Cost-Effectiveness Analysis of Texas Department of Transportation Compressed Natural Gas Fleet Conversion

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Increased emphasis on energy efficiency and air quality has resulted in a number of state and federal initiatives examining the use of alternative fuels in motor vehicles. Texas's program for alternative fuels includes compressed natural gas. On the basis of an analysis of 30-year life cycle costs, development of a natural gas vehicle program for the Texas Department of Transportation (TxDOT) would cost about $47 million (in 1991 dollars). These costs include savings from lower-priced natural gas, infrastructure costs for a fast-fueling station, vehicle costs, and operating costs. The 30-year life cycle costs translate into an average annual vehicle cost increase of $596, or about 4.9 cents per vehicle mile of travel, compared with gasoline and diesel. Sensitivity analyses are performed on the discount rate, price of natural gas, maintenance savings, vehicle use, diesel vehicles, extended vehicle life, original equipment manufacturer vehicles, and operating and infrastructure costs. The best results are obtained when not converting diesel vehicles, converting only large fleets, and extending the period the vehicle is kept in service. Combining these factors yields results that are most cost-effective for TxDOT.

Texas, a state rich in natural gas, adopted alternative fuels legislation in 1989. In general, the legislation requires state agencies with more than 15 vehicles and school districts with more than 50 school buses to restrict new vehicle purchases to vehicles capable of operating on an alternative fuel. Alternative fuels, as currently defined, include natural gas, propane, electricity, and methanol. The principal objective of the legislation was to stimulate the development of an alternative fuels market in Texas. Greater use of alternative fuels would assist the state in (*a*) improving air quality; (*b*) promoting economic development, particularly in the natural gas and propane industries; and (*c*) supporting national energy security objectives through reduced dependence on imported oil. An important argument in the development and adoption of the legislation was that use of alternative fuels would save costs for state agencies. Accordingly, the legislation provides for a waiver if affected agencies demonstrate that operation of an alternative-fueled fleet is more expensive than that of a gasoline or diesel fleet over its useful life, alternative fuels are not available in sufficient supply, or the agencies are unable to acquire alternative-fueled vehicles or equipment necessary for their conversion.

Previous work examining the cost-effectiveness of compressed natural gas (CNG) as an alternative fuel is useful in placing this paper in perspective. A brief review of other published works that attempt cost-effectiveness analyses for CNG vehicles relative to gasoline/diesel vehicles is presented in the remainder of this section.

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The California Energy Commission performed what is basically a user cost/benefit analysis, considering several classes of users: individual, small private fleet, large private fleet, and government fleet. The study did not attempt to account for societal impacts (*1*).

Several studies attempted to analyze both economic and environmental factors. First, the American Gas Association (AGA) accounted for the wellhead, distribution, and public filling station costs influencing the price of CNG to individual users (*2*). By including vehicle costs to the user, it computed the difference in costs between operation of vehicles on gasoline/diesel and CNG. By estimating the difference in emissions of reactive hydrocarbons and carbon monoxide between CNG and gasoline/diesel vehicles, it computed the cost (or savings) to remove a ton of each via conversion to CNG.

With a methodology similar to that of AGA, Radian performed two studies in 1990 analyzing CNG as a replacement fuel. It used scenarios from several proposed federal alternative fuel legislative efforts of that time. The study differs from the AGA's study in that it targeted converted fleets, whereas AGA's study targeted individual vehicles (*3,4*).

Sperling performed a very thorough multiobjective study, which addressed most of the factors (both economic and societal) generally considered to be important. The study uses quantitative and qualitative measures to determine preferred near-term fuel choices in various geographic regions of the world, in addition to discussing five possible future vehicular-fuel pathways (*5*).

A recent study by the authors differs from the previous literature in an important way. A comprehensive model that accounts for virtually all possible incremental cost components and relevant factors was developed to analyze the cost-effectiveness of CNG (*6,7*). The current analysis uses a net present value (NPV) model developed in the authors' previous work to analyze vehicle fleets. This entails the use of actual fleet characteristics (vehicle miles traveled, fuel efficiencies, etc.) for the Texas Department of Transportation (TxDOT). A detailed discussion of the model's operation and assumptions is available elsewhere (*6,7*). Some of the more important assumptions of the NPV model are discussed in the next section.

BASIC ASSUMPTIONS

A monetary cost/benefit fleet analysis based on the NPV of all future incremental costs and benefits over a 30-year life cycle time horizon is used. The NPV model is designed to provide a level of service to the fleet manager and users comparable with that of existing gasoline/diesel fill stations. Consequently, slow-fill is not included in the analysis. The model assumes continuous fast-filling of all near-empty vehicles on a daily basis. Moreover, social benefits, such as cleaner air, energy security, economic growth, although important, are not incorporated into the model analysis. However, if the NPV in the model is negative, this can be identified as the minimum value that social benefits must attain for the alternative to be cost-effective. The decision on the value of social benefits is highly debatable and will be left to policy makers. Finally, cleanup costs and tank removal for existing gasoline stations are not included, since they are a sunk cost; these costs will be incurred regardless of any future fuel selected. But to the extent that future inspection and maintenance costs of tanks are identified, they should be taken into account in a comparative analysis of fuels. This cost factor is not included in the model.

Some of the basic assumptions used in the model are as follows:

1. Dedicated (and optimized) original equipment manufacturer (OEM) natural gas vehicles (NGVs) are available in Year 11.
2. Diesel vehicle conversions begin in Year 6. In addition, all diesel conversions and OEM diesels are dedicated and not dual-fuel engines.
3. Vehicle conversion costs, based on a fairly mature NGV market, are given in Table 1.
4. Conversion kits and tanks are transferred between vehicles at the labor costs given in Table 1 when a converted vehicle is retired from the fleet. When replaced with an OEM, the kit and tanks remain on the retired vehicle with a $200 and $500 increase in the salvage value of gasoline-converted and diesel-converted vehicles, respectively.
5. For gasoline dual-fuel vehicles, the fuel economy is assumed to be only 95 percent of what it is for a gasoline-only vehicle. For OEMs dedicated to CNG, the fuel economy is increased by 15 percent. Diesel converted vehicles have only 74 percent of the economy of a comparable diesel-only vehicle. Finally, for dedicated OEM diesels the fuel economy is 80 percent of a diesel-only vehicle.
6. Tank recertification costs are $55 per tank, including labor. Tank recertification costs are discontinued as a separate cost for OEM vehicles.
7. Fuel prices are as follows: natural gas, $0.076/m^3$ ($2.50/mcf); gasoline, $0.235/L ($0.89/gal); diesel, $0.225/L ($0.85/gal). The fuel prices do not include federal fuel taxes.
8. Capital fueling infrastructure costs are as follows: dispenser, $25,000; dryer, $10,000. Compressor and storage are sized to meet continuous fast-filling of all vehicles requiring fueling in a day; setup cost is computed at 25 percent of the combined compressor, storage, and dispenser costs. These dispenser and dryer costs may be too high for small fleet refueling stations. The fueling station has an estimated 30-year life. Sensitivity tests on these values are reviewed in a later section.

NPV SUMMARY ANALYSIS

TxDOT Fleet Summary

There are 314 locations around the state that currently serve as fill stations for the 8,377 vehicles used in this analysis. The vehicles are classified into four groups: automobiles, light trucks (pickup trucks), heavy-duty gasoline trucks, and heavy-duty diesel trucks. Automobiles and light trucks are gasoline fueled, with the exception of a few diesels included in the light truck group. The average fleet size is biased upwards because of the existence of several large fleets. More than 75 percent of the locations have 30 or fewer vehicles in their fleet, as shown in Figure 1, but 73 percent of the vehicles are in fleets with more than 20 vehicles.

Whereas the locations are analyzed individually, representative fleets are used for the sensitivity analyses performed on important variables. On the basis of an analysis of the 314 fleets, five representative sizes were chosen and are given in Table 2. The values for the variables from the representative fleets, given in Table 3, are calculated from all the fleets of that particular size grouping. These data are used as the baseline for the sensitivity analyses discussed later.

Thirty-Year Life Cycle Analysis

The fleets stationed at the 314 TxDOT locations were evaluated by the NPV model. The basic input data included the number of vehicles of each type in the fleet, fuel consumption, and annual miles traveled. The results of the NPV analysis are summarized in Table 4. Overall, implementation of a natural gas fleet for TxDOT would cost $47.1 million over a 30-year period, or $5 million per year annualized. This amounts to an average increase in annual cost per vehicle of $596, or about 4.9 cents per vehicle mile traveled.

TABLE 1 Natural Gas Vehicle Costs (1991 Dollars)

	Automobiles	Light Trucks	Heavy-Duty Gasoline Trucks	Heavy-Duty Diesel Trucks
Conversion Costs:				
Kit	$700	$700	$700	$2,000
Labor	$800	$600	$600	$2,350
Tank(s)	$450	$900	$2,000	$2,000
Total	$1,950	$2,200	$3,300	$6,350
OEM differential	$900	$900	$900	$2,800

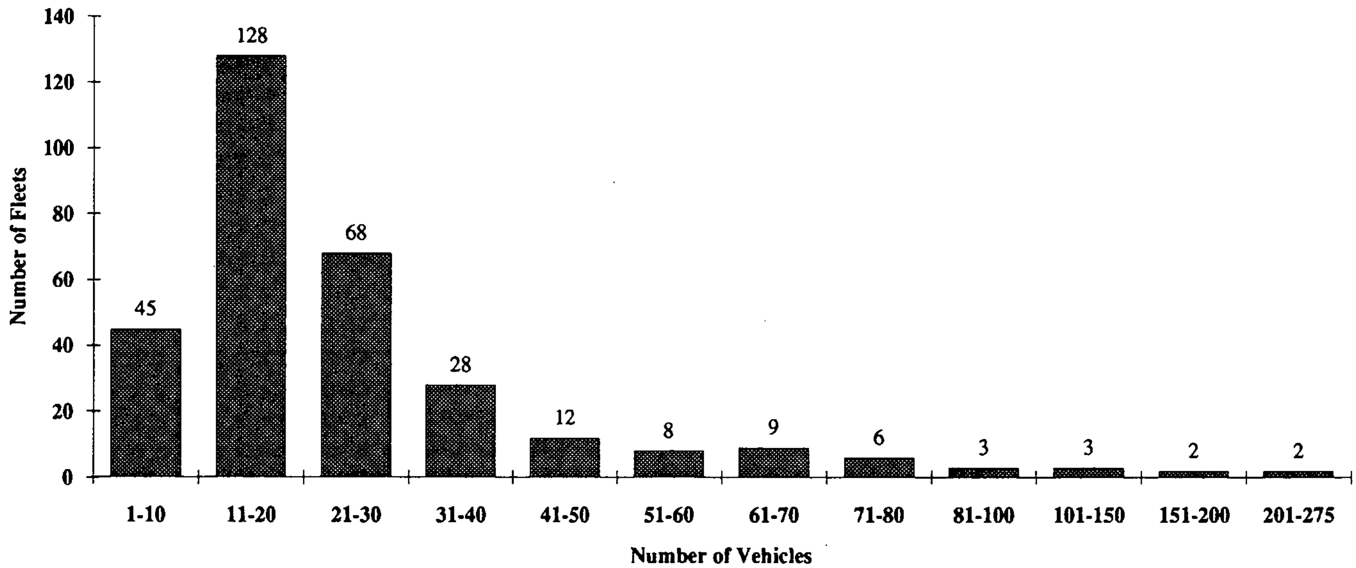

FIGURE 1 Fleet size distribution.

The 30-year NPV costs range from a low of −$73,656 in District 29, Garza County, to a high of −$688,548 in District 29, Travis County. The overall distribution for all locations is shown in Figure 2. More than 72 percent of the locations have a 30-year NPV between −$100,000 and −$160,000 [More detailed information on all fleets is given elsewhere (*8*).]

Because of the fixed fueling infrastructure costs required for each of the fleets, the NPV results are highly dependent on the number of vehicles in the fleet. On a cost per vehicle basis, the larger fleets are much cheaper to operate on CNG than are smaller fleets. The District 12, Houston District Office location, with 257 vehicles, ranks 313 in the 30-year NPV analysis but first in the lowest annual cost increase per vehicle (−$229). On the other hand, District 29, Garza County, although ranking first in NPV, ranks 314 on an annual cost increase per vehicle basis. There is a high negative correlation between the number of vehicles in a fleet and the average annual cost increase per vehicle, as shown in Figure 3. The exponential relationship between fleet size and annual cost increase per vehicle can be empirically calibrated as follows:

$$y = 973.31(0.9899^{f}) \quad (1)$$

where y is the average annual cost increase per vehicle and f is the fleet size.

TABLE 2 Representative Fleet Groups

Fleet Group	Number of Vehicles	Percentage of Vehicles
1-10 vehicles	385	4.6
11-20 vehicles	1,847	22.0
21-30 vehicles	1,707	20.4
31-50 vehicles	1,480	17.7
51 or more vehicles	2,958	35.3
TOTAL	8,377	100.0

SENSITIVITY ANALYSES

The NPV model has a number of assumptions affecting the cost-effectiveness of CNG fleet conversion and operation. Extensive sensitivity analysis has been performed to examine the robustness of the conclusion vis-à-vis the underlying assumptions and to help identify the fleet operating characteristics and economic scenarios under which CNG adoption is likely to become cost-effective. Another important role of this analysis is to determine the principal directions along which policy actions might be directed to encourage CNG adoption. The focus of the analysis is on a systematic assessment of the model's sensitivity to each of its principal elements, taken individually. This assessment will highlight the range of applicability of the model and its results and provide the building blocks for various policy scenarios. Because the effects of the various elements appear to be largely additive with limited interactions, single-factor sensitivity analyses allow reasonable estimation of the direction and general magnitude of changes in results due to changes in several factors simultaneously. Nevertheless, we consider explicitly several scenarios involving the combined effects of changes in several factors; these have been selected for their inherent substantive interest, as an illustration of the proposed approach, and for their clear policy significance. (The various sensitivity tests are summarized on an NPV basis in Table 5 and on an annual cost increase per vehicle basis in Table 6.)

Base Case

On the basis of the information contained in Table 3, analyses were performed on the five representative TxDOT fleets. The results are summarized in Table 7. The net present value worsens as the fleet size increases, but the cost increase per

TABLE 3 Summary Fleet Data for Sensitivity Analyses[a]

Fleet Group	Autos	Light-Trucks	Heavy-Duty Gasoline	Heavy-Duty Diesel	All Vehicles[b]
(1-10)					
Number of Vehicles	1	2	1	5	9
Annual Travel					
kilometers	36,239	29,506	20,817	21,753	26,032
miles	22,509	18,327	12,930	13,511	16,169
Annual Fuel Consumed					
liters	4,190	5,409	7,169	6,306	6,154
gallons	1,107	1,429	1,894	1,666	1,626
Annual Repair Costs	$989	$923	$1,490	$1,776	$1,437
(11-20)					
Number of Vehicles	1	5	2	7	15
Annual Travel					
kilometers	36,806	25,910	19,908	19,652	22,981
miles	22,861	16,093	12,365	12,206	14,274
Annual Fuel Consumed					
liters	4,553	4,674	7,676	5,481	5,394
gallons	1,203	1,235	2,028	1,448	1,425
Annual Repair Costs	$880	$753	$1,628	$1,592	$1,253
(21-30)					
Number of Vehicles	2	13	3	8	26
Annual Travel					
kilometers	26,807	22,490	17,056	18,702	20,999
miles	16,650	13,969	10,594	11,616	13,043
Annual Fuel Consumed					
liters	3,248	3,944	7,104	5,443	4,735
gallons	858	1,042	1,877	1,438	1,251
Annual Repair Costs	$628	$653	$1,659	$1,638	$1,072
(31-50)					
Number of Vehicles	3	20	4	10	37
Annual Travel					
kilometers	24,150	21,405	15,282	19,719	20,565
miles	15,000	13,295	9,492	12,248	12,773
Annual Fuel Consumed					
liters	2,960	3,777	6,529	5,908	4,576
gallons	782	998	1,725	1,561	1,209
Annual Repair Costs	$636	$623	$1,530	$1,597	$986
(51 or more)					
Number of Vehicles	19	54	4	11	88
Annual Travel					
kilometers	17,985	18,636	16,139	17,834	18,291
miles	11,171	11,575	10,024	11,077	11,361
Annual Fuel Consumed					
liters	2,033	3,289	6,575	5,587	3,433
gallons	537	869	1,737	1,476	907
Annual Repair Costs	$527	$675	$1,560	$1,790	$815

[a]All annual figures are per vehicle.
[b]Totals may not add up due to rounding.

TABLE 4 Summary CNG NPV Analysis for 314 TxDOT Locations

	30-Year NPV	Percent of Subtotal
Savings Differential:		
Gasoline	$34,582,695	81.8
Diesel	$7,702,222	18.2
Subtotal	$42,284,918	100.0
Costs Differential:		
Infrastructure	-$36,950,573	41.4
Vehicle	-$26,424,427	29.6
Operating	-$25,967,923	29.1
Subtotal	-$89,342,924	100.0
TOTAL	$-47,058,006	

vehicle and the cost increase per vehicle-mile improve as the fleet size increases.

The model categorizes costs into three groups—infrastructure, vehicle, and operating. Basically, infrastructure consists of the fill-station equipment and setup, vehicle costs are the conversion or OEM purchase costs, and operating costs reflect the operating elements for both the station and the vehicle. The importance of these cost components changes with the size of the fleet (Figure 4). The infrastructure costs are somewhat fixed, whereas vehicle and operating are variable, primarily dependent on the number of vehicles in the fleet and their annual mileage. The relatively high infrastructure cost for small fleets translates into very high annual vehicle cost increases and incremental costs per vehicle mile.

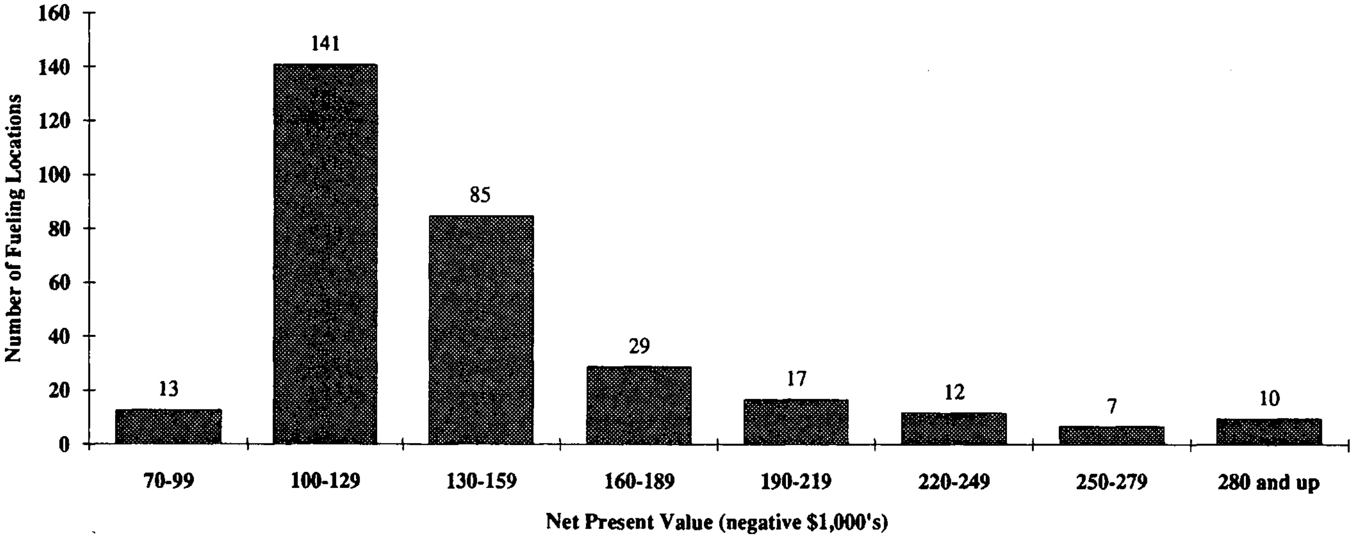

FIGURE 2 **Number of fueling locations by 30-year NPV (all locations have negative NPVs).**

Discount Rate

A 10 percent discount rate is used for the base case analysis, although the model allows any rate to be selected. Two other rates—5 percent and zero—were used for the five fleets to determine whether the discount rate significantly affects the conclusions. Tables 5 and 6 indicate that the effects of altering the discount rate are mixed. With respect to the three largest fleet groups, the NPV improves as the discount rate decreases, as expected. On the other hand, the NPV for the smallest fleet actually gets worse as the discount rate decreases. This is a result of the magnitude and timing of the annual benefits and costs. Annual costs exceed annual benefits for the small fleet; therefore, discounting reduces the net cost for each period. Consequently, as the discount rate increases, the NPV, being negative, improves. The timing of costs and benefits also is a factor behind the unusual change in the NPV for fleets of 11 to 20 vehicles. As the discount rate increases from zero to 5 percent, the NPV decreases, but as the discount rate increases from 5 to 10 percent, the NPV increases slightly.

Overall, regardless of the discount rate selected, the NPV and the annual cost increase per vehicle are negative for the five fleet sizes.

Fuel Prices

The major benefit of natural gas as an alternative fuel is that it is less expensive on an energy basis than gasoline and diesel. A price of $\$0.076/m^3$ ($2.50/mcf) was selected for the base case analysis. Initially, two alternative prices of $\$0.030/m^3$

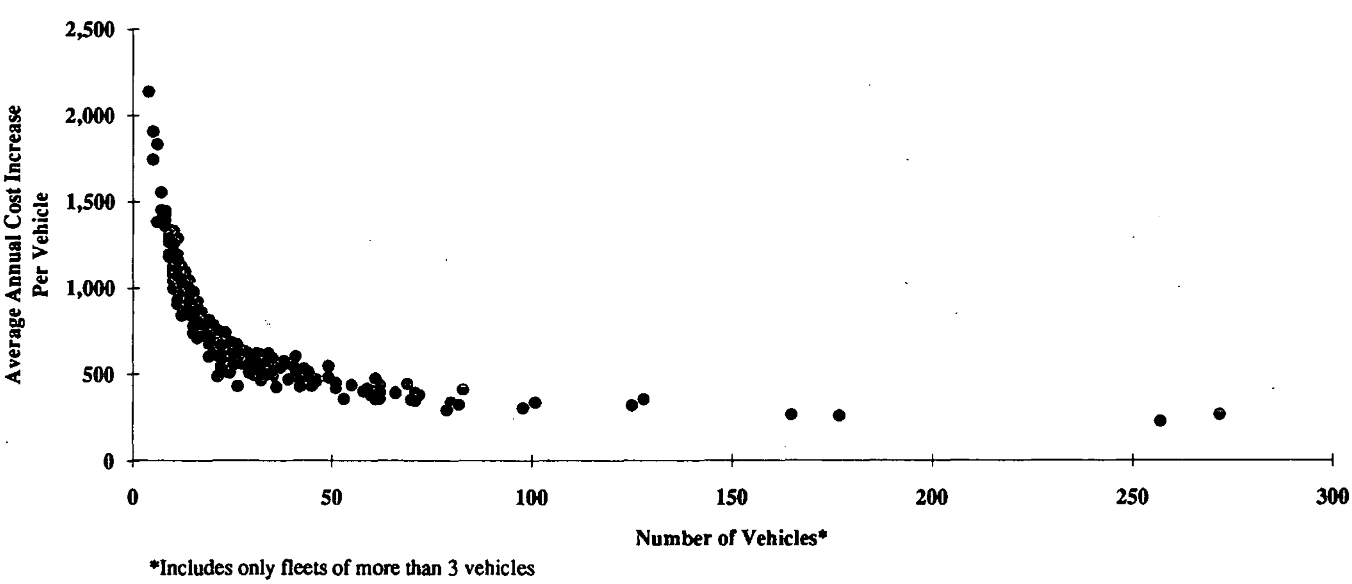

FIGURE 3 **Relationship of fleet size to vehicle cost.**

TABLE 5 Sensitivity Analyses, 30-Year NPV (Dollars)

	Fleet Size				
	1-10	11-20	21-30	31-50	51 & up
Discount Rate					
10%	-109,264	-125,735	-150,013	-177,842	-298,171
5%	-117,221	-125,761	-137,188	-152,977	-239,988
Zero	-118,769	-96,155	-69,406	-44,432	-25,110
Natural Gas Price					
$0.076/m³ ($2.50/mcf)	-109,264	-125,735	-150,013	-177,842	-298,171
$0.030/m³ ($1.00/mcf)	-86,151	-89,930	-95,363	-102,528	-159,443
Free	-70,744	-66,059	-58,930	-52,319	-66,958
Maintenance Savings					
Zero Savings	-109,264	-125,735	-150,013	-177,842	-298,171
10% Savings	-100,182	-112,006	-128,749	-149,528	-237,391
25% Savings	-86,559	-91,413	-96,853	-107,056	-146,220
50% Savings	-63,854	-57,090	-43,693	-36,269	+5,730
Vehicle Miles of Travel					
No Increase	-109,264	-125,735	-150,013	-177,842	-298,171
25% Increase	-110,713	-125,870	-145,952	-179,534	-273,118
50% Increase	-110,518	-123,856	-142,121	-168,890	-266,253
100% Increase	-110,757	-120,608	-130,623	-153,655	-226,155
Effects of Diesel					
Diesel Included	-109,264	-125,735	-150,013	-177,842	-298,171
No Diesel	-77,941	-83,831	-102,480	-117,837	-234,104
Diesel to Gasoline	-82,619	-90,036	-107,787	-124,255	-243,599
Extended Vehicle Life					
No Added Life	-109,264	-125,735	-150,013	-177,842	-298,171
10% Added Life	-84,247	-100,982	-113,628	-126,631	-211,013
25% Added Life	-75,462	-90,903	-82,397	-83,063	-80,572
50% Added Life	-59,405	-64,007	-45,123	-15,819	+40,162
Effects of Dedicated Natural Gas OEM					
Purchased at Year 11	-109,264	-125,735	-150,013	-177,842	-298,171
Purchased At Year 1	-82,654	-80,510	-75,537	-76,025	-80,866
Year 1 Without Diesel	-65,334	-58,036	-50,059	-43,988	-47,147
Operating and Infrastructure Effects					
Base Case - No Changes	-109,264	-125,735	-150,013	-177,842	-298,171
Various Adjustments	-70,066	-77,877	-88,298	-102,924	-169,511
10% Extend Life, OEM at Year 1, No Replacement of Diesel Vehicles					
Base Case - No Changes	-109,264	-125,735	-150,013	-177,842	-298,171
Combined Effects	-49,893	-35,448	-19,963	+5,351	+36,436

($1.00/mcf) and free natural gas were used, as indicated in Tables 5 and 6.

Since the NPV results remained negative for all fleets with both scenarios, the break-even price for each of the fleets was estimated. Table 8 gives the break-even price for gasoline and diesel, assuming a natural gas price of $0.076/m³ ($2.50/mcf) and a constant 1.1 cents/L (4 cents/gal) price differential between gasoline and diesel. The gasoline/diesel prices include state taxes but not federal taxes.

Maintenance Savings

Anecdotal and theoretical evidence suggests that there may be maintenance savings associated with natural gas vehicles compared with gasoline/diesel vehicles. The range in savings is most likely from 10 to 20 percent. However, because of a lack of empirical support, the base case does not assume any savings in maintenance costs. The effects of maintenance savings for the sensitivity tests presented here are based on the actual average maintenance costs for the existing fleets reported in Table 3. Three savings rates (10, 25, and 50 percent) were selected. The results of these analyses are summarized in Tables 5 and 6. Significant maintenance savings are required to change the bottom line. Maintenance savings improve the results most dramatically for larger fleets. A 25 percent savings in maintenance costs for the smallest fleet would yield only a 21 percent reduction in the annual cost increase per vehicle but would result in a 51 percent reduction in the annual cost increase per vehicle for the largest fleet. More empirical support is needed to accurately account for reductions in maintenance costs.

Vehicle Use

The mileage estimates for each of the vehicle groups are based on current operations. If annual mileage were to increase, there would be improvements in the NPV in most cases. Three scenarios—25, 50, and 100 percent increase—were constructed to illustrate the effect of vehicle miles of travel on the model output. The results are summarized in Tables 5 and 6. The NPVs for the smallest fleet are counterintuitive and are a result of the timing of cash flows and the change in the number of years the vehicle is kept. Gasoline and diesel vehicles are assumed to operate for 90,000 and 150,000 mi, respectively. The ideal scenario is to replace a vehicle as close to the availability of OEM as possible, because of the beneficial effects of OEM vehicles, as described later. In general, the increased mileage per vehicle generates greater benefit than cost. Because of the various factors influencing the NPV (i.e., timing of introduction of OEM vehicles, fuel price, etc.),

TABLE 6 Sensitivity Analyses, Annual Cost Increase per Vehicle (Dollars)

	Fleet Size				
	1-10	11-20	21-30	31-50	51 & up
Discount Rate					
10%	-1,288	-889	-612	-510	-359
5%	-847	-545	-343	-269	-177
Zero	-440	-214	-89	-40	-10
Natural Gas Price					
\$0.076/m³ (\$2.50/mcf)	-1,288	-889	-612	-510	-359
\$0.030/m³ (\$1.00/mcf)	-1,015	-636	-389	-294	-192
Free	-834	-467	-240	-150	-81
Maintenance Savings					
Zero Savings	-1,288	-889	-612	-510	-359
10% Savings	-1,181	-792	-525	-429	-286
25% Savings	-1,020	-646	-395	-307	-176
50% Savings	-753	-404	-178	-104	+7
Vehicle Miles of Travel					
No Increase	-1,288	-889	-612	-510	-359
25% Increase	-1,305	-890	-595	-515	-329
50% Increase	-1,303	-876	-580	-484	-321
100% Increase	-1,305	-853	-533	-441	-273
Effects of Diesel					
Diesel Included	-1,288	-889	-612	-510	-359
No Diesel	-2,067	-1,112	-604	-463	-323
Diesel to Gasoline	-974	-637	-440	-356	-294
Extended Vehicle Life					
No Added Life	-1,288	-889	-612	-510	-359
10% Added Life	-993	-714	-464	-363	-254
25% Added Life	-889	-643	-336	-238	-97
50% Added Life	-700	-453	-184	-45	+48
Effects of Dedicated Natural Gas OEM					
Purchased at Year 11	-1,288	-889	-612	-510	-359
Purchased At Year 1	-974	-569	-308	-218	-97
Year 1 Without Diesel	-1,733	-770	-295	-173	-65
Operating and Infrastructure Effects					
Base Case - No Changes	-1,288	-889	-612	-510	-359
Various Adjustments	-826	-551	-360	-295	-204
10% Extend Life, OEM at Year 1, No Replacement of Diesel Vehicles					
Base Case-No Changes	-1,288	-889	-612	-510	-359
Combined Effects	-1,323	-470	-118	+21	+50

average miles traveled per vehicle may not be as significant as reported in the previous TRB paper (*6*).

Diesel Vehicles

Conversion of diesel vehicles to natural gas is much more complicated than is conversion of gasoline vehicles to natural gas. (During the model development, there was not a widely accepted conversion kit available for diesel vehicles.) In addition, because of the efficiencies of the diesel engine, there are important losses in fuel economy when converting from diesel to natural gas. Two analyses were performed on diesel vehicles to determine their effect on NPV. The first scenario removes diesel vehicles from the fleet analysis. The second treats existing diesel vehicles like heavy-duty gasoline vehicles and converts them to natural gas along with the other gasoline vehicles. The results of these scenarios are given in Tables 5 and 6. Conversion of diesel vehicles has a negative effect on NPV. On an annual cost increase per vehicle basis, the costs for the removal of diesel vehicles improve for the three largest fleet groups and decrease for the two smallest fleet groups, again because of the nature of fixed refueling facility costs on a small number of vehicles. Not surprisingly, replacing diesel with gasoline (spark ignition) vehicles before converting to CNG use decreases the annual cost increase per vehicle. Overall, converting diesel vehicles, as they currently exist, has a negative effect on cost-effectiveness. There is more to gain in converting gasoline vehicles than diesel vehicles.

Extended Vehicle Life

Some natural gas proponents argue that because natural gas burns cleaner than gasoline and diesel, vehicles using natural gas should have a longer operating life. Although this contention is not fully supported by operating data to date (because of less experience with CNG vehicles and converted rather than dedicated OEM vehicles), the model can be adjusted to evaluate the impact of extending the life of vehicles. Three scenarios (10, 25, and 50 percent extended life) were analyzed and the results summarized in Tables 5 and 6. The model results were adjusted to accommodate the differences in the number and timing of vehicle purchases. For example, the fleet group of 1 to 10 vehicles requires the purchase of one automobile every 4 years, or eight automobiles over the 30-year life cycle. Extending the life by 50 percent, however, requires the purchase of one natural gas automobile every 6 years, or five vehicles over the 30-year life cycle. Each of the fleet size groups was adjusted to reflect the additional savings

TABLE 7 Savings and Costs—Summary of Base Case

	Fleet Size				
	1-10	**11-20**	**21 - 30**	**31 - 50**	**51 and up**
SAVINGS					
Gasoline Price Difference	$32,193	$62,402	$113,695	$159,615	$346,548
Automobiles	$6,069	$6,586	$9,395	$12,829	$54,998
Light Trucks	$15,782	$33,879	$73,711	$108,741	$254,291
Heavy Duty Trucks	$10,342	$21,936	$30,588	$38,045	$37,259
Diesel Price Difference	$18,346	$22,327	$25,183	$34,468	$35,568
Maintenance	$0	$0	$0	$0	$0
Total Savings	**$50,540**	**$84,729**	**$138,878**	**$194,083**	**$382,116**
COSTS					
Infrastructure					
Land	$0	$0	$0	$0	$0
Station setup	-$15,880	-$18,585	-$22,556	-$26,920	-$39,499
Compressor	-$21,193	-$22,609	-$24,666	-$26,983	-$34,169
Storage Vessels	-$15,876	-$24,915	-$38,245	-$52,759	-$94,415
Dispenser	-$24,857	-$24,857	-$24,857	-$24,857	-$24,857
Dryer	-$9,943	-$9,943	-$9,943	-$9,943	-$9,943
Subtotal	-$87,747	-$100,908	-$120,267	-$141,462	-$202,882
Vehicle					
Conversion Kit	-$7,749	-$12,504	-$20,141	-$27,960	-$62,612
Tanks	-$9,895	-$16,853	-$27,632	-$38,639	-$77,568
Labor	-$11,026	-$17,170	-$26,966	-$36,895	-$85,118
OEM	-$5,178	-$6,199	-$9,186	-$13,853	-$20,986
Subtotal	-$33,848	-$52,725	-$83,925	-$117,348	-$246,284
Operating					
Station Maintenance	-$5,650	-$8,753	-$13,359	-$18,411	-$33,913
Cylinder Recert.	-$1,927	-$3,666	-$6,274	-$8,326	-$19,242
Power	-$13,846	-$17,473	-$22,902	-$28,825	-$46,907
Labor - fuel time loss	-$7,976	-$11,756	-$18,306	-$25,457	-$54,767
NG Fuel Tax	-$8,809	-$15,184	-$23,857	-$32,098	-$76,292
Additional Training	$0	$0	$0	$0	$0
Subtotal	-$38,208	-$56,831	-$84,699	-$113,117	-$231,120
Total Costs	**-$159,803**	**-$210,464**	**-$288,890**	**-$371,926**	**-$680,287**
Savings - Cost	**-$109,264**	**-$125,735**	**-$150,013**	**-$177,842**	**-$298,171**
Annual Cost Increase per Vehicle	-$1,288	-$889	-$612	-$510	-$359
Incremental Cost/mile	-$0.0903	-$0.0669	-$0.0491	-$0.0418	-$0.0323

from fewer and later vehicle purchases. The effect of extending vehicle life can be significant. For example, in the largest vehicle group a 25 percent increase in vehicle life results in a 75 percent increase in the 30-year NPV. Again, these improvements may be somewhat offset by increased maintenance costs on components not affected by fuel type (such as drivetrain, brakes, transmission, etc.). Only close monitoring and evaluation of NGVs over time will validate the overall effect of extended vehicle life.

OEM Vehicles

The base case analysis provides for the availability of OEM vehicles in Year 11. Actual purchase of OEM vehicles is dependent on vehicle replacement for each fleet. Two scenarios were analyzed with respect to the introduction of OEMs. The first assumes OEM vehicles are available in Year 1 for spark ignition (gasoline) vehicles and in Year 6 for diesel vehicles. The second converts only gasoline vehicles in Year 1 (i.e., there are no diesel conversions). The results of the two scenarios are summarized in Tables 5 and 6. Improvements in the NPVs for OEM are driven by three factors. First, and most significant, the OEM cost differential is $900 for spark ignition vehicles ($2,800 for diesel) compared with $1,950, $2,200, and $3,300 for gasoline-converted CNG automobiles, light trucks, and heavy-duty trucks, respectively ($6,350 for diesel). (The OEM price estimates are based on a mature market, which in the base case is estimated to occur at about Year 11. Current OEM prices, based on a limited supply of vehicles, are much higher.) For all fleet sizes, this OEM/conversion cost differential accounts for at least 55 percent of the improvement in the NPV. The second factor relates to the improvement in fuel efficiency of an OEM vehicle versus a converted vehicle.

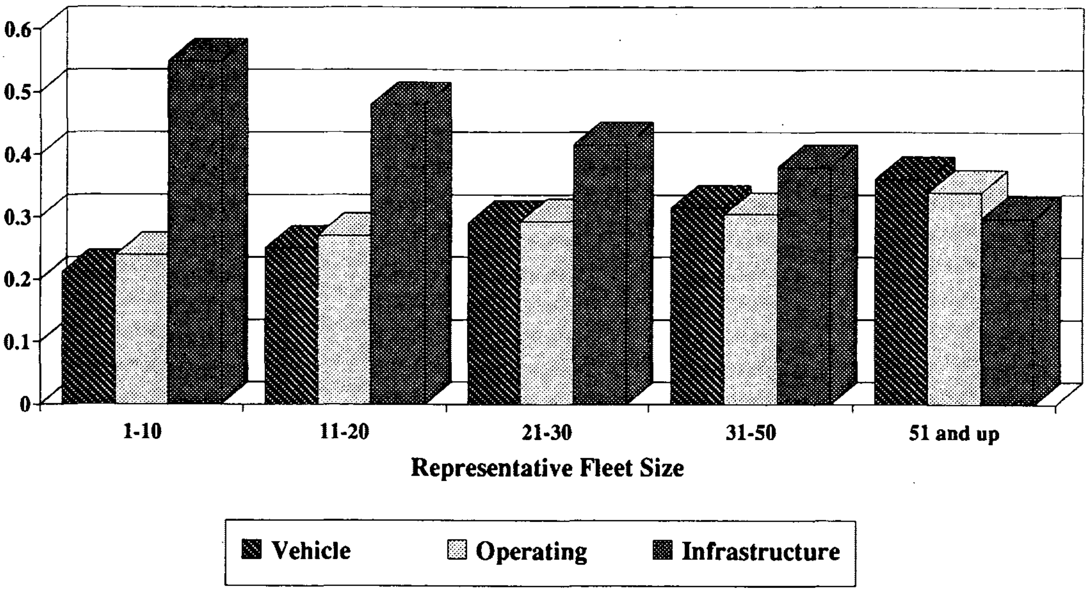

FIGURE 4 Cost component distributions for vehicle fleets.

The model incorporates a 5 percent reduction in fuel economy for converted gasoline vehicles versus a 15 percent improvement in fuel economy for an optimized OEM vehicle. Similarly, the model uses a 26 percent reduction for converted diesels versus a 20 percent reduction for optimized OEMs replacing diesels. The improvements in fuel efficiency translate into lower infrastructure costs and operating costs, in addition to increased fuel savings. The final factor relates to recertification. The model assumes that recertification costs will be factored into vehicle inspection costs for OEM vehicles and that the current requirements for tank removal on converted vehicles will not be necessary. Consequently, OEMs have no incremental costs associated with cylinder recertification. This also translates into additional natural gas consumption, which increases the savings differential, since the model assumes that converted vehicles must operate on gasoline during recertification of their pressurized storage vessels.

The results indicate that, for smaller fleets, replacement of diesel vehicles with OEM vehicles reduces the annual cost increase per vehicle. For larger fleets, replacement of diesel vehicles increases the annual cost increase per vehicle. The larger fleets are more indicative of the effects of introducing OEM vehicles to replace diesels. The improvement in the annual cost increase per vehicle for the smaller fleets is driven by the fixed infrastructure costs. However, as fleet size increases, these fixed costs become less significant and variable costs become more important. Arguably (considering only fleet economics, and not air quality benefits, etc.), replacement of vehicles, regardless of fleet size, should focus on gasoline and not diesel vehicles. This strategy could change as improvements in natural gas engines are made for diesel vehicles.

TABLE 8 NPV Break-Even Price for Gasoline and Diesel

	Gasoline		Diesel	
Fleet Group	($/liter)	($/gallon)	($/liter)	($/gallon)
1-10	0.52	1.96	0.51	1.92
11-20	0.44	1.65	0.43	1.61
21-30	0.39	1.46	0.38	1.42
31-50	0.36	1.38	0.35	1.34
51 & up	0.35	1.32	0.34	1.28

Operating and Infrastructure Costs

The previous sensitivity tests focused, principally, on vehicle parameters; this subsection examines some of the basic assumptions regarding operating and infrastructure costs. Taken individually, these various cost items are not significant. Therefore, several of the cost items will be analyzed in combination to determine their collective effect on NPV.

On the basis of a literature review, our research found that station maintenance cost estimates range from 3 to 10 cents per gallon equivalent of CNG. The base case for the model assumes a maintenance cost of 4.5 cents per CNG gallon equivalent. Three cents per gallon equivalent is used in this sensitivity test.

With respect to power costs, the model assumes that the maximum possible energy is used by the compressor (i.e., the motor draws full power whenever operating). The actual energy usage should be less, since the motor only draws full power when the back pressure of the storage vessels is near maximum. The base case rate of 6.3 cents/kW-hr of electricity is reduced to 2 cents/kW-hr for sensitivity purposes.

Cylinder recertification costs, although not significant relative to the other operating costs, affect savings and other infrastructure costs. For sensitivity purposes, recertification requirements and costs of CNG pressure vessels are eliminated.

Finally, in estimating the labor costs associated with additional refueling, $15/hr is used for the base case. The sensitivity tests use $7.50/hr. Likewise, two infrastructure cost items—dispenser and dryer—are reduced by 50 percent. The base case for the model assumes $25,000 and $10,000 for the dispenser and dryer, respectively.

The results of these changes in operating and infrastructure costs are summarized in Tables 5 and 6. Collectively, the changes in the operating and infrastructure cost assumptions reduce the average annual cost increase per vehicle by about one-third for each of the fleet groups. There are no changes in the conclusions for any of the fleet groups.

Selected Combined Effects

The next area of sensitivity examines the effects of combining some of the previous factors. The three most logical factors to combine are extended vehicle life, replacement with OEM vehicles, and nonconversion of diesel vehicles. Although there is a strong case for including maintenance savings, it is unlikely that there would be net maintenance savings for a vehicle with an extended life. Traditionally, maintenance costs for vehicles increase exponentially over time. In fact, there may be a stronger case for arguing that total maintenance costs will increase if a vehicle is kept for a longer time. In this analysis, we assume that maintenance savings are offset by the increased life of the vehicle. The results of the combined analysis are given in Tables 5 and 6.

As noted previously in the discussion of diesel vehicles, fixed costs are the most significant costs affecting the annual cost increase per vehicle for the two smallest fleets. These fixed costs are significant enough that introduction of diesel vehicles improves the overall cost-effectiveness, which is not the case for the larger fleets. The same is true for the combined analysis. Unlike the larger fleets, introduction of diesel vehicles actually reduces the annual cost increase per vehicle for the two smallest fleets—from −$1,323 to −$674 and from −$470 to −$390 for fleets of 1 to 10 and 11 to 20 vehicles, respectively.

CONCLUSIONS

On the basis of the operating assumptions of the model, introduction of natural gas vehicles into the TxDOT fleet will cost an estimated $47 million over the next 30 years, or $5 million annually. On the basis of the sensitivity analyses, costs could be held to a minimum by focusing on conversion of the larger fleets, utilization of OEM vehicles whenever practicable, and the delay of diesel conversions. TxDOT should continue to closely monitor its vehicles to determine the effects of natural gas on maintenance costs and resulting opportunities for holding the vehicles for a longer period of time. Extending the operating life of vehicles can have a pronounced effect on vehicle costs by reducing the number of vehicle purchases over time.

The sensitivity tests provide insight into the significance of various model parameters. By focusing on the larger fleets (i.e., fleets with more than 30 vehicles), TxDOT could realize some cost savings, if the combined effects presented in the previous section hold true. Assuming a more mature OEM market (i.e., CNG vehicles for gasoline replacements cost only $900 more per vehicle), a 10 percent extended life with no additional maintenance costs, and no diesel conversions, TxDOT could save about $180,000 annually. Moreover, this group of fleets accounts for about 53 percent of the vehicles listed in Table 2. Increasing the range to include vehicles in smaller fleets and diesel vehicles means that TxDOT will require additional outlays to support a CNG-vehicle program.

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