, but this fleet could convert more vehicles in subsequent years and increase the margin. No accounting of imposed fines is included here for lack of compliance which would also increase the margin and probably decrease headaches, paperwork and litigation.

Examining the Parameters

There are nine variables in the equation presented here. We may shift the marginal cost curve by changing six of them: average miles driven, miles per gallon, interest rates, conversion costs, fill station costs, and natural gas costs. Three of these parameter studies are presented in the following figures. The base study is roughly similar to the mid-sized fleet presented in examples above. In each case the middle line is based on 5,000 annual miles per vehicle and 15 miles per gallon. The vertical line is cost per ton of HC reduction, the chosen indicator for comparison of benefits. The horizontal axis is number of vehicles. (To get fleet gallons of energy use divide annual miles by miles per gallon and multiply it by the number of vehicles.) At zero, the marginal cost of CNG use is equal to the cost of gasoline use for a fleet manager. Understandably, the characteristics of this baseline fleet may be atypical, but the importance of the following figures is to identify the trends developed by parameter variation.

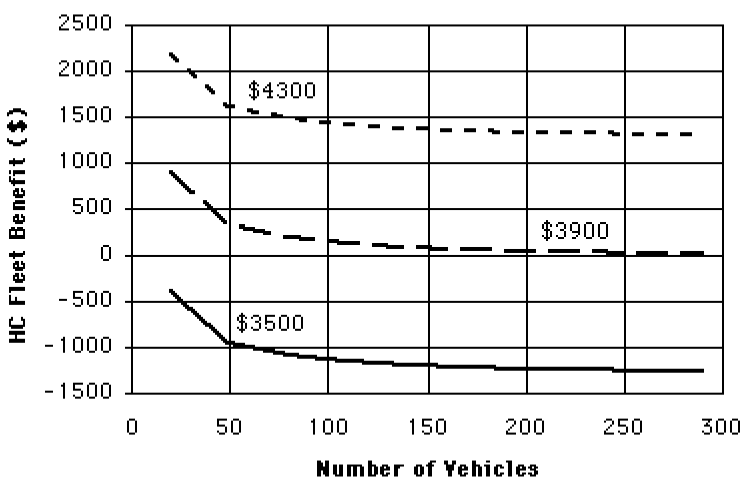

Figure 3. Vehicle conversion cost impact upon HC emission social cost benefit.

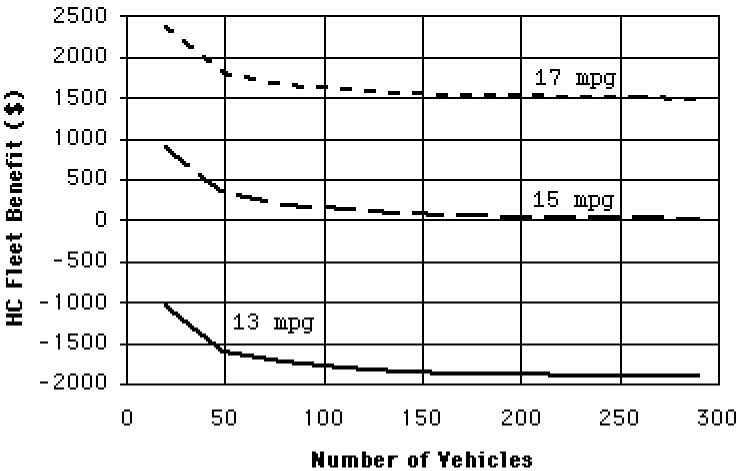

Figure 4. Vehicle efficiency alterations to emissions cost. Natural gas price variability would produce a similarly shaped set of curves as would any other 'running' cost.

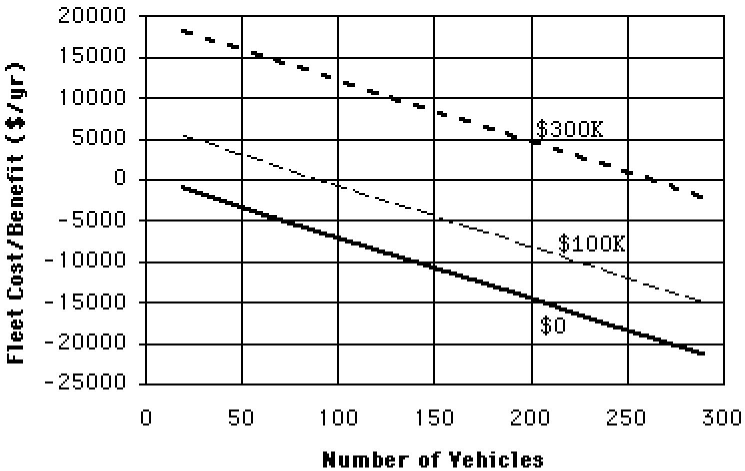

Figure 5. Initial capital cost items, like fuelling equipment costs shown here, will produce this type of cost/benefit relationship. Note that several fueling systems scenarios could be adopted including public, private fast or slow-fill, or a combination of any of these elements.

What do these graphs tell us? The first point is intuitive: the more energy is consumed the greater the benefits are in switching to CNG when it is the cheaper fuel. A second point is somewhat more interesting. Using the approach outlined here it is possible to more accurately estimate the breakeven point for a given fleet. Given costs and input data, this analysis will dramatically illustrate the number of vehicles required to run in order to reduce costs. The basic point made by calculating costs in this way is the cost curve declines and eventually reaches a breakeven point as the number of units (gallon equivalents) increases. In other words, other calculations of the costs and benefits of conversion to alternative fuels have left out the question of what level of use are vehicles being operated at, and how many equivalent gallons of gasoline costs are being spread over. Furthermore, small changes in the parameters lead to large shifts in the cost curves. Increasing average miles, or decreasing miles per gallon, lowers the break-even point substantially.

Implications for the Continued Expansion of Alternative Fuels

The analysis presented within this study has produced some results which are intuitively obvious, and some which are not so obvious. A key concept is a break-even point which is determined by the fixed costs of technological innovation. What we have demonstrated is how a firm's fixed costs will decline when they adopt natural gas as a vehicle fuel because natural gas costs less than gasoline on an equivalent gallon basis. As these fixed costs are spread out over units which proxy energy consumption (like gasoline gallon equivalents) then a fuel like CNG becomes cost effective even in the absence of a subsidy. The second point, somewhat unexpected, is how small a fleet can be in order for natural gas to be cost effective.

Increasing automotive natural gas fueling infrastructure and sales leading to economy of scale may lead to a decreased unit cost. Operating and maintenance costs will always be an issue and must be figured into cost estimates, but may be negligibly different than existing equipment. Indeed, natural gas vehicles show less wear in engine components and may realize decreased upkeep costs. Fill station systems may require as much attention as present systems, inadequate results from demonstration stations have been collated to validate this point.

The parameter which determines the cost effectiveness of CNG, and other alternative fuels, is the difference between the price of the alternative fuel and a gallon of gasoline. Obviously as demand for CNG, or other alternative fuels, increases then the price will rise relative to gasoline. On order to fully understand the costs and benefits of conversion to alternative fuels price changes must be estimated and incorporated into the analysis.

Summary

In summary it is found that typical fleets adopting natural gas as a fuel can save substantial operating finances. Smaller fleets would probably purchase fuel at a public station and could, like a mid-sized fleet using a donated station, save money. The model here can address small trickle fill (slow-fill) units as well as fast-fill options when calculating capital costs. The hypothetical large fleet examined here indicates that high mileage carriers can reduce fueling expenses proportional to the difference in fuel cost and relatively easily pay off capital investments. The majority of fleets in this country fall between the two extremes and need to be assessed on an individual basis for which the model presented is an appropriate tool. The presented model can be expanded to account for other costs and is only limited by the investigator patience and the availability of accurate data. This modeling scheme can also be applied to any alternative fuel type.

Our use of examples concerning fleets highlights problems in the development of a market for NG vehicles. If fixed costs can be spread out over more energy units then they become less and less of a factor in the adoption of NG vehicles. The key to solving the "chicken and egg" problem in the adoption of NG vehicles is finding ways to expand the market for these vehicles. Three methods have emerged in our use of real world examples. First, direct purchase of OEM vehicles, and/or conversion of the federal fleet, could well expand the market to the point where fixed costs could become negligible. Second, subsidies from the natural gas industry similar to what occured in the example concerning the university fleet. Third, some sort of subsidy, such as a tax credit for conversion, as was illustrated in the section where we examined the effects of changes in the parameters. Central to our discussion throughout the article is the price differential between petroleum and alternative fuels.

Not only do alternative fuels have to overcome fixed costs of production but some cost more to produce than gasoline. Currently, natural gas appears to be the fuel which can compete best in terms of price. It should be pointed out that niether of these fuels, gasoline or natural gas, are produced in a truly competitive market. The influence of OPEC and Saudi Arabia is well known in the production of petroleum. Less well known is the fact that natural gas is sold in a regulated utility environment. The price differential between gasoline and natural gas might either remain as it is for the forseeable future or move rapidly toward equality. Analyzing future price changes is beyond the scope of this article. We believe, however, that use of our formula can aid in assessing the costs and benefits of conversion whatever the shifts in various parameters.

Despite obvious cost advantages, natural gas remains underutilized as an alternative fuel because of problems with fixed costs. Our formula helps define these costs more precisely in the context of actual vehicle use. The formula can also help both public and private decision makers in assessing the costs and benefits of alternative fuels. Thus, incorporating fixed costs into the decision making process, as shown here, is itself a valuable tool in developing alternative fuels. As our examples indicate a mix of public and private decisions can greatly expand the use of natural gas in the transportation sector. These include federal and state purchases of dedicated vehicles which reduce the fixed costs of producing those vehicles. The expansion of demand by both federal, state, and private fleets will reduce the fixed costs of private fill stations. Potential subsidies from both the natural gas industry and government which reduce the barrier fixed costs impose on individual's choice of alternative fueled vehicles. Because the formula provides a per ton estimate of pollution reduction it allows decision maker to asssess both the private and public benefits of alternative fuels. We hope this small addition to the literature on alternative fuels will aid in the development of low cost alternatives to the problem of air pollution.

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