Technical Report

October 2000 • NREL/TP-540-29226

SuperShuttle CNG Fleet Evaluation

Final Report

Leslie Eudy

National Renewable Energy Laboratory

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Golden, Colorado 80401-3393

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Acronyms and Abbreviations

AFV	Alternative fuel vehicle
ANOVA	Analysis of variance
AQIRP	Auto/Oil Air Quality Improvement Research Program
CAAA	Clean Air Act Amendments of 1990
CFV	Clean Fuel Vehicle
CFR	*Code of Federal Regulations*
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
Cold CO	Cold driving cycle (20° F)
CRADA	Cooperative Research and Development Agreement
DIA	Denver International Airport
DOE	Department of Energy
EPA	Environmental Protection Agency
ETC	Environmental Testing Corporation
FTP-75	Federal Test Procedure
gge	Gasoline gallon equivalent
GRI	Formerly Gas Research Institute
GTI	Gas Technology Institute (formed by joining of GRI and the Institute of Gas Technology)
HC	Hydrocarbon
ILEV	Inherently low emission vehicle
LDT	Light Duty Truck
LDT4	Light Duty Truck class 4
LEV	Low emission vehicle
LPG	Liquified petroleum gas
mpeg	Miles per equivalent gallon
mpg	Miles per gallon
mph	Miles per hour
NMHC	Non-methane hydrocarbon
NMOG	Non-methane organic gases
NOx	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
OTT	Office of Transportation Technology
RFA	National average reformulated gasoline
rpm	Revolutions per minute
RVP	Reid Vapor Pressure
SFTP	Supplemental Federal Test Procedure
SHED	Sealed Housing for Evaporative Determination
SULEV	Super ultra low emission vehicle
THC	Total hydrocarbon
UDDS	Urban dynamometer driving schedule
ULEV	Ultra low emission vehicle
US06	Aggressive driving schedule

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Introduction

The mission of the U.S. Department of Energy's (DOE) Office of Transportation Technologies (OTT) is to promote the development and deployment of transportation technologies that reduce U.S. dependence on foreign oil, while helping to improve the nation's air quality and promoting U.S. competitiveness. In support of this mission, DOE has directed its National Renewable Energy Laboratory (NREL) to conduct projects to evaluate the performance and acceptability of alternative fuel vehicles (AFVs). NREL has undertaken several fleet study projects, which seek to provide objective real-world fleet experiences with AFVs. For this type of study we collect, analyze, and report on operational, cost, emissions, and performance data from AFVs being driven in a fleet application. The primary purpose of such studies is to make real-world information on AFVs available to fleet managers and other potential AFV purchasers. Fleet representatives who are considering AFVs can use this information to help them make informed decisions about what type of fuel or vehicle will best meet their needs.

This fleet study was jointly sponsored by Gas Technology Institute (GTI)[1] and the U.S. Department of Energy and was conducted for DOE's Field Operations Program by the National Renewable Energy Laboratory (NREL).

Project Participants

This project required the cooperation and support of several participants. Each participant and their respective roles are listed below.

SuperShuttle – Purchased and operated the vehicles, provided operational, mileage, and maintenance data.

GTI – Provided funding for the data collection and emissions testing as a joint project sponsor (through a Cooperative Research and Development Agreement, or CRADA, with NREL).

U.S. DOE – Provided funding for the data collection, analysis, and reporting as a joint sponsor.

Natural Fuels Company – Provided fueling stations, advised SuperShuttle on financial and technical issues and managed emissions contract.

National Renewable Energy Laboratory (NREL) – Coordinated and managed project as well as collected, analyzed, and reported operational, performance, and emissions data.

Ford Motor Company – Provided technical assistance and rebates.

Sill-Terhar Ford Dealership – Handled the vehicle orders and service.

Environmental Testing Corporation – Conducted emissions tests at prescribed mileage intervals.

[1] Gas Research Institute and the Institute of Gas Technology combined in April 2000 to form GTI.

Fleet Characteristics

SuperShuttle originated in Los Angeles in 1983 as a shuttle service that focused on shared ride door-to-door airport passenger service. The company currently services 23 airports, with 1,000 vehicles transporting more than 20,000 passengers each day. SuperShuttle has been operating in Colorado since mid 1996, serving the local community and Denver International Airport (DIA). Their fleet of 85 vehicles includes 18 AFVs, fueled by both liquefied petroleum gas (LPG) and compressed natural gas (CNG).

For this project, data was collected from 13 passenger vans operating in the Boulder/Denver, Colorado, area. The study vehicles were all 1999 Ford E-350 passenger vans based at SuperShuttle's Boulder location. Five of the vans were dedicated CNG, five were bi-fuel CNG/gasoline, and three were standard gasoline vans that were used for comparison. Table 1 summarizes the specifications of the study vehicles. Note that 1999 was the last year that Ford offered the E-series van for commercial sale with a bi-fuel option.

One of SuperShuttle's 15-passenger vans

Table 1. Vehicle Specifications

	Dedicated CNG	Bi-Fuel CNG	Gasoline
Make	Ford	Ford	Ford
Model	E350 Van	E350 Van	E350 Van
Model Year	1999	1999	1999
Engine Displacement	5.4L	5.4L	5.4L
Engine Configuration	V8	V8	V8
Engine Family Code	XFMXT05.4RP6	XG9XT05.46GN	XFMXH05.4BBF
Compression Ratio	9.1	9.1	9.1
Horsepower	200 @ 4500 rpm	200 @ 4500 rpm (CNG)/ 235 @4250 rpm (gasoline)	235 @ 4250 rpm
Fuel Tank Capacity	14 gge[1]	8.5 gge CNG/ 35 gal gasoline	35 gal
Certification Standard	CA SULEV[2] Federal ULEV/ILEV[3]	LEV[4] (CNG) Tier 1 (gasoline)	Tier 1[5]

[1] gasoline gallon equivalent
[2] California super-ultra low emission vehicle
[3] federal ultra-low emission vehicle/inherently low emission vehicle
[4] low emission vehicle
[5] based on engine dynamometer tests

SuperShuttle Boulder operated its vehicles three shifts per day, seven days per week. Although the 13 study vans were generally operated for at least one shift per day, some were used for two or three shifts. Drivers were not assigned a particular vehicle, but instead choose their vehicle at the beginning of each shift. The drivers were responsible for fueling their vehicles at the end of their shift. The gasoline and CNG fuel was obtained at public stations in the area. The closest station offering CNG is 3.2 miles from the SuperShuttle Boulder facility. This station was used for fueling the vans approximately 88% of the time during the study. The CNG station at the airport was used the remainder of the time.

The vans were operated in two basic types of service: in-town shuttle service around the Boulder area (mostly stop-and-go driving) and inter-city service between Boulder and DIA. The inter-city service between Boulder and DIA involved highway driving at higher speeds. Boulder is approximately 45 miles from DIA, and the vans were expected to accumulate about 70,000 miles per year. Figure 1 shows the service area covered by the study vans.

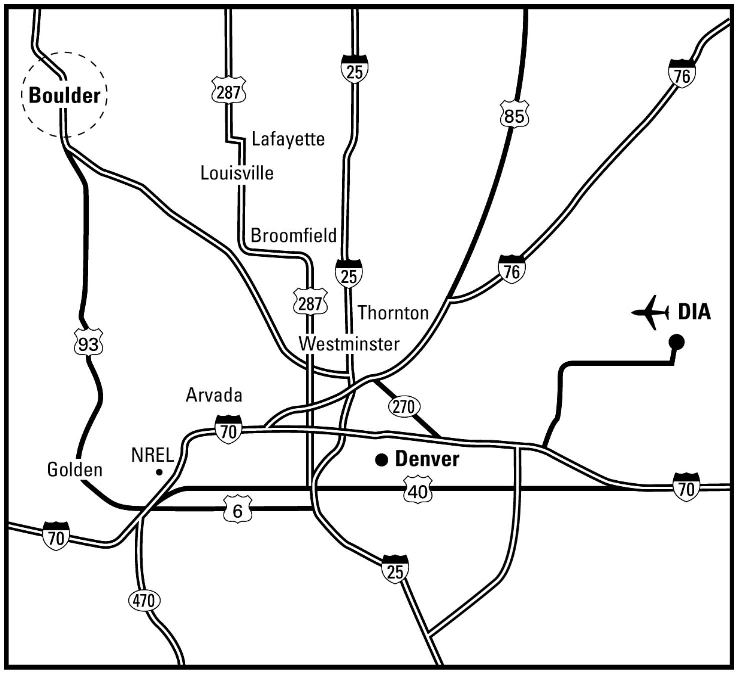


Figure 1. Service area for SuperShuttle Boulder

Data Collection and Evaluation

Operational Data

The operational data collected in the study include maintenance and repair records (scheduled and unscheduled), fuel usage and cost, and mileage records. These records were collected from several sources. Each month, SuperShuttle's shop manager supplied maintenance, repair, and mileage reports. At its Boulder location, SuperShuttle employs mechanics that perform all scheduled maintenance along with some unscheduled service. SuperShuttle follows the manufacturer’s recommended intervals for scheduled maintenance as closely as possible. At each service, mechanics change the oil and oil filter, perform any other scheduled service based on the vehicle mileage, and conduct a thorough inspection of the vehicle and its systems. Sill-Terhar Ford, located in Broomfield, Colorado, completed most of the warranty work and other unscheduled repairs. Copies of the work orders from both the SuperShuttle garage and from the Sill-Terhar dealership were part of the monthly data submission.

Natural Fuels, the local natural gas fuel provider, transferred the CNG fueling records to NREL electronically in a spreadsheet. Gasoline fuel records were submitted by SuperShuttle in hard copy form each month.

Vehicle drivers were responsible for fueling the vehicles they operated. SuperShuttle tracks fueling records on their vehicles using credit cards issued to each vehicle. Drivers use these cards in an electronic reader each time they fuel. Date and time of fueling as well as the amount and price of the fuel are automatically recorded for each transaction. The driver, however, inputs the odometer reading. Because of this, accurate records depend on the diligence of each driver. Although drivers were informed of the importance of their part in the program, and encouraged to provide accurate odometer records, many of the records contained odometer readings that were obviously erroneous. The fuel economies calculated from those records resulted in both extremely high and often negative numbers. We used statistical methods to determine a reasonable range of acceptable values for each of the dedicated vans. Values that fell out of that range were eliminated from the final calculation. The remaining "good" records were sufficient in number to provide confidence in the results.

Because the bi-fuel vehicles can be operated on either CNG or gasoline, calculation for fuel economy is more complicated. In this study, we elected to report average fuel economy for the bi-fuel vans based on combined CNG/gasoline usage. The average fuel economy was calculated based on monthly odometer readings reported by SuperShuttle's Shop Manager and total fuel used for each month.

Emissions Testing

Three rounds of emissions tests were performed on the 13 study vans. These tests followed the EPA's Federal Test Procedure (FTP-75). Results from FTP-75 tests typically include non-methane hydrocarbons (NMHC), carbon monoxide (CO), oxides of nitrogen (NOx), methane (CH_4), and carbon dioxide (CO_2). A detailed description of the procedure can be found in the *Code of Federal Regulations* (CFR 40 Part 86, http://www.epa.gov/epacfr40/cfr40toc.htm). Environmental Testing Corporation (ETC) in Aurora, Colorado performed all emissions tests. The tests were scheduled at odometer levels of approximately 10,000 miles, 40,000 miles, and 70,000 miles over the course of the year-long data collection. Because of the slower than expected mileage accumulation of the dedicated CNG vans, the Round 3 scheduled odometer target was lowered to 60,000 miles. During the second round of testing, three vans of each type were subjected to more detailed testing, which included an evaporative test, and additional tests to measure emissions under aggressive driving (US06) and cold conditions (Cold CO). Table 2 gives the matrix of tests performed.

Table 2. Emissions Test Matrix

Vehicle Type	Fuel	Round 1	Round 2			Round 3
		10,000 miles	40,000 miles			60,000 miles
		# FTP-75	# FTP-75	# US06	# Cold CO	# FTP-75
Dedicated CNG	CNG	5	5	3	3	5
Bi-fuel CNG	CNG	5	5	3	3	5
	Gasoline	5	5	3	3	5
Gasoline	Gasoline	3	3	3	3	3

Detailed Test Procedures during Round 2

The Clean Air Act Amendments of 1990 (CAAA) included requirements to review and revise, as necessary, the regulations for motor vehicles to insure that they were effective in meeting the National Ambient Air Quality Standards. During the review of the FTP-75 procedure, EPA determined that the driving conditions used in the test were not representative of the current driving styles prevalent in the country. As a result, a Supplemental Federal Test Procedure (SFTP) was designed to address the shortcomings of the procedure. The SFTP took effect for a percentage of vehicle models beginning with the 2000 model year. The four elements addressed were aggressive driving (high speed and/or high accelerations), microtransient driving (rapid speed fluctuations), emissions during air conditioner operation, and driving immediately following startup of the vehicle. Two procedures were developed to represent these conditions: the US06, to represent aggressive and microtransient driving, and the SC03, to account for air conditioner operation, microtransient driving, and driving immediately after startup. The US06 driving cycle is 600 seconds long with a high speed of 80.3 mph. The FTP-75, for comparison, is 2457 seconds long with a high speed of 56.7 mph. The SC03 driving cycle is performed at 95° F, and is 596 seconds long. The high speed is 54.8 mph, and the average speed is 21.5 mph. (Note: because of budget constraints, the SC03 emissions test was not performed during this evaluation.) The FTP-75 includes cold-start emissions, while the US06 and SC03 are performed after the vehicle is warmed up. The driving cycles used in the study are shown in Appendix A.

As a part of the CAAA, EPA also established certification standards and test procedures for cold CO emissions. These regulations took effect for vehicles beginning in the 1994 model year. The regulations were in response to CO levels that exceed those mandated by the National Ambient Air Quality Standards primarily occurring between the months of November and February. In a cold CO test, the vehicle is driven over the same cycle as the FTP-75, but at a temperature of 20° F. The fuel used is a typical winter grade gasoline adjusted for Reid Vapor Pressure (RVP). The EPA standard for cold CO emissions is 12.5 g/mi for light-duty trucks (LDTs) with a loaded vehicle weight of over 3,750 lbs.

In addition to the Cold CO and US06 tests, the study vehicles were subjected to an evaporative emissions procedure known as the hot soak. Immediately after the dynamometer test, the vans were driven into a Sealed Housing for Evaporative Determination (SHED), which measures emissions from the engine and vehicle systems as it cools. Natural gas vehicles are designed with a sealed system and should have no evaporative emissions. Because of this, dedicated CNG vehicles do not have the evaporative emissions controls used on gasoline vehicles.

Test Fuel

The gasoline fuels used in the emissions testing were obtained from Phillips Petroleum Company. Using the same blend of test fuel ensures an accurate comparison between vehicles. Prior to testing, each vehicle was subjected to a fuel changeover procedure designed to minimize carryover effects from the fuel in the tank. This procedure follows the Auto/Oil Air Quality Improvement Research Program's (AQIRP) vehicle testing procedures. The gasoline test fuel, referred to as RFA, represents an industry-average blend. Fuel for cold tests must be adjusted to a winter-grade fuel. Table 3 gives some of the properties of the gasoline test fuels used in this program.

The CNG test fuel was taken from the fueling station located at DIA. The CNG from this station is similar to that of the national average and is closely monitored throughout the year. A single batch of fuel for each round was taken from the site and stored in a fuel trailer for use by the test lab. Quality control analysis was performed on a sample of each batch. Table 4 gives the composition of the CNG fuel used during the second round.

The dedicated vans (CNG and gasoline) were tested on their respective fuels; the bi-fuel vans were tested on both CNG and RFA.

Table 3. Gasoline Test Fuel Specifications

Fuel Properties	RFA	Cold CO
Specific Gravity	0.75	0.73
Sulfur (ppm)	328	334
Reid Vapor Pressure (pounds/square inch)	8.9	11.5
Aromatics (% by volume)	33.2	26.2
Olefins (% by volume)	10.1	9.7
Saturates (% by volume)	56.7	64.1

Table 4. Composition of the CNG Test Fuel

Compound	Mole %
Methane	91.74
Ethane	4.46
Propane	0.83
Isobutane	0.11
N-Butane	0.13
Isopentane	0.04
N-Pentane	0.03
Hexanes+	0.04
Balance (Nitrogen + Carbon Dioxide)	2.62

Fleet Experience

In order to get a complete picture of this fleet's experience with integrating AFVs into their operations, more subjective data was also collected. This included documenting the steps SuperShuttle had taken to obtain and put the vehicles into service, as well as fleet personnel and customer's perceptions and opinions about AFVs. This information will aid fleet managers and other potential customers in making the decision about adding AFVs to their fleets. Interviews were conducted with the fleet's management before the project started and also at it's conclusion. We also conducted a customer survey to determine the level of knowledge and acceptance of AFVs by members of the general public who used the SuperShuttle service.

Summary of Results

Vehicle Use

By the end of March 2000, the study vans had accumulated between 41,275 miles and more than 70,000 miles. Table 5 lists vehicle usage during the 12-month data collection period. The gasoline vans accumulated the most miles and the dedicated CNG vans accumulated the fewest miles. The gasoline vehicles had higher total miles in part because they arrived several weeks before the first AFVs and were put into service immediately. The calculations for average monthly mileage listed in the table include the mileage from April 1999 through March 2000. The average monthly mileage accumulation for both the gasoline and the bi-fuel vans was higher than that of the dedicated CNG vans. The gasoline vans averaged 5,493 miles per month and the bi-fuel vans averaged 5,161 miles per month, while the dedicated vans averaged only 3,692 miles per month. The gasoline and bi-fuel CNG vans were used in a similar percentage of short in-town and longer airport trips. However, mainly because of the fleet's concern with vehicle range, the dedicated CNG vans were used mostly in local service around Boulder, resulting in shorter trips and lower overall mileage accumulation.

Table 5. Vehicle Mileage Data

ID number	Vehicle Type	Final mileage	Miles Accumulated Apr 99-Mar 00	Total Months in service	Avg. Miles Accumulated per Month
231	Gasoline	68797	61179	12	5098
232	Gasoline	65793	58609	12	5483
233	Gasoline	70774	64772	12	5898
	Average		**61520**		**5493**
234	Dedicated CNG	50213	47882	12	3990
235	Dedicated CNG	41275	38929	12	3244
236	Dedicated CNG	49009	47348	12	3946
237	Dedicated CNG	46093	44247	12	3687
238	Dedicated CNG	44695	43105	12	3592
	Average		**44302**		**3692**
239	Bi-fuel CNG	65087	63014	12	5251
240	Bi-fuel CNG	62667	62059	12	5172
241	Bi-fuel CNG	55989	55367	12	4614
242	Bi-fuel CNG	69213	68499	12	5708
243	Bi-fuel CNG	61285	60695	12	5058
	Average		**61927**		**5161**

Fuel Economy and Cost

At the beginning of the data collection, only 2 of the CNG fueling cards were set up to prompt the driver for mileage. As a result, most of the records during the first 3 to 4 months of the project were not complete for the CNG vans. In order to make a fair comparison; fuel economy and fuel cost results are based on fueling records from July 1999 through March 2000. During this time period, the records are complete for the vans with one exception. Records for two of the dedicated CNG vans were mistakenly combined for several months. Unit 237 was credited for twice as many fueling records as usual, while unit 234 had no records. Because there was no way to determine which records belonged to which vehicle, these months were eliminated from the calculations for those vans only.

Table 6 summarizes the fuel economy and cost data for the study vans. The average fuel economy and fuel costs are listed for each van type. (Average fuel economy and cost for each vehicle can be found in Appendix B, Table B1.) As previously noted, the fuel economy for the bi-fuel vans is a combined CNG/gasoline value. Percentage of CNG use varied by month for each of the bi-fuel vehicles, from a low of 1.3% to a high of 74%. During the July 99 – March 00 time period, the bi-fuel vehicles averaged 28.3% CNG use by volume. (See table B2 for the percentages by vehicle.)

Table 6. Fuel Economy Data Summary (July 99 – March 00)

Vehicle Type	Average Fuel Economy (mpeg)	Fuel Cost (cents per mile)
Dedicated CNG	10.6	8.16
Bi-Fuel CNG*	11.6	10.06
Gasoline	11.7	11.43

* based on combined CNG and gasoline fuel economy

Comparisons between vehicle types show that the dedicated CNG vans had a lower average fuel economy than the gasoline or the bi-fuel vans. This could be the result of the lower percentage of highway driving on the dedicated CNG vans. With an average fuel economy of 10.6 mpeg (miles per equivalent gallon of gasoline), the dedicated CNG vans should have a range of around 148 miles per fill. Although this was more than enough for a round trip to the airport, drivers did not always have adequate time in their schedules to fuel between trips. Fuel economy for the bi-fuel vans was similar to that of the gasoline vans. Cost of fuel, however, shows an economic advantage for the dedicated CNG vans. The fuel cost of the dedicated vans was 8.16 cents per mile. This was 28.6% lower than the cost of the conventional gasoline vans and approximately 19% lower than the bi-fuel vans. The bi-fuel vans cost 10.06 cents per mile to fuel, which was approximately 12% lower than the cost for the gasoline vans. During the data collection period, the price of CNG was very stable. CNG prices ranged from a low of $0.85 to a high of $0.91 per gge with an average of $0.86. Although gasoline prices were low when the study began, there was a steady increase over the 12-month data collection period. Gasoline prices ranged from a low of $0.91 to a high of $1.48 per gallon, with an average of $1.21 per gallon. Figure 2 shows SuperShuttle's average cost of CNG and gasoline each month during the study.

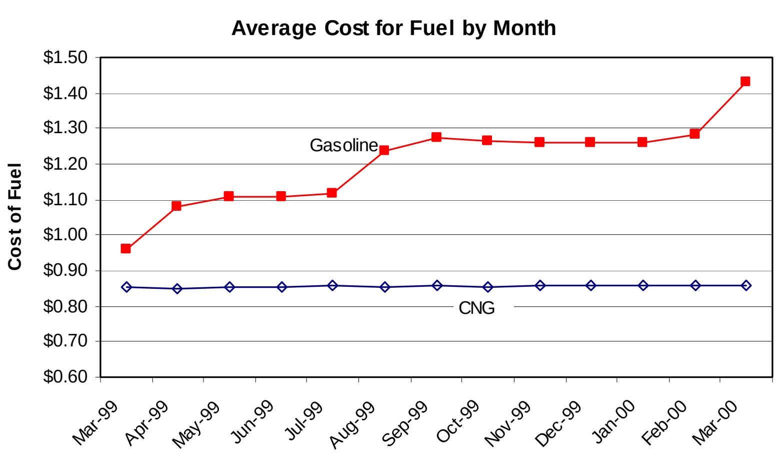


Figure 2. Average cost of fuel during the study

Maintenance Cost

The maintenance records for each van were collected throughout the evaluation period. At the end of the study, the average miles for both the gasoline and bi-fuel vans were about 15,000 miles higher than the average mileage for the dedicated CNG vans. To make an equitable comparison between the types, the analysis was conducted on records through the 50,000-mile service. Separate totals for each vehicle can be found in Appendix B.

The maintenance records were separated into several categories:
- Scheduled maintenance – oil changes, air filter changes, transmission services, tire rotation
- Unscheduled maintenance – brake service, alignments, injector flushes
- Tires & Windshields – tire and windshield replacement
- Warranty – all repairs covered under the manufacturer warranty

SuperShuttle operates a service shop at their Boulder facility, where they perform all scheduled maintenance and some unscheduled maintenance on their fleet. Ford recommends a scheduled oil change interval of 5,000 miles for the E350 vans. SuperShuttle takes a preventive maintenance approach with their vehicles. At each service, mechanics perform any scheduled maintenance that is due, such as oil and oil filter change, air filter change, or tire rotation. In addition to scheduled tasks, they perform a thorough check of the entire vehicle to determine if any other maintenance is necessary.

Table 7 shows the average service intervals for each type of van. The bi-fuel vans had the highest total number of service visits at 71, followed by the dedicated CNG vans with 64 visits, and the gasoline vans with 44 visits. The higher total services for the AFVs was expected because there were 5 each of the dedicated and bi-fuel vans, while there were only 3 gasoline vans. The average number of visits per vehicle was similar for the bi-fuel and gasoline vans, and slightly less for the dedicated CNG vans: 14.6 for the gasoline, 12.8 for the dedicated CNG, and 14.2 for the bi-fuel vans. The difference in service between the 3 types of van is shown in the number of days and miles between scheduled maintenance. The 3 gasoline vans were serviced an average of every 20 days, while the dedicated CNG vans were serviced every 40 days. This result is not surprising with the faster mileage accumulation of the gasoline vans. SuperShuttle maintenance personnel also noticed that used oil from the dedicated CNG vans appeared clean. For this reason, they lengthened the mileage between services for those vans. The bi-fuel vans were serviced at an interval similar to that of the dedicated CNG vans.

Table 7. Average Service Interval by Vehicle Type

	Type of Van		
	Dedicated CNG	Bi-fuel CNG	Gasoline
Number of vehicles	5	5	3
Total number of services	64	71	44
Average services/vehicle	12.8	14.2	14.6
Average number of days between service	40	26	20
Average number of miles between service	4577	4545	4023

The cost of tires was separated from the scheduled maintenance to prevent skewed results. SuperShuttle optimized the use of the tires on the 13 vans including spares. During the study, the gasoline vans acquired mileage quickly, requiring tire replacement before the other types of vans.

SuperShuttle used their extra tires, including spares from the other vans in the project, on those gasoline vans. Because of this, the tire replacement on the gasoline vans cost nothing, while tire replacement for the dedicated CNG vans included the price of all 4 tires. Therefore, tires were removed from consideration as a differentiating cost between vehicle types. Windshield replacement will vary from fleet to fleet, and was also removed to better reflect the actual cost of unscheduled maintenance. The state of Colorado uses a sand/gravel mix during winter weather conditions, resulting in a higher percent of cracked windshields than might occur in other areas of the country.

Table 8 gives the average maintenance and repair cost for each type of van in cents per mile. Comparison of scheduled maintenance between van types shows that both the dedicated CNG vans and the bi-fuel vans cost SuperShuttle less to maintain than the gasoline vans. Unscheduled maintenance was similar for the bi-fuel and the gasoline vans. The higher unscheduled maintenance cost for the dedicated CNG vans was due to injector flushes. (During the study, the dedicated CNG vans had a problem with contaminate build-up in the injectors which caused the check-engine-light to come on. For a detailed description of the problem, see the Fleet Experiences section later in the document.) If the cost for flushing the system were removed, the average unscheduled maintenance cost for the dedicated vans would drop to 0.45 cents per mile which is comparable to that of the bi-fuel and gasoline vans. Adding the scheduled and unscheduled maintenance costs produces a total cost of maintenance for the study vans. The results for this study show that the dedicated CNG vans cost only 1.4% more to maintain than the gasoline vans. The bi-fuel vans cost 11.8% less to maintain compared to the gasoline vans.

Table 8. Summary of Maintenance and Repair Costs in Cents per Mile

Vehicle Type	Dedicated CNG	Bi-Fuel CNG	Gasoline
Scheduled Maintenance	2.09	2.14	2.43
Unscheduled Maintenance	0.82	0.44	0.45
Total	2.91	2.58	2.87

It is important to note that the data presented in this report represent only one year of operation for the vehicles. SuperShuttle typically operates company owned vehicles in excess of 100,000 miles before they are retired. Maintenance comparison between the technologies could change as the vehicles age. Life cycle costs could be determined through a prolonged study. The drawback to multi-year projects is that by the time the results are published, the technology has changed so that the information is no longer current.

During the data collection period, one gasoline, 3 dedicated CNG, and 4 bi-fuel vans were taken to the dealership for warranty repairs. Warranty repairs were not included in the analysis because the manufacturer covered the costs. Although there was no direct cost to SuperShuttle as a result of these repairs, there would be a cost associated with excessive down time for the vehicles. Most of the repairs involved diagnosis of the check-engine-light problem. The most notable repair covered under warranty involved a leaking CNG filler valve. The filler neck/valve assembly was replaced on two dedicated CNG vans and one bi-fuel van. Details on the warranty repairs for the study vans are included in Tables B7 and B7a in Appendix B.

Total Operating Costs

Table 9 shows the average fuel and maintenance costs. These costs are combined to give total operating cost per mile for each type of vehicle. The average maintenance cost includes scheduled and unscheduled maintenance. Because the maintenance results were not significantly different for the study vehicles, in SuperShuttle's case, the cost difference was a direct result of fuel cost during the study. When you compare the total operating costs for the 3 van types, the dedicated CNG vans cost 11.07 cents per mile to operate, which was 22.6% less than the gasoline vans. The bi-fuel vans cost 12.62 cents per mile to operate, which was 11.6% less than the gasoline vans. Keep in mind that these results were based on (1) one year of data collection, (2) fuel price during the study period, and (3) the dedicated CNG vans being used in a smaller percentage of highway driving. If these results remain consistent over time, a fleet accumulating 70,000 miles on a vehicle per year could see cost savings of over $2000 per vehicle by operating dedicated CNG vans in their fleet instead of standard gasoline vans. SuperShuttle's Boulder operation typically sees accumulations of 60,000 to 70,000 miles on their vans in a year.

Table 9. Summary of Total Operating Costs (cents per mile)

Vehicle Type	Dedicated CNG	Bi-Fuel CNG	Gasoline
Average Fuel Cost	8.16	10.06	11.43
Average Maintenance Cost	2.91	2.58	2.87
Total Operating Costs	11.07	12.64	14.3

Emissions Testing Results

The natural gas study vehicles were classified as heavy light-duty trucks, class 4, (LDT4). The applicable EPA emissions standards are listed in Table 10. The dedicated CNG vans were certified to Federal ULEV standards and the bi-fuel vans were certified to LEV on CNG and Tier 1 on gasoline. The gasoline vans were certified to Tier 1 standards as a heavy-duty vehicle. Heavy-duty vehicles are not certified using a chassis dynamometer; rather, the engine is certified using an engine dynamometer. Results of the engine test are given in brake-horsepower hour, and are not comparable with grams per mile of a chassis test. Because these vehicles were tested using the same procedures, comparisons between vehicles can be made for this study.

Table 10. Federal Certification Exhaust Emissions Standards for Heavy Light-Duty Trucks

	5 years/ 50K miles				**11 years/ 120K miles**			
	NMHC	**NMOG**	**CO**	**NOx**	**NMHC**	**NMOG**	**CO**	**NOx**
Tier 1	0.39	-	5.0	1.1	0.56	-	7.3	1.53
LEV	-	0.195	5.0	1.1	-	0.28	7.3	1.5
ULEV	-	0.117	2.5	0.6	-	0.167	3.7	0.8

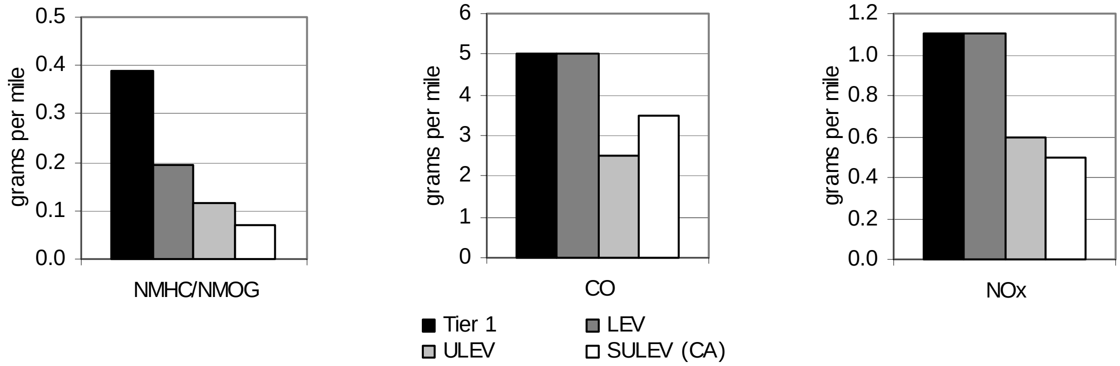


Figure 3. Regulated Emissions Standard – 5 years or 50,000 miles

Figure 3 shows a graphical representation of the standards at 50,000 miles or 5 years. The California super ultra-low emission vehicle (SULEV) standard is shown on the graphs for comparison.

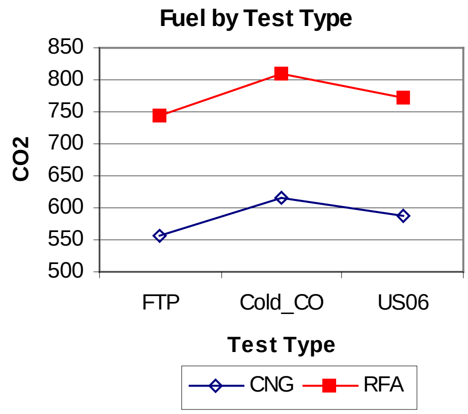
This section describes the results from the emissions testing done on the 13 study vans. The results are separated into two sections: comparison of the dedicated vans, and comparison of the bi-fuel vans tested on each fuel. The summary tables give the average emissions by vehicle type and fuel, the percent difference between these averages, and an indication of whether the difference was statistically significant at the 95% confidence level.

Percent difference was calculated using the following formula:

$$\frac{\overline{X}_{CNG} - \overline{X}_{RFA}}{\overline{X}_{RFA}} \times 100$$

where $\overline{X}$ is the average emissions test result for a vehicle type on the fuel indicated. A negative value indicates that the CNG test results are lower than the RFA results. The statistical significance was determined using JMP® software, which is a PC-based statistical analysis package developed by SAS Institute. Using this software, a multi-variable analysis of variance, or ANOVA, was performed. Four models were used in this analysis. Two models considered the FTP-75 results; one comparing the dedicated CNG vans to the gasoline vans, and one comparing the bi-fuel vans on each fuel. The effects tested for these models were test fuel, test round, and fuel x round (fuel by round interaction). The remaining two models were for the detailed study vehicles in Round 2 only. These models compared the effects of test type, test fuel, and fuel x test type; one model for the dedicated vans and another for the bi-fuel vans. The columns under the heading “Significance Tests” give the results of the analysis. A “y” in the fuel column indicates a difference in the average emissions between fuels that is statistically significant at the 95% confidence level, independent of other factors. For example, in Table 11 there is a “y” in the fuel column and an “n” in the round column for NMHC emissions. This indicates that the difference between fuels for the compound NMHC was significant, while the difference between the three rounds was not significant. A “y” in the fuel x round column indicates that there is a significant difference between the way each fuel reacts with respect to round. It is possible to have significant differences between the two major factors, but have no significant difference when the two factors are combined.

An example of this is shown in the figure on the right. There is a significant difference in CO_2 emissions between fuels for each test type, and between test type for each fuel. In this case, how the two fuels react with regard to test type is not significantly different.



Results for the gasoline vans were the average of the 3 vans tested during each round, the dedicated results were the average of 4 vans, and the bi-fuel results were the average of 5 vans. Although there were 5 dedicated CNG vans in the program, one of these vans did not reach the 60,000-mileage target in the allotted timeframe. To balance the data set for the statistical analysis, this van was dropped from the final calculations. Detailed results by vehicle, including the results from Rounds 1 and 2 on the dedicated CNG van that was removed, are located in Appendix A.

Summary of Results for the Dedicated Vans

A comparison of the FTP-75 results for the dedicated CNG and gasoline vans is shown in Table 11. Figure 4 gives a graphical representation of the regulated emissions and CO_2. The dedicated CNG vans clearly had significantly fewer emissions of the three regulated compounds than the gasoline vans. Average NMHC was 92% to 96% less, CO was approximately 94% less, and NOx was 70% to 96% less for the CNG tests. The differences between fuels for these constituents were all determined to be statistically significant at the 95% confidence level by the ANOVA analysis. The dedicated CNG vans tested well below the EPA certification standard (ULEV), which was included on the graphs for reference. This was true for all three regulated compounds in all rounds.

In addition to the overall lower average emissions for the CNG vans compared to the gasoline vans, there were also differences in how the emissions rates changed with increasing mileage for the two technologies. Testing the vehicles at different mileage intervals gives an indication of whether they show deterioration over time. Emissions for the dedicated CNG vans were fairly consistent during the study. The round-to-round changes in emissions for the dedicated CNG vehicles tended to be not statistically significant. The exception to this was the increase in NOx from Rounds 1 to 2, which was considered significant. The gasoline vehicles showed a marked increase in all three regulated compounds with increased mileage. This difference was statistically significant for NOx in all three test rounds, and for CO and NMHC between Rounds 2 and 3.

Emissions of CO_2 were 22% to 25% less for the CNG vans than their gasoline counterparts. Neither of the vans appeared to have deterioration over time with respect to CO_2 emissions. Methane emissions were significantly higher for the CNG vans in all three rounds. This is expected, since CNG fuel is primarily composed of methane (approximately 91% for the test fuel used). Although methane is a greenhouse gas, it is not regulated by the EPA because it is considered to be highly non-reactive in forming ozone in the atmosphere. The effects of round and fuel x round were considered significant for CH_4 emissions. The dedicated CNG vans showed a deterioration of CH_4 emissions over time, while the gasoline vans remained fairly constant.

Table 11. Summary of Average FTP Emissions for the Dedicated CNG and Gasoline Vans

	Test Round-mileage target*	Average Results		% Difference between fuels	Significance tests		
		CNG	RFA		Fuel	Round	Fuel x Round
Regulated Emissions (g/mi)							
NMHC	1 – 10K	0.012	0.298	-96.0	y	n	n
	2 – 40K	0.022	0.280	-92.1			
	3 – 60K	0.017	0.390	-95.6			
CO	1 – 10K	0.365	6.140	-94.1	y	y	y
	2 – 40K	0.338	5.873	-94.3			
	3 – 60K	0.500	9.067	-94.5			
NOx	1 – 10K	0.055	1.443	-96.2	y	y	y
	2 – 40K	0.560	1.903	-70.6			
	3 – 60K	0.490	2.763	-82.3			
THC	1 – 10K	0.115	0.357	-67.8	y	y	y
	2 – 40K	0.275	0.333	-17.5			
	3 – 60K	0.318	0.460	-31.0			
Greenhouse gases (g/mi)							
CO_2	1 – 10K	575.9	747.7	-23.0	y	y	y
	2 – 40K	555.7	743.0	-25.2			
	3 – 60K	562.8	720.6	-21.9			
CH_4	1 – 10K	0.103	0.063	61.8	n	y	y
	2 – 40K	0.253	0.053	373.4			
	3 – 60K	0.303	0.067	353.8			
Fuel Economy (mpg)							
Fuel Economy	1 – 10K	11.15	11.82	-5.7	y	y	n
	2 – 40K	11.55	11.9	-3.0			
	3 – 60K	11.77	12.18	-3.3			

* Round 1 @ 10,000 miles; Round 2 @ 40,000 miles; Round 3 @ 60,000 miles

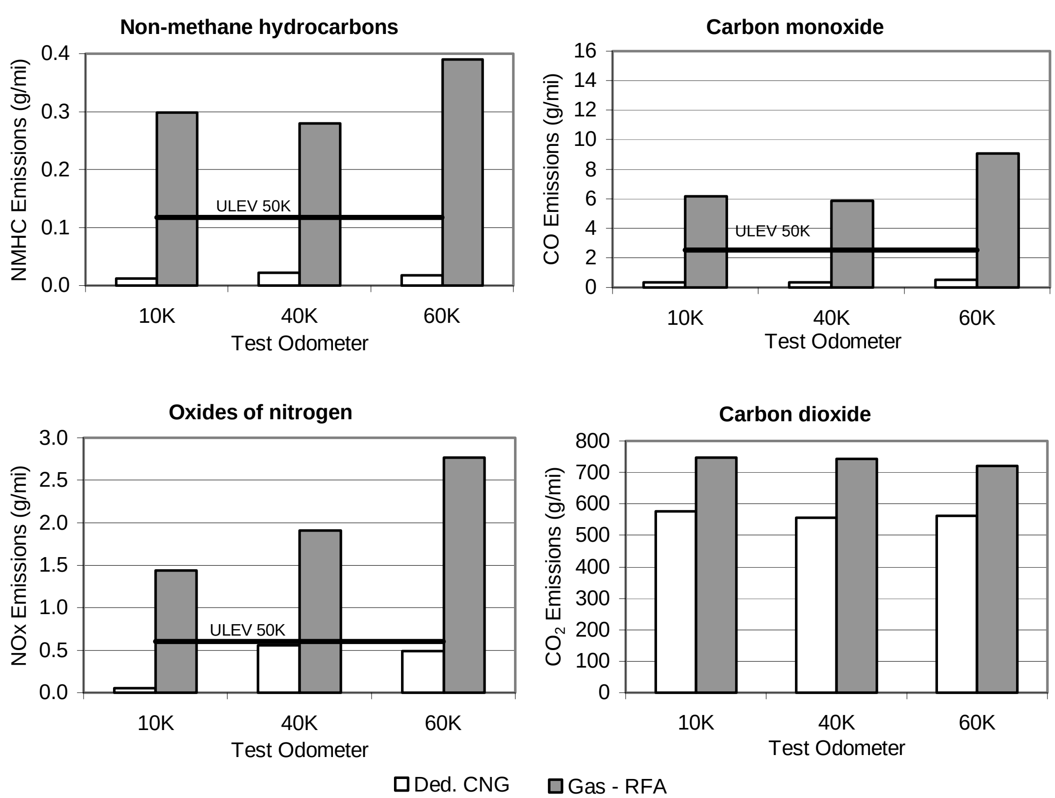


Figure 4. Average emissions for the dedicated CNG and gasoline vans

The EPA FTP-75 includes an urban fuel economy estimate. Table 11 lists the average fuel economy for the dedicated CNG and gasoline vans. Fuel economy for the dedicated CNG vans was between 3% and 5.7% lower than that of the gasoline vans. Although these percentages are small, they were determined to be statistically significant by the JMP analysis. Comparisons between the FTP-75 fuel economy and in-use fuel economy are difficult to make. The SuperShuttle vans were operated in mixed driving cycles that included highway as well as city cycles. As mentioned previously, the different types of van were not always operated in similar service; the dedicated CNG vans were used mainly in urban driving cycles, while the gasoline and the bi-fuel vans saw a larger percentage of highway driving. This could be a reason for the lower in-use fuel economy for the dedicated CNG vans. In addition, driving styles vary from operator-to-operator, which can have a significant effect on the resulting fuel economy. Passenger loading also would have an effect on fuel economy.

In addition to the FTP-75, during Round 2, three of each vehicle type were randomly selected for detailed tests to show how cold conditions and aggressive driving effected the vans emissions. The tables for the detailed study vans give the average results for the three tests on each fuel, the percent difference between fuels and the results of the ANOVA analysis. The effects tested for the ANOVA include fuel, test type, and fuel x test type. All five of the CNG vans were tested on the FTP-75 cycle but, in order to ensure a balanced data set, the FTP results shown in this table were the average of the three vans selected for detailed testing. Detailed results for each van are given in Appendix A.

Table 12 summarizes the results from the detailed study tests on the dedicated CNG and gasoline vans. Figure 5 shows the results graphically. The results show that, with the exception of CH_4, the dedicated CNG vans had the lowest emissions for all constituents on all driving cycles. The difference between fuels was significant for all compounds.

The difference in emissions between the FTP-75 and the Cold CO test show mixed results for the two fuels. Although there were increases in all emissions components for the dedicated CNG vans, only the increase in CO_2 was considered significant. This shows that the emissions of the dedicated CNG vans were not greatly affected by cold temperatures. The gasoline vans had mixed results. For these vans, NMHC and CO_2 emissions were significantly higher during the Cold test, while CO emissions were not significantly different, and NOx emissions were lower. The NOx emissions were 16% less for the Cold CO test, but this difference was not considered significant.

Results of the US06 test show how aggressive driving can have adverse effects on emissions for both the CNG and gasoline vans. Comparison between the FTP-75 and US06 results for the CNG vans show an increase in all measured emissions components for the aggressive driving cycle. Of these components, only the NMHC and CH_4 emissions were not significant. The CO emissions had the most pronounced increase, from 0.39 g/mile in the FTP-75 to 6.8 g/mile in the US06 test. Comparison between FTP-75 and US06 tests for the gasoline vans also showed increases in emissions for all components with the exception of CH_4. The percent increase in emissions for the gasoline vans during the US06 was less than those of the CNG vans, but the increases in CO, NOx, and CO_2 were all considered significant.

Table 12. Detailed Round 2 Study Emissions for the Dedicated CNG and Gasoline Vans

	Test Type	Average Results		% Difference between fuels	Significance tests		
		CNG	RFA		Fuel	Test Type	Fuel x Test Type
Regulated Emissions (g/mi)							
NMHC	FTP	0.024	0.280	-91.3	y	y	y
	Cold CO	0.027	0.670	-95.9			
	US06	0.043	0.378	-88.6			
CO	FTP	0.390	5.873	-93.4	y	y	y
	Cold CO	0.707	5.800	-87.8			
	US06	6.847	8.453	-19.0			
NOx	FTP	0.630	1.903	-66.9	y	y	y
	Cold CO	0.577	1.593	-63.8			
	US06	1.250	3.557	-64.9			
THC	FTP	0.290	0.333	-13.0	y	y	y
	Cold CO	0.363	0.730	-50.2			
	US06	0.377	0.428	-12.0			
Greenhouse gases (g/mi)							
CO_2	FTP	555.0	743.0	-25.3	y	y	n
	Cold CO	615.6	809.5	-24.0			
	US06	586.6	771.2	-23.9			
CH_4	FTP	0.300	0.053	393.8	y	n	n
	Cold CO	0.337	0.060	461.1			
	US06	0.334	0.050	562.2			
Fuel Economy (mpg)							
Fuel Economy	FTP	11.6	11.9	-2.9	y	y	y
	Cold CO	10.4	10.6	-1.7			
	US06	10.7	11.4	-5.8			
Evaporative Emissions (grams/test)							
Evaporative	Hot Soak	0.04	0.18	-77.6	n	n/a	n/a

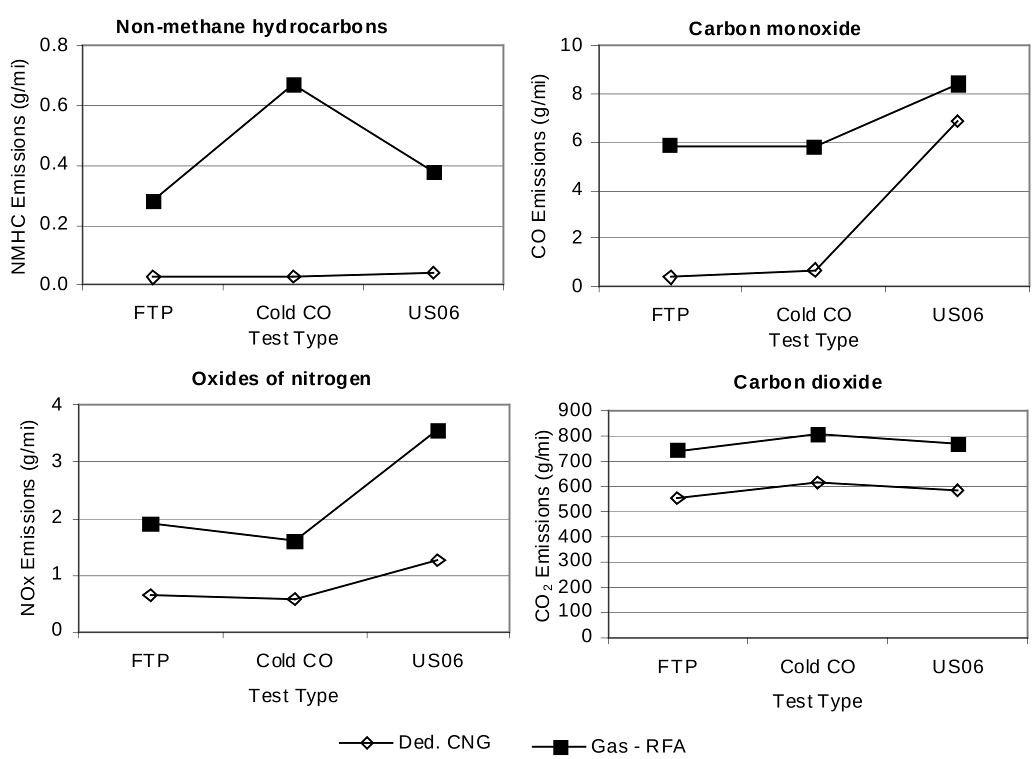


Figure 5. Detailed Round 2 results for dedicated CNG and gasoline vans

Summary of Results for the Bi-fuel vans

The comparisons between CNG and RFA emissions for the bi-fuel vans are shown in Table 13 and Figure 6. (The scales in Figures 4 and 6 are the same to enable easy comparison between all three technologies.) The bi-fuel van was certified to LEV on CNG and Tier 1 on gasoline. The LEV standard was included on the graph for reference. While results from the dedicated vans tended to show an obvious emissions benefit to using CNG, this was not necessarily the case with the bi-fuel vans. Although the NMHC emissions were significantly less when the bi-fuel vans were operated on CNG, the CO emissions were not significantly different, and NOx emissions tended to be higher for the CNG tests.

NMHC emissions ranged from 89% to 91% lower for the CNG tests. This difference between fuels was significant for each round. Emissions of CO for the bi-fuel vans showed mixed results. In Round 1, the CNG tests averaged 7% more than when the same vehicles were tested on RFA. Round 2 and 3 resulted in less CO for the CNG tests; approximately 11% in Round 2 and 5% in Round 3. None of these percentages were statistically significant at the 95% confidence level. Emissions of NOx also showed mixed results; Round 1 averages were statistically the same, in Round 2 the CNG tests were 58% higher, and in Round 3 the CNG tests were 38% higher.

Emissions of all three regulated compounds showed an increase with increasing mileage. Although this was true for CNG and gasoline, the rate of deterioration over time was different for the two fuels. When the bi-fuel vans were tested on CNG, emissions of NMHC showed a slight deterioration over time, while deterioration of NOx emissions showed a marked increase. The opposite was true when the bi-fuel vans were tested on gasoline; emissions of NOx showed a slight increase, while NMHC emissions seemed to deteriorate at a greater rate. Deterioration of CO emissions over time was similar for CNG and gasoline. These differences between rounds tended to be significant at the 95% confidence level.

Comparison of greenhouse gas emissions from the bi-fuel vans show significantly less CO_2 for the CNG tests, and significantly higher CH_4. Emissions of CO_2 were approximately 20% less when the vans were tested on CNG. The CO_2 emissions decreased over time, which was the case with both the CNG and gasoline tests.

Fuel economy measured during the FTP-75 for the bi-fuel vans showed that the CNG tests were 9.2% to 10.4% less than that of the tests using RFA. This difference was statistically significant at the 95% confidence level. The difference between rounds was not significant for either fuel.

As with the dedicated vans, 3 of the bi-fuel vans were randomly selected for detailed testing during the second round. Table 14 gives the results for the bi-fuel vans tested on each fuel. Figure 7 shows the comparison for NMHC, CO, NOx, and CO_2 for the bi-fuel vans.

The difference between fuels on the bi-fuel vans showed mixed results. NMHC, CO, and CO_2 emissions were all significantly lower for the CNG tests, while NOx, and CH_4 emissions were both higher for the CNG tests. When you compare the FTP and Cold CO tests for the bi-fuel vans tested on CNG, there was not a significant difference in any emissions components with the exception of CO_2, which was significantly higher during the cold temperature test. Comparison between these tests for the bi-fuel vans on RFA shows a decrease in CO that was not significant, and increases in NMHC, NOx, CO_2 and CH_4. The increases in NMHC and CO_2 were significant.

Table 13. Summary of Average FTP Emissions for the Bi-fuel Vans Tested on CNG and RFA

	Test Round-mileage target*	Average Results		% Difference between fuels	Significance test		
		CNG	RFA		Fuel	Round	Fuel x Round
Regulated Emissions (g/mi)							
NMHC	1 – 10K	0.022	0.235	-90.5	y	y	y
	2 – 40K	0.026	0.302	-91.2			
	3 – 60K	0.038	0.354	-89.2			
CO	1 – 10K	6.844	6.374	7.4	n	y	n
	2 – 40K	9.918	11.13	-10.9			
	3 – 60K	14.45	15.25	-5.3			
NOx	1 – 10K	0.880	0.884	-0.5	n	y	y
	2 – 40K	1.746	1.104	58.2			
	3 – 60K	2.212	1.606	37.7			
THC	1 – 10K	0.416	0.280	48.6	y	y	y
	2 – 40K	0.558	0.36	55.0			
	3 – 60K	0.710	0.428	65.9			
Greenhouse gases (g/mi)							
CO_2	1 – 10K	578.8	727.0	-20.4	y	y	n
	2 – 40K	573.1	723.1	-20.7			
	3 – 60K	560.4	715.0	-21.6			
CH_4	1 – 10K	0.396	0.048	725.0	y	y	y
	2 – 40K	0.530	0.056	846.4			
	3 – 60K	0.672	0.072	833.3			
Fuel Economy (mpg)							
Fuel Economy	1 – 10K	10.89	12.15	-10.4	y	n	n
	2 – 40K	10.9	12.1	-9.9			
	3 – 60K	11.0	12.1	-9.2			

* Round 1 @ 10,000 miles; Round 2 @ 40,000 miles; Round 3 @ 60,000 miles

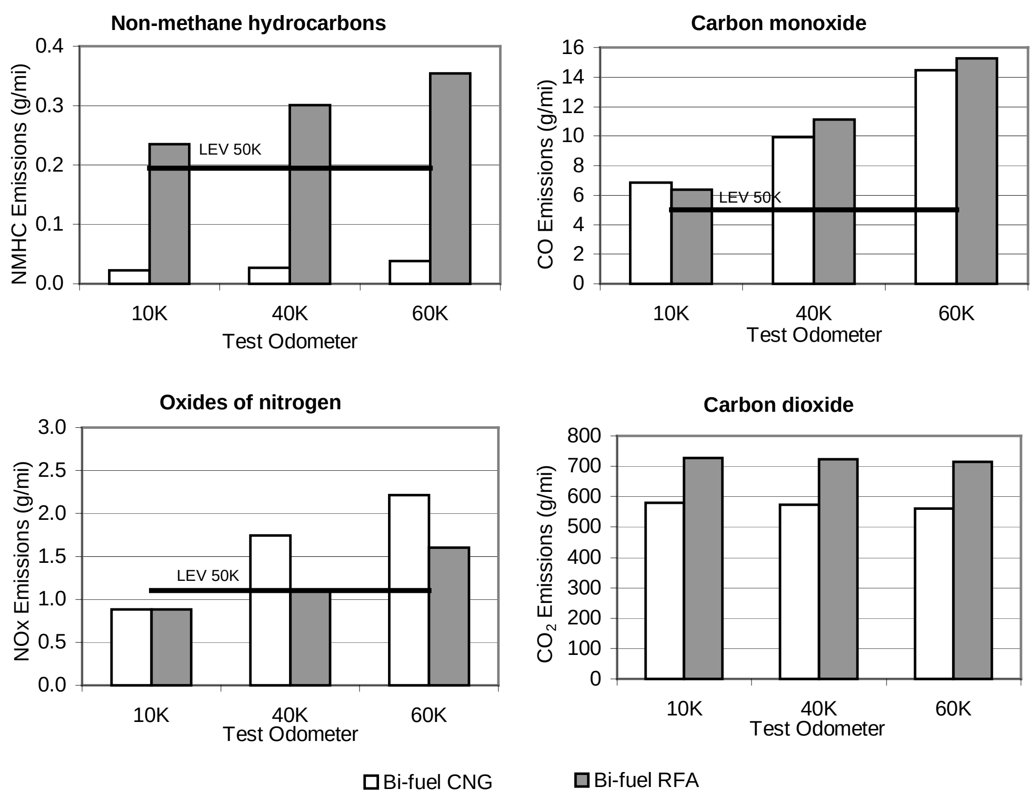


Figure 6. Average emissions for the bi-fuel vans on CNG and RFA

Table 14. Detailed Round 2 Study Emissions for the Bi-fuel Vans Tested on CNG and RFA

	Test Type	Average Results		% Difference between fuels	Significance tests		
		CNG	RFA		Fuel	Test Type	Fuel x Test Type
Regulated Emissions (g/mi)							
NMHC	FTP	0.030	0.284	-89.4	y	y	y
	Cold CO	0.039	0.695	-94.4			
	US06	0.094	0.701	-86.5			
CO	FTP	11.05	9.65	14.5	y	y	y
	Cold CO	6.667	8.257	-19.3			
	US06	22.44	87.54	-74.4			
NOx	FTP	1.997	1.247	60.2	y	y	n
	Cold CO	2.400	1.373	74.8			
	US06	3.757	1.623	131.5			
THC	FTP	0.603	0.343	75.7	n	y	n
	Cold CO	0.603	0.757	-20.3			
	US06	0.957	0.859	11.4			
Greenhouse gases (g/mi)							
CO_2	FTP	570.4	719.8	-20.8	y	y	y
	Cold CO	637.0	800.5	-20.4			
	US06	614.3	687.4	-10.6			
CH_4	FTP	0.570	0.057	905.9	y	y	n
	Cold CO	0.563	0.063	789.5			
	US06	0.862	0.159	443.3			
Fuel Economy (mpg)							
Fuel Economy	FTP	10.9	12.2	-10.4	y	y	n
	Cold CO	9.9	10.7	-7.2			
	US06	9.9	10.8	-8.9			
Evaporative Emissions (grams/test)							
Evaporative	Hot Soak	27.2	0.19	14,163	y	n/a	n/a

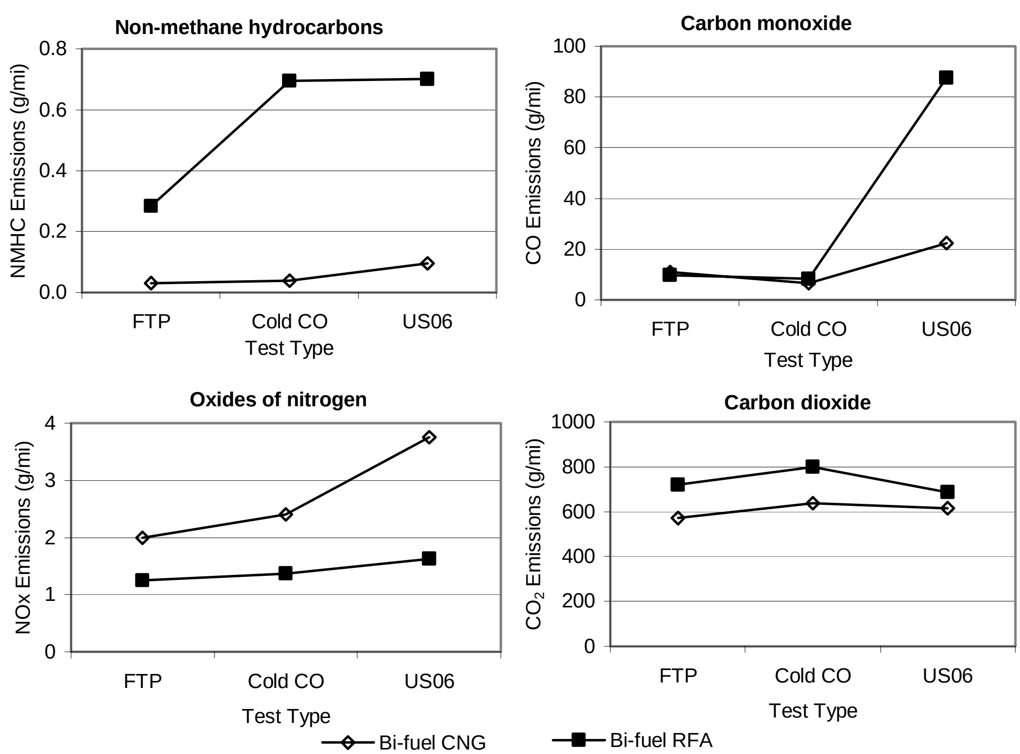


Figure 7. Detailed round 2 results for bi-fuel vans tested on CNG and RFA

The results of the US06 tests on the bi-fuel vans show the adverse effects of aggressive driving on emissions. Emissions of all but one component increased over the FTP-75 results. The CO_2 emissions for the RFA tests show a decrease from the FTP-75 to the US06 that was significant. Comparison of the FTP-75 and US06 tests for the bi-fuel vans using CNG shows increases in NMHC and CO that were not significant, and increases in NOx, CO_2, and CH_4 that were significant. Testing the bi-fuel vans on RFA resulted in increases in NMHC and CO that were significant, increases in NOx and CH_4 that were not significant, and a decrease in CO_2 that was significant.

US06 CO emissions were extremely high for the bi-fuel vans. When tested on CNG the average CO emissions were over 22 g/mile. The results when the bi-fuel vans were tested on RFA were even higher: more than 87 g/mile of CO. These high averages were not the result of one poorly performing van. The three vans tested had CO values ranging from 17 to 26.7 g/mile on CNG, and ranged from 75 to 103 g/mile for the RFA tests (see Tables A7 and A8 in the appendix for the results by vehicle). It is interesting to note that the van with the highest CO emissions on RFA also had the lowest CO emissions when tested on CNG.

Evaporative Emissions

The evaporative emissions for the dedicated and bi-fuel vans are also listed in Tables 12 and 14, respectively. The results are from a one-hour hot soak test occurring immediately after the FTP-75 while the engine is still hot, and are given in grams per test. The hot soak measures emissions coming off a heated vehicle after it is parked. As mentioned earlier, CNG vehicles are designed with a closed system, and should therefore have no evaporative emissions. This was nearly the case for the dedicated vehicles tested during this project. Although the gasoline vans had very low evaporative hydrocarbons (0.18 g), the evaporative emissions for the dedicated CNG vans were more than 77% lower.

The results for the bi-fuel vans were not as expected. When tested on RFA, the bi-fuel vans had low evaporative emissions, similar to that of the standard gasoline vans. When tested on CNG, however, these vans had evaporative emissions that greatly exceeded the standard. The average evaporative emissions for the 3 detailed study vehicles was 27.2 grams, which was over 14,000% higher than when the same vans were tested on gasoline. All three of the bi-fuel vans tested had high evaporative emissions after the CNG test, ranging from a low of 9.2 grams to a high of 38.6 grams. Because the test results were given in grams of total hydrocarbon, it is unclear how much of the total was methane. However, the fact that the evaporative emissions measured during the gasoline tests were low, while the CNG tests resulted in high numbers leads one to believe that the evaporative emissions were composed mostly of methane. One likely explanation for the source of the emissions could be leaks at the injectors following operation on CNG. Any natural gas in the engine at shutdown would be released into the SHED during the hot soak.

Fleet Experience

This section describes the steps that SuperShuttle and the other project partners took to implement AFVs into their fleet and discusses some of the more subjective aspects of the fleet's experience with CNG vehicles. A detailed Start-Up Experience brochure has been published and can be downloaded from the website: http://www.ott.doe.gov/otu/field_ops/supershuttle.html. The support of the local fuel provider and the vehicle manufacturer was essential in helping this operation get off the ground.

Getting Started

SuperShuttle, which was started in Los Angeles in 1983, is a shuttle service that focuses on shared ride door-to-door airport passenger service. Over the years, it has grown to service 23 airports, with 1,000 vehicles transporting more than 20,000 passengers each day. The company has been operating in Colorado since mid-1996, serving the local community and DIA. Their fleet of 85 vehicles includes 18 AFVs fueled by both liquefied petroleum gas (LPG) and CNG. SuperShuttle management decided to add AFVs to its Boulder fleet after hearing a presentation given by the local CNG fuel provider, Natural Fuels. This presentation spelled out the potential cost savings of using CNG vehicles, and explained the financial incentives available to fleets purchasing AFVs.

There are several rebates, credits, and tax incentives available to fleets that add AFVs to their operations. SuperShuttle Boulder's possible incentives included:

- Ford's offer of a $2000 discount per vehicle to AFV purchasers to help offset the incremental cost of the vehicles.
- The Colorado Office of Energy Conservation's rebate to AFV buyers, which is based on the emissions certification level of the vehicle.

    - Ultra low emission vehicle (ULEV) = 80% of the incremental cost.
    - Low emission vehicle (LEV) = 50% of the incremental cost

- The Federal Energy Policy Act Tax Credit under which businesses and individuals may deduct from their taxable income the incremental cost of AFVs up to $2000 maximum.
- The Colorado House Bill (Tax Credit) which provides a tax credit that is the lesser of:

    - 5% of the vehicle purchase price including AFV option, or
    - 50% of the OEM alternative fuel system option.

(Note: the incentives listed here have changed since the project started. For information on the new incentives for Colorado or for laws and incentives for other states, go to DOE's Alternative Fuel Vehicle Fleet Buyer's Guide at - http://www.fleets.doe.gov/.)

In addition, Colorado has enacted a Clean Fuel Fleet Program to reduce emissions from vehicle exhaust by requiring fleets with 10 or more vehicles to include clean fuel vehicles (CFVs) in their fleets on a percentage basis. By purchasing CFVs, SuperShuttle generated credits that it could use to satisfy those requirements.

Ross Alexander, Vice President of Operations for SuperShuttle Boulder and Yellow Cab of Denver, made the decision to go with CNG vans for the Boulder operation. He saw the opportunity for cost savings as well as an opportunity to increase public acceptance of the clean technology. The incentives available reduced the incremental cost of the AFVs, making them cost competitive with the gasoline vehicles.

Natural Fuels Corporation is the local CNG fuel provider for the area. They currently operate 37 open access CNG fueling stations in Colorado, Wyoming, and Nebraska. Natural Fuels was instrumental in getting SuperShuttle's AFV program started. In addition to giving advice and providing information on vehicles, incentives, and rebates, they increased compression and storage capacity at the fueling facility closest to SuperShuttle to ensure the fleet's supply of CNG. Natural Fuels set up a CNG fueling account that included separate fueling cards for each van. These cards allowed the drivers to fuel the vans at any Natural Fuels' fueling site. The mechanics at Natural Fuels have performed some of the repair work needed on the CNG vans. They also conducted CNG training sessions for the drivers and other fleet personnel.

In addition to producing the vehicles used in the study, Ford Motor Company trained the local dealership personnel to service and maintain CNG vehicles. The service technicians at Sill-Terhar Ford dealership participated in a 3-day course given by the manufacturer. Completion of the course meant the dealership was certified to service natural gas vehicles, including the performance of warranty work.

There were some difficulties in getting the CNG vans to SuperShuttle once the orders were placed. A quality control issue with the fueling valve caused Ford to halt production of the natural gas vehicles while the valve supplier corrected the problem. Although the vehicles were ordered in September of 1998, they were not delivered to SuperShuttle until mid-March 1999. The delay caused some difficulties for SuperShuttle management, who had to scramble to replace several vehicles that had gone off lease. Arrival of the gasoline vehicles eased the burden somewhat, but SuperShuttle still had to supplement its service using taxis.

Once SuperShuttle received the vans and put them into service, their operations ran smoothly. Drivers liked the vans, and reported that performance was the same as the gasoline versions. Their only complaint was the shorter range of the dedicated vans. Because of this, the dedicated vans were driven mostly in town, resulting in lower mileage accumulation and perhaps lower fuel economy. To keep the project on track, program funds were provided for a drivers incentive program. From late December 1999 through February 2000, the top 5 drivers with the highest weekly mileage using CNG fuel were awarded gift certificates to a local grocery store. As a result, the monthly mileage accumulation for these vans remained steady at a time of year when SuperShuttle traditionally experiences lower rates of use.

Vehicle Problems

Midway through the study, SuperShuttle began to experience some problems with the dedicated CNG vans. The check-engine-light came on in Unit 238 after approximately 16,000 miles of service. The performance of the van was not effected by this occurrence, but it was taken to the dealership for diagnostics. The service technician at the dealership made a minor repair (replaced a vacuum hose) and reset the code. Within two weeks the check-engine-light was back on and the vehicle was returned to the dealership. After diagnostics, another minor repair was made (replaced mass airflow sensor). Within a mile from the dealership, the light was back on. By this time, several of the other dedicated vans were experiencing the same problem. Diagnostic tests at the dealership revealed no problems with the vehicles. Ford's alternative fuel division in Michigan was contacted for advice on the situation.

As a result, two Ford engineers traveled to Boulder to investigate the problem. Inspection of these vans revealed oil contamination on the injectors and in the fuel rail. The injectors were replaced on Unit 238 and the vehicle went back into service. Ford recommended the remaining dedicated CNG vans have their injectors flushed to remove any similar deposits. Contamination at the fuel site was suspected, and the injectors removed from Unit 238 were sent to Ford for further analysis.
Technicians at Natural Fuels flushed the injectors on the dedicated vans. They also investigated the potential contamination at the Boulder fueling site. They upgraded the site by replacing the dispenser with a new system capable of dispensing CNG at a higher flow rate. In addition to an improved filtration system, the new dispenser gives drivers a quicker fill.

Analysis of the injectors revealed that they were opening properly and were not leaking. There was, however, indication of some flow restrictions, which verified the vehicle codes that caused the check-engine-lights to come on. The conclusion of the report was that, based on past experience, compressor oil contamination was most likely the cause. The problems of compressor oil carryover have been well documented by organizations in the natural gas industry. A recent publication by the California Energy Commission entitled "*Evaluation of Compressed Natural Gas Fueling Systems*" spells out past problems and possible resolutions to this issue. Ford and Natural Fuels continue to work with SuperShuttle to prevent further occurrences of the problem. The bi-fuel vans did not appear to experience the problem. This could be because of the low percentage of CNG use in those vans.

Conclusion of the Fleet Experience

SuperShuttle continues to use its natural gas vans in daily operations. As gasoline prices climb, they find they rely on the vans to keep costs in check. "Our fuel bills increased," said Ross Alexander, "but they would have been more than double if not for the AFVs." Mr. Alexander is looking into additional CNG vehicles for both the Boulder operation as well as for Yellow Cab of Denver, which he also manages. When asked his feelings at the end of the project, Bill Fries, General Manager of the SuperShuttle Boulder office, replied "we like the CNG vans. We see a cost savings because of the fuel price, but we are also comfortable with the vans." He sees the reduced range of dedicated CNG vehicles as the only drawback, but believes the newer extended range vehicles might solve that problem. The 2000 Model Year E350 van from Ford uses 3600 psi tanks and has an extended range option. The estimated driving range for this option is 225 to 425 miles per fill. George Stone, manager of SuperShuttle's maintenance shop in Boulder, feels the CNG vans operate the same as standard gasoline vans. According to Mr. Stone, the average driver would not know a van was running on an alternative fuel by the performance of the vehicle. He would recommend CNG vans, but reserves final judgement until he sees how they perform at higher mileage.

Survey of Fleet Personnel and Customers

Customer survey – During the first 4 months of the data collection, customers riding in the AFVs were asked if they would participate in a brief survey. The actual survey questions, along with details on the responses, are shown in Appendix C. A total of 68 surveys were completed during this time. The most important findings were that:

70% of respondents were not aware that the van they were riding in was an AFV
85% of respondents were aware that CNG is a domestic product
74% felt that development of alternatives to petroleum was important
63% felt that use of CNG for a transportation fuel was acceptable, and
59% would be influenced to use the services of a company based on their use of environmentally friendly products.

When asked the reasons for their answers, most respondents stated that air quality was important to them. Numerous other respondents stated the need to reduce petroleum imports.

Drivers survey – In addition to the opinions of customers using the service, we wanted to know the drivers' opinions about AFVs in general and the study vans in particular. Two surveys were given to the drivers of the vans; one at the beginning of the study, and the other at the conclusion of the data collection period. The first survey determined if the drivers had previous alternative fuel experience, and asked their opinion on how they expected the vans to perform compared to comparable gasoline vehicles. Drivers were also asked if they had any concerns about operating a CNG vehicle. The second survey asked the drivers to comment on how the vans actually performed during their use.

The start-up survey was intended to determine if the drivers had pre-conceived notions about how an AFV would perform. We also wanted to know if lack of information about, or exposure to a new technology would result in negative feelings about the vehicles. The first 2 questions asked drivers if they had experience with alternative fuels, and if so, which fuels had they used. The number of drivers exposed to AFV technology in SuperShuttle's case was very high (73%), because the fleet has had several LPG vans in their operation for some time. Of those drivers with previous alternative fuel experience, 88% had used LPG fueled vehicles. The third question asked drivers how they expected the AFVs to perform compared to similar gasoline vehicles. The majority of drivers (81%) responded that they felt the AFVs would perform the same or somewhat worse than the gasoline vans.

The last two questions dealt with maintenance of the AFVs. When asked how the AFVs would compare to gasoline vehicles with respect to scheduled maintenance, the majority of drivers (55%) said the AFVs would require the same number of services. Twenty-seven percent responded that the AFVs would require less scheduled maintenance than gasoline vans. When asked how they expected AFVs to compare with respect to unscheduled maintenance, the majority (73%) of drivers said AFVs and gasoline vehicles would have the same number of unscheduled maintenance services.

The final survey was designed to determine if the drivers' perceptions about AFVs changed as they became familiar with the vehicles. Most of the drivers surveyed responded that they had been driving the AFVs for approximately a year or more (62.5%). When asked to rate the performance of the CNG vehicles in comparison to the gasoline vehicles, most drivers (62.5%) considered the AFVs to perform the same or somewhat worse than the gasoline vans. Seventy-five percent of the drivers indicated that their opinions on the performance of the vans had not changed over time.

The drivers were also asked if they had any concerns about the CNG vehicles. The most common complaint (50% of respondents) was that the vans did not have enough range. Finally, the drivers were asked if they would recommend AFVs to others considering their purchase. Most of the drivers (62.5%) responded that they would recommend AFVs to others. The most common reason given was their concern for the environment. Other reasons for recommending AFVs were that the vehicles were economical, given the rise in gasoline prices, and that they helped reduce dependence on foreign oil. The drivers that responded that they would not recommend AFVs listed low range and lack of sufficient fueling infrastructure as reasons.

Summary

Results from this evaluation show that the performance of the dedicated and bi-fuel CNG vans compare well with the conventional gasoline vans. The mileage accumulation for the bi-fuel vans was similar to that of the gasoline vans, but the dedicated vans lagged behind because of the range issue. As the fueling infrastructure grows and extended range models are introduced, this should be less of a factor in the operation of dedicated CNG vehicles.

Fuel economy was less for the CNG vans, which could be because the dedicated CNG vans were used mainly for in-town driving. The lower price of CNG fuel more than made up for the difference in fuel economy. During the study period, the dedicated CNG vans cost 28% less to fuel than the gasoline vans. This could add up to substantial savings depending on the number of CNG vehicles in a fleet and the annual vehicle miles traveled. SuperShuttle could save over $1600 per year on fuel for each dedicated CNG van accumulating 50,000 miles. This is based on the following fuel prices during the study period: CNG averaged $0.86 per gallon, gasoline averaged $1.21 per gallon. If gasoline prices continue to rise, fuel cost savings will be even higher. Despite the lower than desired use of CNG (average of 28.6%), the bi-fuel vans also cost less (12%) to fuel than the gasoline vans.

Comparison of maintenance for the study vehicles shows some minor differences between the types of vehicles. The maintenance interval for the CNG vans (both dedicated and bi-fuel) was approximately 500 miles more than the gasoline vans. The dedicated CNG vans averaged 12.8 services per van, while the gasoline and bi-fuel vans averaged 14.2 and 14.6 services per vehicle respectively over the same mileage intervals. The cost of scheduled maintenance for the dedicated CNG vans was lower (13.8%) than that of the gasoline vans, but the cost of unscheduled maintenance was slightly higher due to injector contamination. The bi-fuel vans cost 11.8% less than the gasoline vans for scheduled maintenance, but unscheduled maintenance was the same.

When comparing the overall operating cost, the dedicated CNG vehicles were the most cost effective, costing about 22.6% less to operate than the gasoline vans. These savings were mostly due to lower fuel costs and could be even greater, if the price of gasoline continues to rise relative to CNG. The bi-fuel vehicles cost 11.6% less to operate than the gasoline vans.

FTP-75 emissions results show an obvious benefit of the dedicated CNG vans compared to the conventional gasoline vans. All of the regulated emissions compounds were significantly lower from the dedicated CNG vans. Results from the bi-fuel van were mixed. Although the NMHC emissions were lower when the vans were tested on CNG, CO emissions were not significantly different and NOx emissions were significantly higher. There also appeared to be a deterioration of emissions over time for the bi-fuel vehicles. Emissions of all three regulated compounds increased in each round for both dedicated CNG and gasoline. Results of the US06 and Cold CO emissions tests showed that the dedicated CNG vans had an emissions benefit over the gasoline vans when tested using alternative procedures such as the US06 aggressive driving cycle and the Cold CO test. As with the FTP tests, the bi-fuel vans had mixed results during the detailed tests. NMHC emissions were lower when the bi-fuel vans were tested on CNG, but the NOx emissions were higher. Emissions of CO during the US06 test were expected to be high, but the results for the bi-fuel vans were extremely high for both fuels.

Although SuperShuttle's experience with implementing AFVs into their fleet was not always smooth, the overall results were good. They are realizing economic and environmental benefits of using the dedicated CNG vans, and plan to add more in the near future. The managers of this fleet genuinely like the natural gas vans and would recommend them to other fleets interested in AFVs.

Acknowledgements

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Appendix A
Detailed Emissions Data

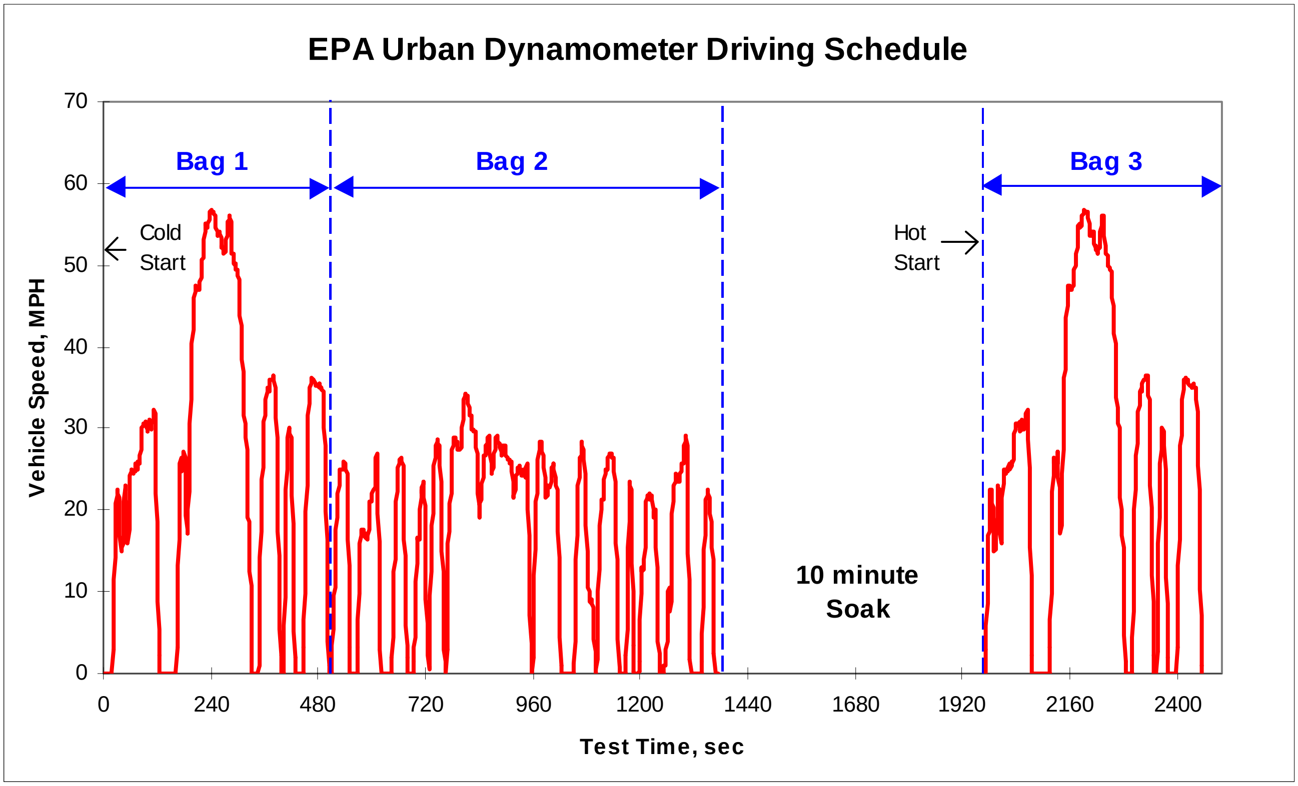

Figure A1. EPA FTP-75 driving cycle

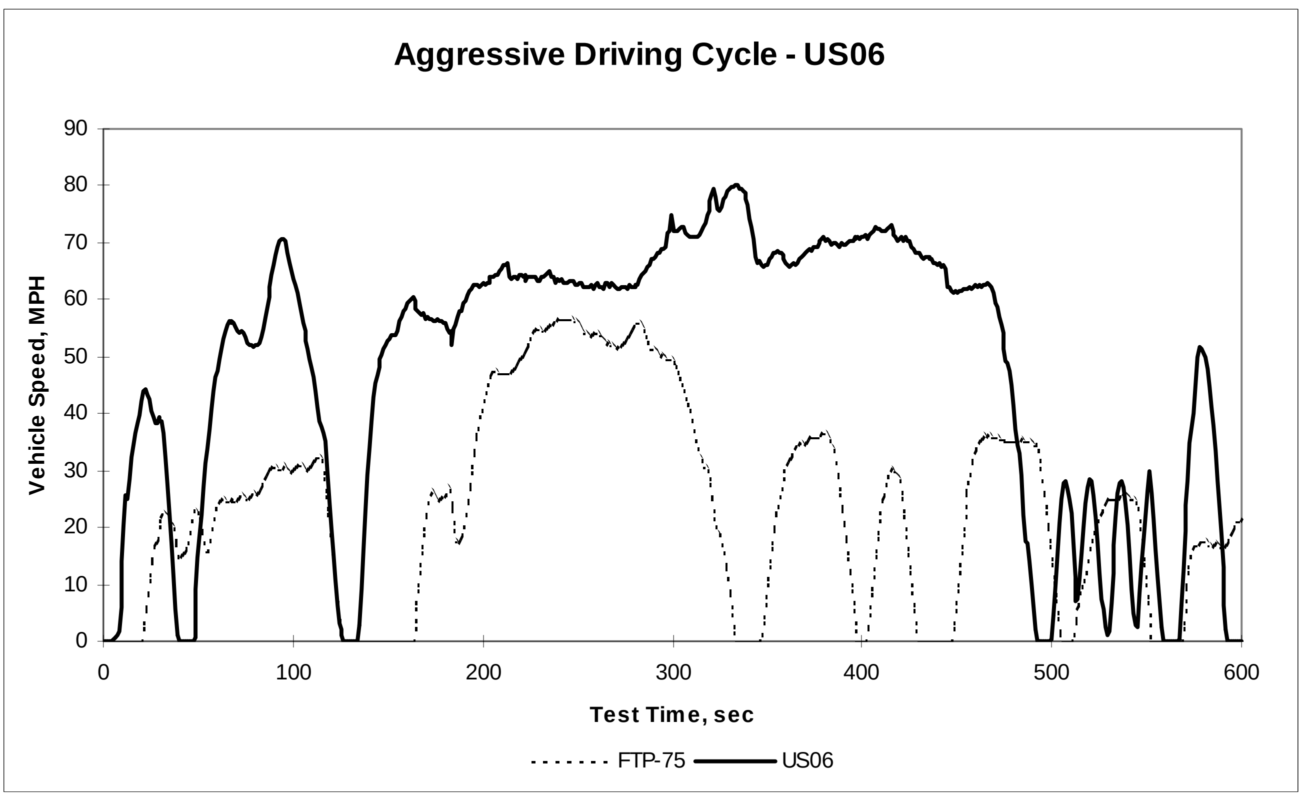

Figure A2. US06 Driving Cycle (first 600 seconds of the FTP-75 superimposed for comparison)

Table A1 - FTP Gasoline Control Emissions Results

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Round 1	SS231GFC	4/17/1999	10209	RFA	11.67	0.06	5.48	758.61	0.2842	1.77	0.34
	SS232GFC	4/15/1999	9546	RFA	11.76	0.06	5.38	752.44	0.2875	1.27	0.34
	SS233GFC	4/28/1999	9673	RFA	12.03	0.07	7.56	731.96	0.3234	1.29	0.39
				Count	3	3	3	3	3	3	3
				Average	11.82	0.063	6.14	747.67	0.298	1.443	0.357
				STD*	0.187	0.006	1.231	13.951	0.022	0.283	0.029
Round 2	SS231GFC	09/24/1999	40308	RFA	11.85	0.05	6.22	745.43	0.2678	2.02	0.32
	SS232GFC	10/01/1999	41865	RFA	12	0.05	5.26	737.62	0.2651	1.8	0.31
	SS233GFC	09/22/1999	41523	RFA	11.85	0.06	6.14	745.87	0.3062	1.89	0.37
				Count	3	3	3	3	3	3	3
				Average	11.9	0.053	5.873	742.97	0.280	1.903	0.333
				STD*	0.087	0.006	0.533	4.641	0.023	0.111	0.032
Round 3	SS231GFC	01/25/2000	60535	RFA	12.01	0.07	10.61	728.42	0.3289	3.08	0.4
	SS232GFC	02/11/2000	62291	RFA	12.21	0.07	9.72	717.03	0.5033	2.61	0.58
	SS233GFC	01/24/2000	62309	RFA	12.31	0.06	6.87	716.22	0.337	2.6	0.4
				Count	3	3	3	3	3	3	3
				Average	12.177	0.067	9.067	720.56	0.390	2.763	0.46
				STD*	0.153	0.006	1.954	6.822	0.098	0.274	0.104

Table A2 - FTP Dedicated CNG Emissions Results

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Round 1	SS234CF	06/10/1999	8298	CNG	11.04	0.1	0.34	581.39	0.0105	0.05	0.11
	SS235CF	06/09/1999	10650	CNG	11.27	0.12	0.25	569.77	0.0052	0.06	0.12
	SS236CF	07/01/1999	9739	CNG	11.29	0.11	0.33	568.85	0.0244	0.05	0.13
	SS237CF	06/09/1999	10594	CNG	11.16	0.09	0.37	575.4	0.0053	0.05	0.1
	SS238CF	06/10/1999	8113	CNG	11.11	0.11	0.42	577.85	0.008	0.07	0.12
				Count	5	5	5	5	5	5	5
				Average	11.174	0.106	0.342	574.65	0.0107	0.056	0.116
				STD*	0.106	0.011	0.062	5.331	0.008	0.009	0.011
Round 2	SS234CF	01/19/2000	38394	CNG	11.42	0.25	0.52	561.57	0.0424	0.71	0.3
	SS235CF	03/07/2000	38033	CNG	11.58	0.21	0.32	554.15	0.0133	0.25	0.22
	SS236CF	01/27/2000	38100	CNG	11.63	0.3	0.18	551.98	0.0155	0.73	0.32
	SS237CF	02/05/2000	41247	CNG	11.51	0.22	0.18	557.9	0.0155	0.35	0.23
	SS238CF	02/01/2000	38220	CNG	11.63	0.24	0.47	551.48	0.0154	0.45	0.25
				Count	5	5	5	5	5	5	5
				Average	11.554	0.244	0.334	555.42	0.0204	0.498	0.264
				STD*	0.09	0.035	0.159	4.270	0.012	0.215	0.044
Round 3	SS234CF	05/27/00	58477	CNG	11.31	0.30	0.42	567.1	0.0154	0.27	0.31
	SS235CF**			CNG							
	SS236CF	6/14/00	60025	CNG	11.57	0.20	0.40	554.4	0.0143	0.19	0.21
	SS237CF	7/18/00	61843	CNG	12.03	0.35	0.26	568.13	0.0195	0.57	0.37
	SS238CF	7/14/00	58044	CNG	12.17	0.36	0.92	561.7	0.0198	0.93	0.38
				Count	4	4	4	4	4	4	4
				Average	11.77	0.303	0.50	562.82	0.017	0.49	0.318
				STD*	0.399	0.073	0.289	6.307	0.003	0.336	0.078

** Unit 235 dropped from Round 3 due to low mileage

Table A3 - FTP Bi-fuel CNG Emissions Results

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Round 1	SS239CF	05/27/1999	9310	CNG	10.8	0.48	8.77	580.38	0.0153	0.96	0.49
	SS240CF	06/04/1999	9723	CNG	10.96	0.38	5.92	576.35	0.0226	0.9	0.4
	SS241CF	05/28/1999	10601	CNG	10.85	0.31	6.29	581.86	0.0167	0.71	0.33
	SS242CF	06/08/1999	10095	CNG	10.83	0.45	9.33	577.53	0.0382	0.83	0.48
	SS243CF	06/07/1999	10130	CNG	10.99	0.36	3.91	577.71	0.0185	1	0.38
				Count	5	5	5	5	5	5	5
				Average	10.89	0.396	6.84	578.77	0.022	0.88	0.416
				STD*	0.084	0.069	2.217	2.273	0.009	0.115	0.068
Round 2	SS239CF	11/04/1999	40505	CNG	10.65	0.71	13.88	579.82	0.0272	2.04	0.74
	SS240CF	10/28/1999	40382	CNG	10.79	0.43	9.41	579.74	0.0183	1.27	0.45
	SS241CF	01/11/2000	44001	CNG	11.19	0.51	10.74	556.36	0.0379	1.67	0.55
	SS242CF	10/19/1999	41297	CNG	10.9	0.49	8.53	574.92	0.0249	2.28	0.52
	SS243CF	11/16/1999	41083	CNG	10.95	0.51	7.03	574.72	0.0239	1.47	0.53
				Count	5	5	5	5	5	5	5
				Average	10.896	0.53	9.918	573.11	0.026	1.75	0.558
				STD*	0.201	0.106	2.593	9.688	0.007	0.412	0.109
Round 3	SS239CF	02/17/2000	58771	CNG	11.18	0.79	18.77	543.17	0.0451	1.97	0.84
	SS240CF	02/25/2000	58634	CNG	10.81	0.72	14.55	569.89	0.0438	2.36	0.76
	SS241CF	04/29/2000	59496	CNG	10.91	0.54	10.51	571.58	0.0247	2.22	0.56
	SS242CF	02/09/2000	63182	CNG	11.15	0.62	14.01	553.05	0.0379	2.49	0.66
	SS243CF	03/11/2000	58649	CNG	10.92	0.69	14.41	564.18	0.0401	2.02	0.73
				Count	5	5	5	5	5	5	5
				Average	10.99	0.67	14.45	560.37	0.0383	2.212	0.71
				STD*	0.162	0.096	2.932	12.04	0.008	0.221	0.106

Table A4 - FTP Bi-fuel RFA Emissions Results

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Round 1	SS239CF	05/19/1999	9277	RFA	12.11	0.05	6.45	728.98	0.2272	0.89	0.27
	SS240CF	06/03/1999	9697	RFA	12.02	0.05	6.83	733.96	0.237	0.97	0.28
	SS241CF	06/01/1999	10645	RFA	12.23	0.04	5.65	722.99	0.2134	0.85	0.25
	SS242CF	06/07/1999	10069	RFA	12.23	0.05	6.54	721.86	0.245	0.95	0.3
	SS243CF	06/04/1999	10105	RFA	12.15	0.05	6.4	726.96	0.2511	0.76	0.3
				Count	5	5	5	5	5	5	5
				Average	12.15	0.048	6.374	726.95	0.235	0.884	0.28
				STD*	0.088	0.004	0.438	4.869	0.015	0.084	0.021
Round 2	SS239CF	10/22/1999	40330	RFA	12.2	0.04	6.05	724.21	0.2454	1.07	0.29
	SS240CF	10/26/1999	40357	RFA	11.73	0.05	13.44	741.58	0.3221	0.59	0.37
	SS241CF	11/20/1999	38618	RFA	12.58	0.06	9.34	697.02	0.2801	1.23	0.34
	SS242CF	10/13/1999	41237	RFA	11.78	0.07	13.55	738.2	0.3263	1.44	0.4
	SS243CF	11/15/1999	41049	RFA	12.17	0.06	13.28	714.44	0.3339	1.19	0.4
				Count	5	5	5	5	5	5	5
				Average	12.09	0.056	11.132	723.09	0.302	1.104	0.36
				STD*	0.348	0.011	3.348	18.206	0.038	0.317	0.046
Round 3	SS239CF	02/17/2000	58745	RFA	12.45	0.07	15.64	694.3	0.3389	1.85	0.41
	SS240CF	02/23/2000	58583	RFA	11.99	0.08	15.78	721.17	0.3913	1.61	0.47
	SS241CF	04/27/2000	59470	RFA	12.01	0.06	11.31	727.61	0.2932	1.26	0.36
	SS242CF	02/16/2000	63063	RFA	11.89	0.07	16.55	726.68	0.3368	1.74	0.41
	SS243CF	03/10/2000	58616	RFA	12.22	0.08	16.99	705.37	0.4105	1.57	0.49
				Count	5	5	5	5	5	5	5
				Average	12.112	0.072	15.25	715.03	0.354	1.606	0.428
				STD*	0.224	0.008	2.273	14.618	0.047	0.223	0.052

Table A5 – Gasoline Control - Detailed Round 2 Tests

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Cold CO	SS231GFC	09/30/1999	40353	RFA	10.5	0.07	6.98	816.01	0.6835	1.78	0.75
	SS232GFC	10/05/1999	41899	RFA	10.64	0.06	5.49	807.27	0.6922	1.66	0.76
	SS233GFC	09/23/1999	41549	RFA	10.62	0.05	4.93	805.36	0.6352	1.34	0.68
				Count	3	3	3	3	3	3	3
				Average	10.587	0.06	5.8	809.55	0.670	1.593	0.73
				STD*	0.076	0.01	1.059	5.678	0.031	0.227	0.044
US06	SS231GFC	09/24/1999	40319	RFA	11.44	0.06	9.8	765.99	0.529	3.89	0.5902
	SS232GFC	10/01/1999	41878	RFA	11.36	0.0412	7.94	775.8	0.2327	3.1501	0.274
	SS233GFC	09/22/1999	41534	RFA	11.42	0.05	7.62	771.82	0.3709	3.63	0.42
				Count	3	3	3	3	3	3	3
				Average	11.407	0.050	8.453	771.20	0.377	3.557	0.428
				STD*	0.042	0.009	1.177	4.934	0.148	0.375	0.158

Table A6 – Dedicated CNG - Detailed Round 2 Tests

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Cold CO	SS234CF	01/20/2000	38420	CNG	10.45	0.3	0.91	613.02	0.0336	0.62	0.33
	SS237CF	02/03/2000	38246	CNG	10.47	0.42	0.75	611.67	0.0274	0.45	0.45
	SS238CF	01/28/2000	39126	CNG	10.31	0.29	0.46	622.19	0.0213	0.66	0.31
				Count	3	3	3	3	3	3	3
				Average	10.41	0.337	0.707	615.63	0.027	0.577	0.363
				STD*	0.087	0.072	0.228	5.724	0.006	0.112	0.076
US06	SS234CF	01/20/2000	38420	CNG	10.79	0.460	8.409	581.48	0.060	0.988	0.520
	SS237CF	02/03/2000	38246	CNG	10.62	0.268	5.790	595.72	0.029	1.448	0.297
	SS238CF	01/28/2000	39126	CNG	10.83	0.274	6.343	582.74	0.039	1.314	0.313
				Count	3	3	3	3	3	3	3
				Average	10.747	0.334	6.847	586.65	0.043	1.250	0.377
				STD*	0.112	0.109	1.380	7.881	0.016	0.237	0.124

Table A7 – Bi-fuel CNG - Detailed Round 2 Tests

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Cold CO	SS239CF	11/08/1999	40550	CNG	9.74	0.61	8.32	645.45	0.0374	2.29	0.65
	SS241CF	01/11/2000	44029	CNG	9.89	0.61	7.88	635.93	0.0515	2.38	0.66
	SS242CF	10/20/1999	41323	CNG	10.1	0.47	3.8	629.53	0.0285	2.53	0.5
				Count	3	3	3	3	3	3	3
				Average	9.91	0.563	6.667	636.97	0.039	2.4	0.603
				STD*	0.181	0.081	2.492	8.011	0.012	0.121	0.090
US06	SS239CF	11/04/1999	40516	CNG	9.61	1.0605	26.7549	623.7164	0.0756	4.3122	1.1361
	SS241CF	01/11/2000	44014	CNG	10.31	0.7208	17.0545	594.8269	0.0847	2.6042	0.8055
	SS242CF	10/19/1999	41308	CNG	9.69	0.8061	23.5021	624.4288	0.1227	4.3548	0.9288
				Count	3	3	3	3	3	3	3
				Average	9.87	0.862	22.437	614.32	0.094	3.757	0.957
				STD*	0.383	0.177	4.937	16.889	0.025	0.999	0.167

Table A8 – Bi-fuel RFA - Detailed Round 2 Tests

	Vehicle ID	Test Date	Odometer	Fuel	MPG	CH_4	CO	CO_2	NMHC	NOx	THC
Cold CO	SS239CF	11/03/1999	40479	RFA	10.56	0.06	8.25	809.25	0.7376	1.49	0.8
	SS241CF	11/23/1999	38670	RFA	10.68	0.07	8.89	799.31	0.6399	1.68	0.71
	SS242CF	10/14/1999	41272	RFA	10.78	0.06	7.63	792.95	0.708	0.95	0.76
				Count	3	3	3	3	3	3	3
				Average	10.673	0.063	8.257	800.50	0.695	1.373	0.757
				STD*	0.110	0.006	0.630	8.215	0.050	0.379	0.045
US06	SS239CF	10/22/1999	40360	RFA	10.72	0.1584	83.8275	701.4812	0.6737	1.5765	0.832
	SS241CF	11/20/1999	38629	RFA	10.95	0.1778	103.3562	653.233	0.837	1.913	1.0148
	SS242CF	10/13/1999	41256	RFA	10.82	0.14	75.43	707.42	0.591	1.38	0.73
				Count	3	3	3	3	3	3	3
				Average	10.83	0.159	87.538	687.378	0.701	1.623	0.859
				STD*	0.115	0.019	14.328	29.719	0.125	0.269	0.144

Table A9 – Evaporative Emissions for the Dedicated CNG and gasoline control vans

Vehicle ID	Fuel	Hot Soak (g)
SS234CF	CNG	0.065
SS237CF	CNG	0.035
SS238CF	CNG	0.021
	Count	3
	Average	0.040
	STD*	0.022
SS231GFC	RFA	0.186
SS232GFC	RFA	0.049
SS233GFC	RFA	0.306
	Count	3
	Average	0.180
	STD*	0.129

Table A10 – Evaporative Emissions for the Bi-fuel vans tested on CNG and RFA

Vehicle ID	Fuel	Hot Soak (g)
SS239CF	CNG	33.81
SS241CF	CNG	9.22
SS242CF	CNG	38.57
	Count	3
	Average	27.20
	STD*	15.75
SS239CF	RFA	0.348
SS241CF	RFA	0.096
SS242CF	RFA	0.128
	Count	3
	Average	0.191
	STD*	0.137

Appendix B
Detailed Operational Data

Table B1 – Summary of Fueling Data by Vehicle

Vehicle Number	Total Number of Records	Total Amount of Fuel	Total Fuel Cost	Cost (cents/mi)
231	288	3870.05	$4854.05	11.61
232	255	3553.87	$4388.48	11.33
233	313	4182.85	$5215.10	11.34
Average for Gasoline Control Vans				11.43
234	291	1985.43	$1716.42	7.54
235	392	2545.76	$2181.27	8.32
236	527	3668.61	$3146.40	8.18
237	445	3005.28	$2588.26	8.48
238	394	2598.00	$2224.95	8.26
Average for Dedicated CNG Vans				8.16
239	594	4495.81	$5016.84	9.87
240	549	4279.83	$4823.97	10.47
241	419	3587.70	$4157.61	9.83
242	566	4601.75	$5276.39	9.66
243	464	4162.29	$4807.25	10.47
Average for Bi-fuel Vans				10.06

Table B2 – Percentage of CNG use in the Bi-fuel Vans, by vehicle and month

	% CNG use by volume				
Vehicle ID	**239**	**240**	**241**	**242**	**243**
Jul-00	40.9	12.9	23.9	35.0	30.4
Aug-00	32.7	26.5	25.7	30.5	8.6
Sep-99	22.3	22.3	26.3	32.1	15.7
Oct-99	24.2	71.0	24.1	46.9	46.1
Nov-99	9.5	9.2	7.7	1.3	13.5
Dec-99	29.1	27.4	12.4	5.1	18.0
Jan-00	43.3	29.3	25.7	12.5	26.5
Feb-00	21.5	24.1	13.3	8.6	17.4
Mar-00	74.1	73.6	63.4	72.5	48.1
Average	33.06	32.9	24.7	27.2	24.9

Table B3 – Summary of Fuel Price During Data Collection Period

Month	CNG			Gasoline		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Mar-99	$0.85	$0.91	$0.85	$0.91	$1.06	$0.96
Apr-99	$0.85	$0.91	$0.85	$1.06	$1.11	$1.08
May-99	$0.85	$0.91	$0.85	$1.11	$1.11	$1.11
Jun-99	$0.85	$0.91	$0.86	$1.11	$1.11	$1.11
Jul-99	$0.85	$0.91	$0.86	$1.11	$1.16	$1.12
Aug-99	$0.85	$0.91	$0.86	$1.16	$1.33	$1.24
Sep-99	$0.85	$0.91	$0.86	$1.27	$1.29	$1.28
Oct-99	$0.85	$0.91	$0.86	$1.24	$1.27	$1.27
Nov-99	$0.85	$0.91	$0.86	$1.26	$1.27	$1.26
Dec-99	$0.85	$0.91	$0.86	$1.26	$1.26	$1.26
Jan-00	$0.85	$0.91	$0.86	$1.26	$1.26	$1.26
Feb-00	$0.85	$0.91	$0.86	$1.25	$1.34	$1.28
Mar-00	$0.85	$0.91	$0.86	$1.34	$1.48	$1.43
Average CNG Price			$0.86	Average Gasoline Price		$1.20

Table B4 – Summary of Scheduled Maintenance by Vehicle

Vehicle ID	Number of services	Parts Cost	Labor Cost	Other Cost	Total Cost	Cost in cents per mile
Gasoline Vans						
231	21	$301.61	$832.00	0	$1133.61	2.26
232	23	$329.47	$936.00	0	$1265.47	2.50
233	23	$329.47	$936.00	0	$1265.47	2.53
Total	67	$960.55	$2704.00	0	$3664.55	2.43(avg)
Dedicated CNG Vans						
234	18	$226.25	$702.00	0	$928.25	1.93
235	15	$198.39	$598.00	0	$796.39	2.20
236	21	$221.32	$728.00	0	$949.32	2.06
237	15	$162.48	$598.00	0	$760.48	1.66
238	24	$277.04	$884.00	0	$1161.04	2.60
Total	93	$1085.48	$3510.00	0	$4595.48	2.09(avg)
Bi-fuel CNG Vans						
239	22	$265.70	$884.00	0	$1149.70	2.23
240	21	$267.26	$832.00	0	$1099.26	2.24
241	18	$254.11	$728.00	0	$982.11	2.00
242	20	$254.11	$780.00	0	$1034.11	2.09
243	21	$281.97	$806.00	0	$1087.97	2.15
Total	102	$1323.15	$4030.00	0	$5353.15	2.14(avg)

Table B5 – Summary of Unscheduled Maintenance by Vehicle

Vehicle ID	Number of services	Parts Cost	Labor Cost	Other Cost	Total Cost	Cost in cents per mile
Gasoline Vans						
231	2	$120.00	$104.00	0	$224.00	0.45
232	2	$120.00	$104.00	0	$224.00	0.44
233	2	$120.00	$104.00	0	$224.00	0.45
Total	6	$360.00	$312.00	0	$672.00	0.45(avg)
Dedicated CNG Vans						
234	3	$320.63	$104.00	0	$424.63	0.88
235	2	$260.63	$52.00	0	$312.63	0.86
236	3	$320.63	$104.00	0	$424.63	0.92
237	3	$320.63	$104.00	0	$424.63	0.93
238	2	$120.00	$104.00	0	$224.00	0.50
Total	13	$1342.52	$468.00	0	$1810.52	0.82(avg)
Bi-fuel CNG Vans						
239	2	$60.00	$52.00	$74.50	$186.50	0.36
240	2	$120.00	$104.00	0	$224.00	0.46
241	3	$240.00	$104.00	0	$344.00	0.70
242	1	$60.00	$52.00	0	$112.00	0.23
243	2	$120.00	$104.00	0	$224.00	0.44
Total	10	$600.00	$490.00	0	$1090.00	0.44(avg)

Table B6 – Summary of Tires & Windshield Cost by Vehicle

Vehicle ID	Number of services	Parts Cost	Labor Cost	Other Cost	Total Cost	Cost in cents per mile
Gasoline Vans						
231	1	$350.23	$0.00	$26.13	$376.63	0.75
232	1	$175.00	$0.00	$13.06	$188.06	0.37
233	0	$0.00	$0.00	0	$0.00	0.00
Total	2	$525.23	$0.00	$39.19	$564.42	0.37(avg)
Dedicated CNG Vans						
234	1	$322.80	$104.00	0	$426.83	0.89
235	1	$322.80	$104.00	0	$426.83	1.18
236	1	$322.80	$104.00	0	$426.80	0.93
237	2	$497.80	$104.00	0	$601.80	1.32
238	1	$322.80	$104.00	0	$491.80	0.96
Total	6	$1789.00	$520.00	0	$2309.00	1.05(avg)
Bi-fuel CNG Vans						
239	3	$322.80	$169.00	0	$491.80	0.95
240	1	$322.80	$104.00	0	$426.80	0.87
241	2	$497.80	$104.00	$13.06	$614.86	1.25
242	2	$497.80	$104.00	$13.06	$614.86	1.24
243	0	$0.00	$0.00	0	$0.00	0.00
Total	8	$1641.20	$481.00	0	$2148.32	0.86(avg)

Table B7 – Summary of Warranty Work by Vehicle

Vehicle ID	Number of services	Parts Cost	Labor Cost	Other Cost	Total Cost	Cost in cents per mile
Gasoline Vans						
231	0	$0.00	$0.00	0	$0.00	0.00
232	0	$0.00	$0.00	0	$0.00	0.00
233	1	$0.00	$25.26	0	$25.26	0.05
Total	1	$0.00	$25.26	0	$25.26	0.02(avg)
Dedicated CNG Vans						
234	1	$404.00	$44.20	$83.00	$531.20	1.10
235	2	$442.15	$97.88	0	$540.03	1.49
236	0	$0.00	$0.00	0	$0.00	0.00
237	0	$0.00	$0.00	0	$0.00	0.00
238	3	$93.07	$198.11	0	$291.18	0.65
Total	6	$939.22	$340.19	0	$1362.41	0.65(avg)
Bi-fuel CNG Vans						
239	1	$442.15	$60.00	0	$502.15	0.97
240	0	$0.00	$0.00	0	$0.00	0.00
241	4	$47.29	$37.88	0	$85.17	0.17
242	1	$0.00	$49.18	0	$49.18	0.10
243	1	$49.73	$75.76	0	$125.49	0.25
Total	7	$539.17	$481.00	0	$761.99	0.30(avg)

Table B7a – Explanation of Warranty Repairs

Vehicle	Problem	Solution
233	Battery registered no voltage	No problem found – corrected itself
234	CNG leak	Replaced filler valve/neck assembly
235	CNG leak	Replaced filler valve/neck assembly
235	Check Engine light on	No problem found
238	Check Engine light on	Repaired vacuum hose
238	Check Engine light on	Replaced mass airflow sensor
238	Check Engine light on	Replaced fuel injectors
239	CNG leak	Replaced filler valve/neck assembly
241	Clock noisy	Replaced clock spring
241	Runs poorly on CNG - stalls	No problem found
241	Runs poorly on CNG – stalls	No problem found
241	Runs poorly on CNG - stalls	Replaced GFI computer
242	Check Engine light on	No problem found
243	Check Engine light on	Replaced sensor assembly

Appendix C
Customer Survey

Customer Survey:
Participate Locally, Think Nationally!

Chances are, you wouldn't be on this bus if you didn't care about our nation's air quality and dependence on foreign oil. And because the U.S. Department of Energy (DOE) is concerned too, it conducts studies on alternative (non-petroleum) fuels and alternative fuel vehicles (AFVs). This very bus is part of one of those studies! The Gas Research Institute and DOE's National Renewable Energy Laboratory (NREL) have joined with several other partners to evaluate this fleet of vehicles that run on compressed natural gas (CNG).

Boulder's Super Shuttle demonstrated its commitment to the local community by agreeing to replace 10 of its gasoline vehicles with new CNG AFVs. Operating these vehicles enables NREL to collect in-service data and publish information that helps U.S. fleets make AFV purchase decisions, gives auto manufacturers perspectives on "real-world" AFV performance, and allows policy makers to formulate clean air and energy security strategies.

How can you get involved?

By taking a few minutes during your ride to fill out the brief questionnaire below. Give your completed survey to your driver. If you're interested in our programs, contact the Alternative Fuels Hotline at 1-800-423-1DOE, visit the Alternative Fuels Data Center at http://www.afdc.doe.gov, or check out Natural Fuels at http://www.naturalfuels.com.

We appreciate your participation!

Program Participants

SuperShuttle
Department of Energy
National Renewable Energy Laboratory
Gas Research Institute
Natural Fuels
Ford Motor Company
Sill-Terhar Ford Dealership
Environmental Testing Corporation

Customer Survey

Were you aware that you're riding in an alternative fuel vehicle?
1. Yes 2. No

How important do you consider developing alternatives to petroleum to be?

1. unimportant
2. somewhat unimportant
3. neutral
4. somewhat important
5. very important

Are you aware that natural gas is produced in the United States?
1. Yes 2. No

Rate your feelings about using a compressed natural gas vehicle for transportation:

1. unacceptable
2. somewhat unacceptable
3. neutral
4. somewhat acceptable
5. acceptable

What are your main reasons for the previous choice?

Does a company's use of alternative fuels or other environmentally friendly products influence your decision to use their services?
1. Yes 2. No

Why?
Please see reverse.

Any other comments?

Detailed Results of the Customer Survey

Were you aware that you're riding in an alternative fuel vehicle?

Response	Number	Percent
Yes	17	25
No	48	70.6
Total answers	65	95.6
Total # of surveys	68	100

How important do you consider developing alternatives to petroleum to be?

Response	Number	Percent
Unimportant	0	0
Somewhat Unimportant	3	4.4
Neutral	4	5.9
Somewhat important	11	16.2
Important	50	73.5

Are you aware that natural gas is produced in the United States?

Response	Number	Percent
Yes	57	15
No	10	85

Rate your feelings about using a compressed natural gas vehicle for transportation:

Response	Number	Percent
Unacceptable	0	0
Somewhat Unacceptable	1	1.5
Neutral	14	20.9
Somewhat acceptable	10	14.9
Acceptable	42	62.7

What are your main reasons for the previous choice?

Response	Number	Percent
None given	22	32.4
Energy dependence	3	4.4
Cleaner Air	21	30.9
Conserve resources	2	2.9
Don't know enough	11	16.2

Does a company's use of alternative fuels or other environmentally friendly products influence your decision to use their services?

Response	Number	Percent
Yes	39	59.1
No	27	40.9
Number of answers	66	97

Why?

Reasons for respondents answering "Yes":

Response	Number	Percent
None given	14	35.9
Cleaner Air	14	35.9
Reduce energy dependence	3	7.7
Other	6	15.4
Total "yes" answers	39	100

Reasons for respondents answering "No":

Response	Number	Percent
None given	15	55.6
Convenience more important	4	14.8
Price more important	2	7.4
Other	6	22.2
Total "no" answers	27	100

Any other comments?

Should be more timely
Cost is important as to whether I would buy a CNG vehicle
Good for you for participating in research in this area
Good for you guys!
Good for your company to be part of this experiment
Great!
I am not aware of this issue
If I can help in any small way to keep even 1 species of animal on this earth - I will do it!
Keep it going
Keep it up
Shuttles are effective

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13. ABSTRACT *(Maximum 200 words)*
The mission of the U.S. Department of Energy's Office of Transportation Technologies is to promote the development and deployment of transportation technologies that reduce U.S. dependence on foreign oil, while helping to improve the nation's air quality and promoting U.S. competitiveness. In support of this mission, DOE has directed the National Renewable Energy Laboratory to conduct projects to evaluate the performance and acceptability of alternative fuel vehicles. NREL has undertaken several fleet study projects, which seek to provide objective real-world fleet experiences with AFVs. For this type of study we collect, analyze, and report on operational, cost, emissions, and performance data from AFVs being driven in a fleet application. The primary purpose of such studies is to make real-world information on AFVs available to fleet managers and other potential AFV purchasers. For this project, data was collected from 13 passenger vans operating in the Boulder/Denver, Colorado area. The study vehicles were all 1999 Ford E-350 passenger vans based at SuperShuttle's Boulder location. Five of the vans were dedicated CNG, five were bi-fuel CNG/gasoline, and three were standard gasoline vans that were used for comparison.

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