

# SuperShuttle CNG Fleet Evaluation

## Final Report

Leslie Eudy



**NREL**

**National Renewable Energy Laboratory**

1617 Cole Boulevard  
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory  
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

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Prepared under Task No. FU135610



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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             | <i>Code of Federal Regulations</i>  |
| CH <sub>4</sub> | Methane   |
| CNG             | Compressed natural gas  |
| CO              | Carbon monoxide   |
| CO <sub>2</sub> | 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             | Liquefied petroleum gas   |
| mpeg            | Miles per equivalent gallon   |
| mpg             | Miles per gallon  |
| mph             | Miles per hour  |
| NMHC            | Non-methane hydrocarbon   |
| NMOG            | Non-methane organic gases   |
| NO <sub>x</sub> | 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)<sup>1</sup> 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.

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<sup>1</sup> 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**

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

<sup>1</sup> gasoline gallon equivalent

<sup>2</sup> California super-ultra low emission vehicle

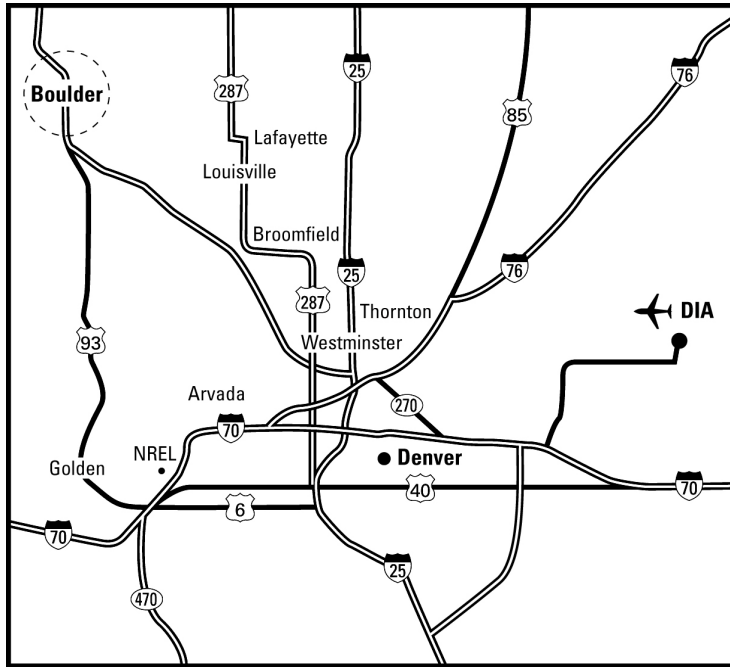
<sup>3</sup> federal ultra-low emission vehicle/inherently low emission vehicle

<sup>4</sup> low emission vehicle

<sup>5</sup> 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<sub>4</sub>), and carbon dioxide (CO<sub>2</sub>). 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 its 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                             |
| <b>Average</b> |               |               | <b>61520</b>                    |                         | <b>5493</b>                      |
| 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                             |
| <b>Average</b> |               |               | <b>44302</b>                    |                         | <b>3692</b>                      |
| 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                             |
| <b>Average</b> |               |               | <b>61927</b>                    |                         | <b>5161</b>                      |

### ***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.

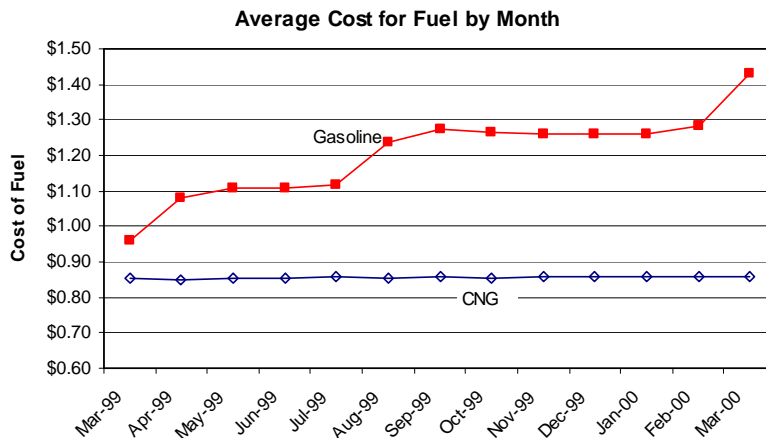
Table 6 summarizes the fuel economy and cost data for the study vans. The average fuel economy and fuel costs are listed for each van type. (Average fuel economy and cost for each vehicle can be found in Appendix B, Table B1.) As previously noted, the fuel economy for the bi-fuel vans is a combined CNG/gasoline 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 (mpege) | 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 mpege (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)

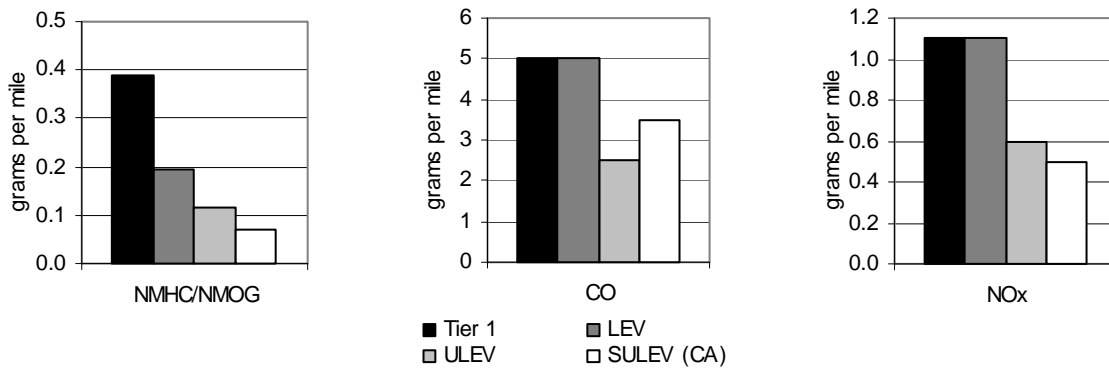
| Vehicle Type             | Dedicated CNG | Bi-Fuel CNG | Gasoline |
|--------------------------|---------------|-------------|----------|
| Average Fuel Cost        | 8.16          | 10.06       | 11.43    |
| Average Maintenance Cost | 2.91          | 2.58        | 2.87     |
| Total Operating Costs    | 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  |
| <b>Tier 1</b> | 0.39               | -     | 5.0 | 1.1 | 0.56                 | -     | 7.3 | 1.53 |
| <b>LEV</b>    | -                  | 0.195 | 5.0 | 1.1 | -                    | 0.28  | 7.3 | 1.5  |
| <b>ULEV</b>   | -                  | 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.

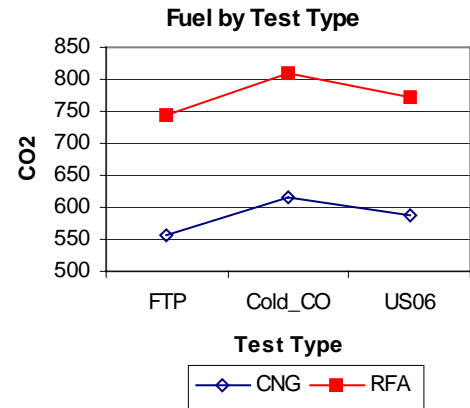
This section describes the results from the emissions testing done on the 13 study vans. The results are separated into two sections: comparison of the dedicated vans, and comparison of the bi-fuel vans tested on each fuel. The summary tables give the average emissions by vehicle type and fuel, the percent 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:

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

where  $\bar{X}$  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<sup>®</sup> 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<sub>2</sub> 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<sub>2</sub>. 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 NO<sub>x</sub> 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.

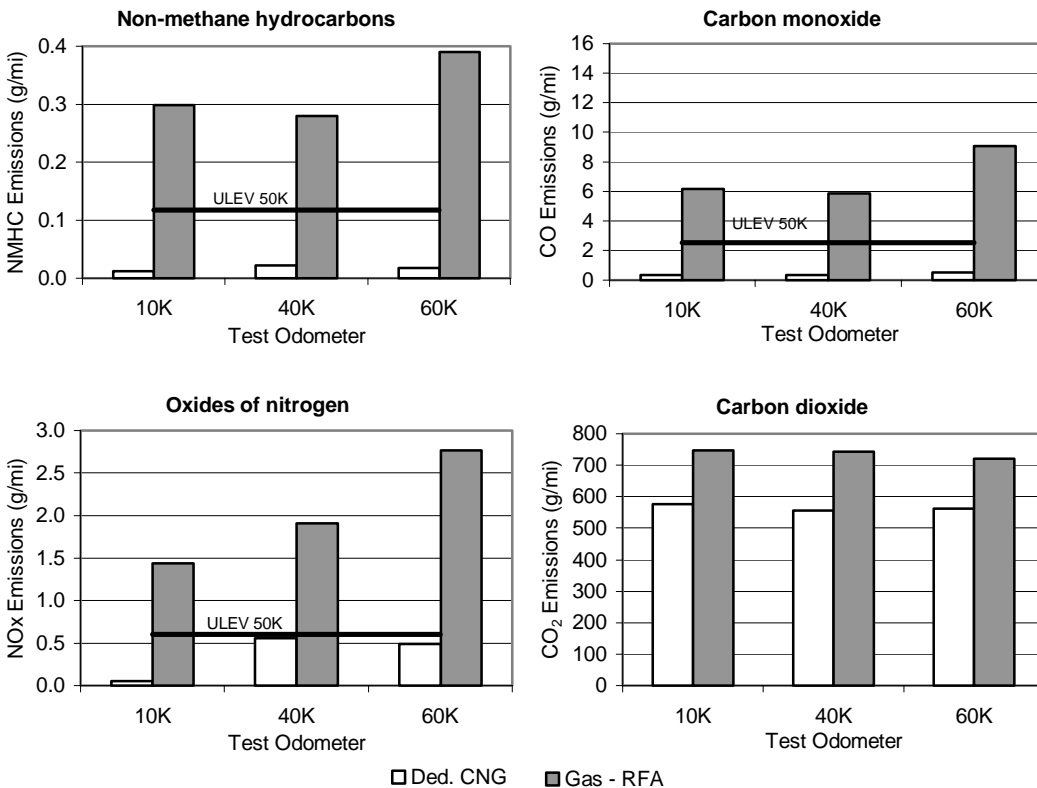
In addition to the overall lower average emissions for the CNG vans compared to the gasoline vans, there were also differences in how the emissions rates changed with increasing mileage for the two technologies. Testing the vehicles at different mileage intervals gives an indication of whether they show 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 NO<sub>x</sub> 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 NO<sub>x</sub> in all three test rounds, and for CO and NMHC between Rounds 2 and 3.

Emissions of CO<sub>2</sub> 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<sub>2</sub> 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<sub>4</sub> emissions. The dedicated CNG vans showed a deterioration of CH<sub>4</sub> 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 <sub>2</sub>            | 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 <sub>4</sub>            | 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.

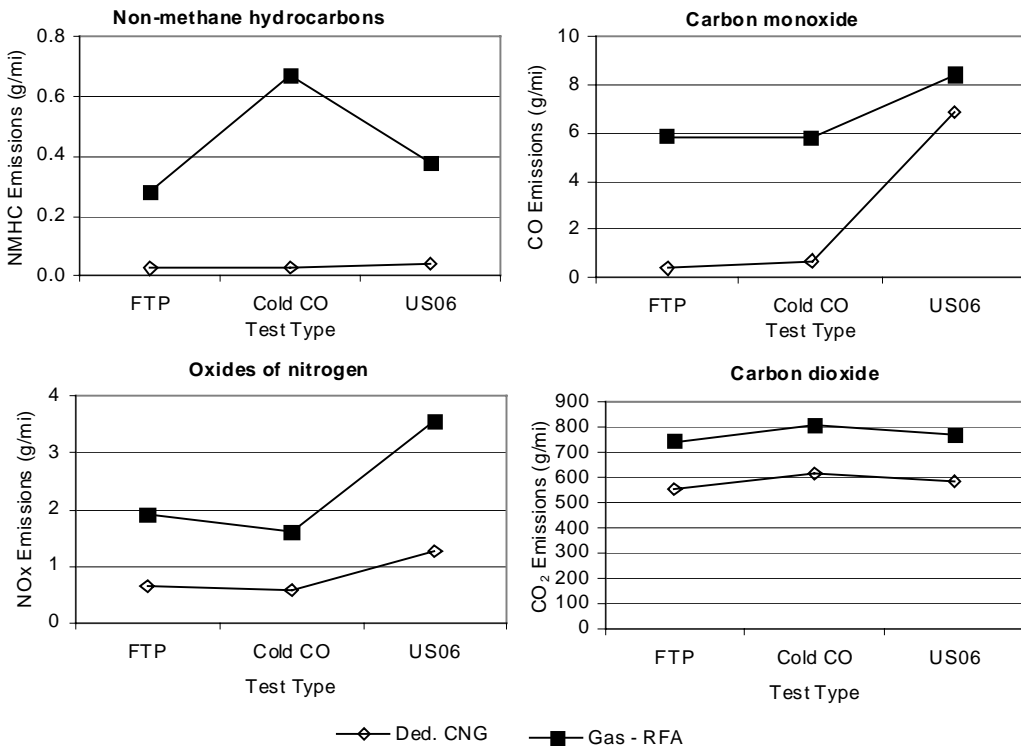
Table 12 summarizes the results from the detailed study tests on the dedicated CNG and gasoline vans. Figure 5 shows the results graphically. The results show that, with the exception of CH<sub>4</sub>, the dedicated CNG vans had the lowest emissions for all constituents on all driving cycles. The difference 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<sub>2</sub> 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<sub>2</sub> emissions were significantly higher during the Cold test, while CO emissions were not significantly different, and NO<sub>x</sub> emissions were lower. The NO<sub>x</sub> 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<sub>4</sub> 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<sub>4</sub>. 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, NO<sub>x</sub>, and CO<sub>2</sub> 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 <sub>2</sub>                    | 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 <sub>4</sub>                    | 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 NO<sub>x</sub> 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 NO<sub>x</sub> 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 NO<sub>x</sub> emissions showed a marked increase. The opposite was true when the bi-fuel vans were tested on gasoline; emissions of NO<sub>x</sub> 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<sub>2</sub> for the CNG tests, and significantly higher CH<sub>4</sub>. Emissions of CO<sub>2</sub> were approximately 20% less when the vans were tested on CNG. The CO<sub>2</sub> 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.

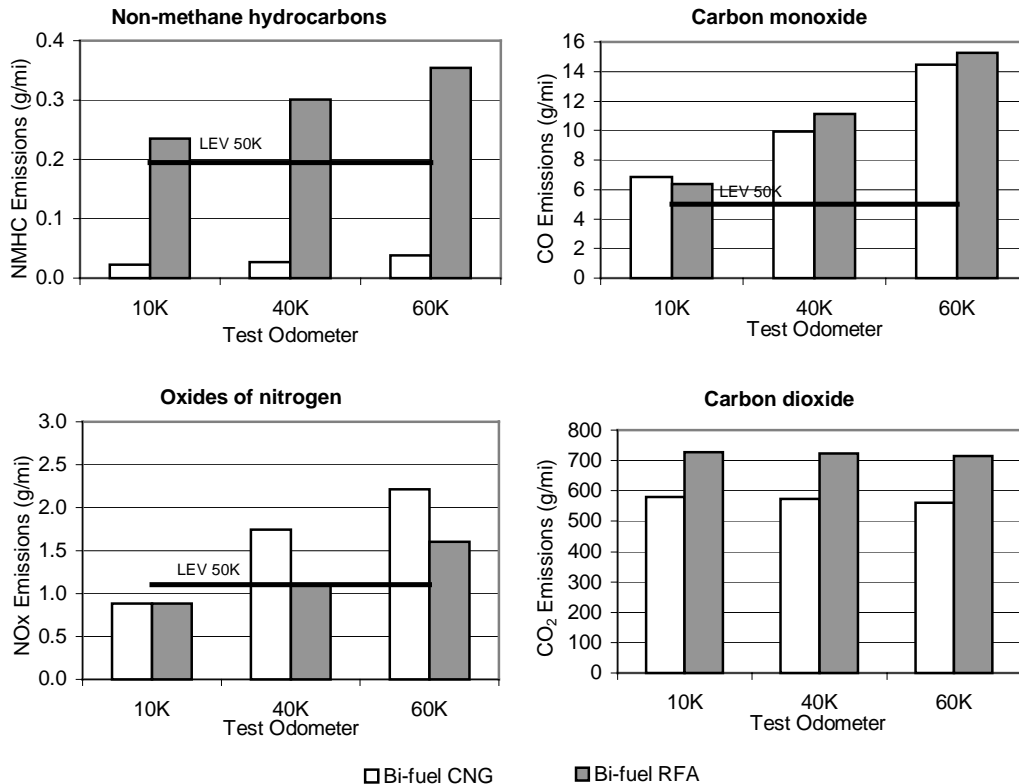
As with the dedicated vans, 3 of the bi-fuel vans were randomly selected for detailed testing during the second round. Table 14 gives the results for the bi-fuel vans tested on each fuel. Figure 7 shows the comparison for NMHC, CO, NO<sub>x</sub>, and CO<sub>2</sub> for the bi-fuel vans.

The difference between fuels on the bi-fuel vans showed mixed results. NMHC, CO, and CO<sub>2</sub> emissions were all significantly lower for the CNG tests, while NO<sub>x</sub>, and CH<sub>4</sub> 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<sub>2</sub>, 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, NO<sub>x</sub>, CO<sub>2</sub> and CH<sub>4</sub>. The increases in NMHC and CO<sub>2</sub> 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 <sub>2</sub>            | 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 <sub>4</sub>            | 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

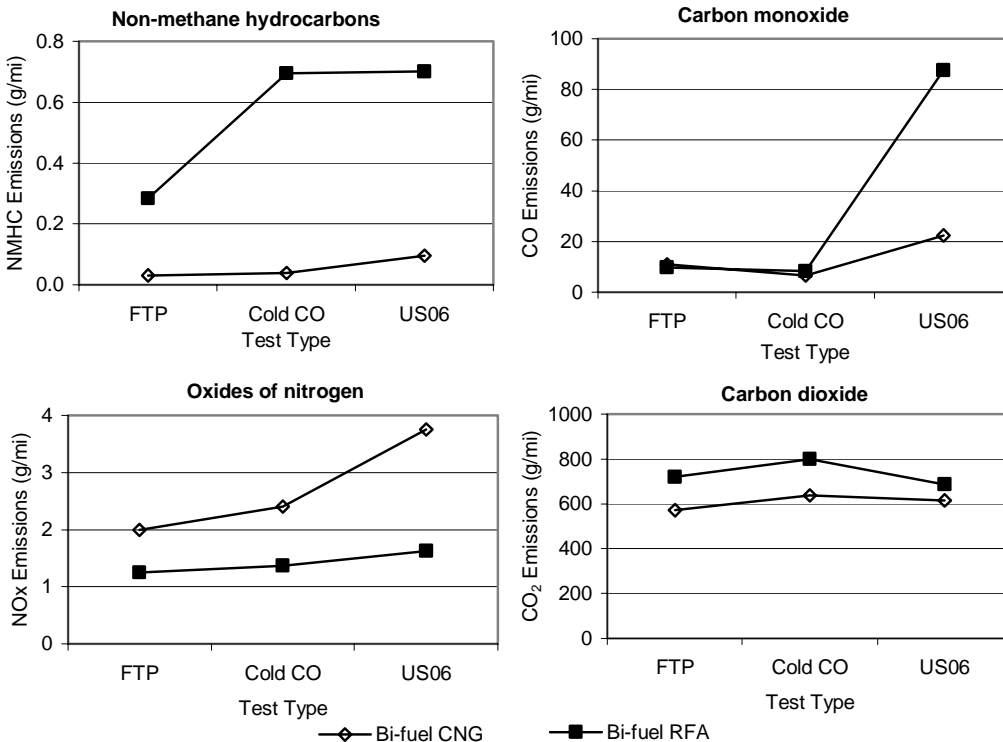


**Figure 6. Average emissions for the bi-fuel vans on CNG and RFA**



**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 <sub>2</sub>                    | 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 <sub>4</sub>                    | 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<sub>2</sub> 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 NO<sub>x</sub>, CO<sub>2</sub>, and CH<sub>4</sub> that were significant. Testing the bi-fuel vans on RFA resulted in increases in NMHC and CO that were significant, increases in NO<sub>x</sub> and CH<sub>4</sub> that were not significant, and a decrease in CO<sub>2</sub> 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](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**

Gas Technology Institute and the Office of Technology Utilization, which is part of the Office of Transportation Technology at the U.S. Department of Energy, jointly sponsored this work. We would like to express our appreciation to Ross Alexander, Bill Fries, George Stone, and all the other SuperShuttle staff who lent their support to this project.

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# **Appendix A**

## **Detailed Emissions Data**

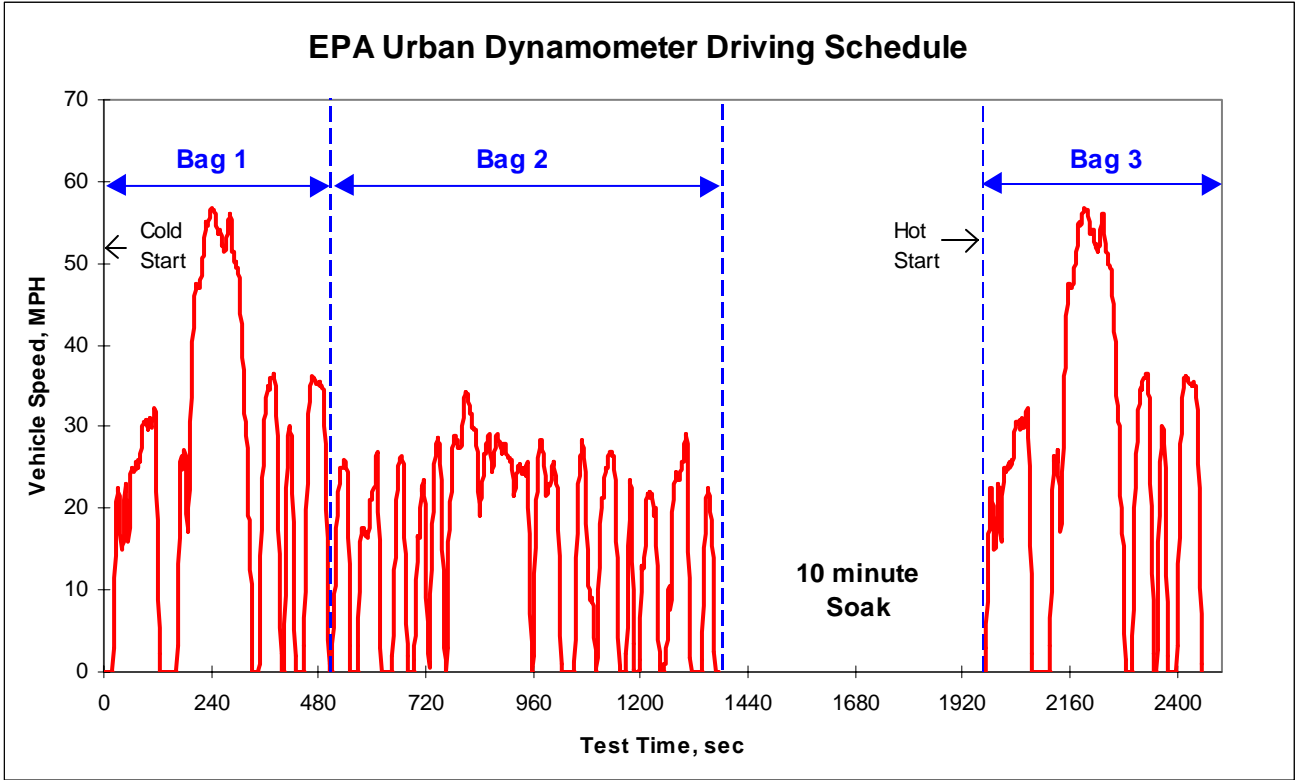


Figure A1. EPA FTP-75 driving cycle

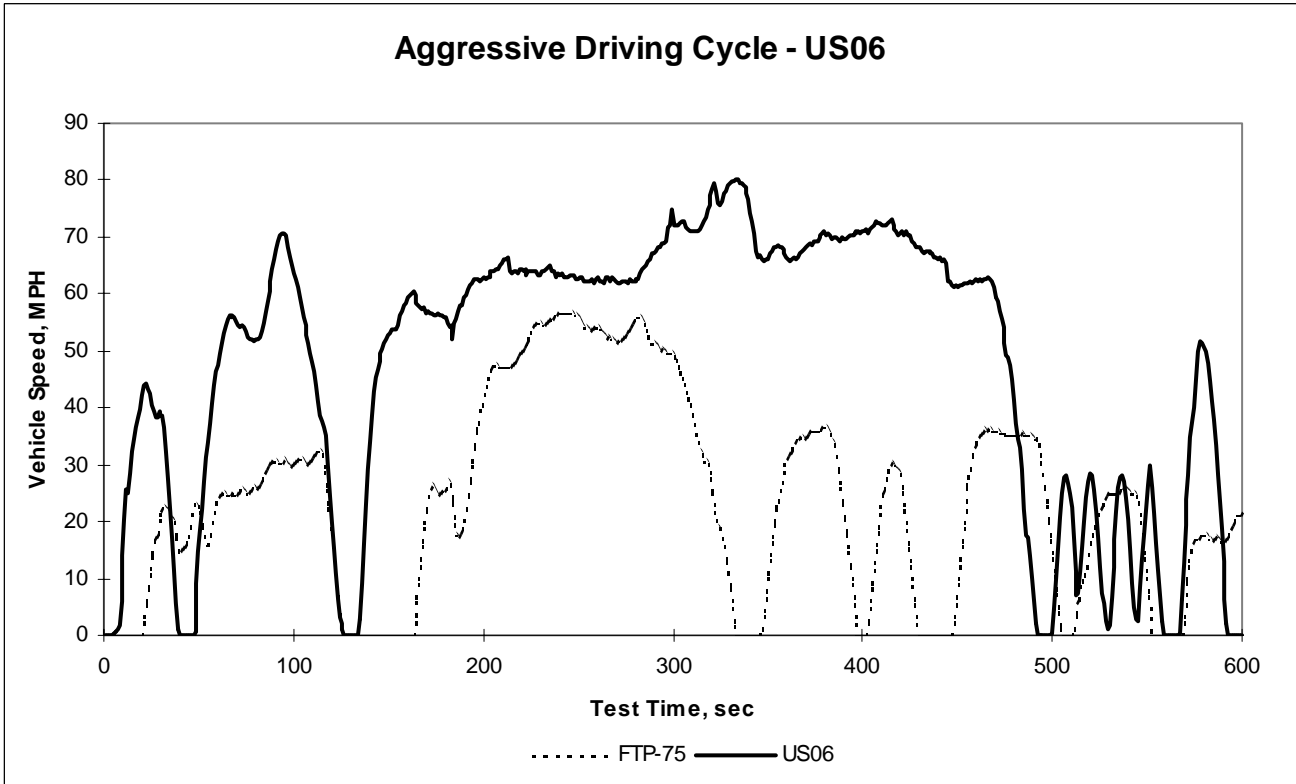


Figure A2. US06 Driving Cycle (first 600 seconds of the FTP-75 superimposed for comparison)

Table A1 - FTP Gasoline Control Emissions Results

|         | Vehicle ID | Test Date  | Odometer | Fuel        | MPG            | CH <sub>4</sub> | CO    | CO <sub>2</sub> | 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  |       |
|         |            |            |          |             | <b>Count</b>   | 3               | 3     | 3               | 3      | 3     | 3     | 3     |
|         |            |            |          |             | <b>Average</b> | 11.82           | 0.063 | 6.14            | 747.67 | 0.298 | 1.443 | 0.357 |
|         |            |            |          | <b>STD*</b> | 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  |       |
|         |            |            |          |             | <b>Count</b>   | 3               | 3     | 3               | 3      | 3     | 3     | 3     |
|         |            |            |          |             | <b>Average</b> | 11.9            | 0.053 | 5.873           | 742.97 | 0.280 | 1.903 | 0.333 |
|         |            |            |          | <b>STD*</b> | 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   |       |
|         |            |            |          |             | <b>Count</b>   | 3               | 3     | 3               | 3      | 3     | 3     | 3     |
|         |            |            |          |             | <b>Average</b> | 12.177          | 0.067 | 9.067           | 720.56 | 0.390 | 2.763 | 0.46  |
|         |            |            |          | <b>STD*</b> | 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 <sub>4</sub> | CO    | CO <sub>2</sub> | NMHC   | NO <sub>x</sub> | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5     | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 11.174 | 0.106           | 0.342 | 574.65          | 0.0107 | 0.056           | 0.116 |
|         |            |            |          | <b>STD*</b>    | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5     | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 11.554 | 0.244           | 0.334 | 555.42          | 0.0204 | 0.498           | 0.264 |
|         |            |            |          | <b>STD*</b>    | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 4      | 4               | 4     | 4               | 4      | 4               | 4     |
|         |            |            |          | <b>Average</b> | 11.77  | 0.303           | 0.50  | 562.82          | 0.017  | 0.49            | 0.318 |
|         |            |            |          | <b>STD*</b>    | 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 <sub>4</sub> | CO    | CO <sub>2</sub> | NMHC   | NO <sub>x</sub> | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5     | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 10.89  | 0.396           | 6.84  | 578.77          | 0.022  | 0.88            | 0.416 |
|         |            |            |          | <b>STD*</b>    | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5     | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 10.896 | 0.53            | 9.918 | 573.11          | 0.026  | 1.75            | 0.558 |
|         |            |            |          | <b>STD*</b>    | 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  |
|         |            |            |          |                |        |                 |       |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5     | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 10.99  | 0.67            | 14.45 | 560.37          | 0.0383 | 2.212           | 0.71  |
|         |            |            |          | <b>STD*</b>    | 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 <sub>4</sub> | CO     | CO <sub>2</sub> | NMHC   | NO <sub>x</sub> | 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   |
|         |            |            |          |                |        |                 |        |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5      | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 12.15  | 0.048           | 6.374  | 726.95          | 0.235  | 0.884           | 0.28  |
|         |            |            |          | <b>STD*</b>    | 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   |
|         |            |            |          |                |        |                 |        |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5      | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 12.09  | 0.056           | 11.132 | 723.09          | 0.302  | 1.104           | 0.36  |
|         |            |            |          | <b>STD*</b>    | 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  |
|         |            |            |          |                |        |                 |        |                 |        |                 |       |
|         |            |            |          | <b>Count</b>   | 5      | 5               | 5      | 5               | 5      | 5               | 5     |
|         |            |            |          | <b>Average</b> | 12.112 | 0.072           | 15.25  | 715.03          | 0.354  | 1.606           | 0.428 |
|         |            |            |          | <b>STD*</b>    | 0.224  | 0.008           | 2.273  | 14.618          | 0.047  | 0.223           | 0.052 |

**Table A5 – Gasoline Control - Detailed Round 2 Tests**

| Cold CO | Vehicle ID | Test Date  | Odometer | Fuel           | MPG            | CH <sub>4</sub> | CO    | CO <sub>2</sub> | NMHC   | NOx    | THC    |       |
|---------|------------|------------|----------|----------------|----------------|-----------------|-------|-----------------|--------|--------|--------|-------|
|         | 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   |       |
|         |            |            |          | <b>Count</b>   | 3              | 3               | 3     | 3               | 3      | 3      | 3      |       |
|         |            |            |          | <b>Average</b> | 10.587         | 0.06            | 5.8   | 809.55          | 0.670  | 1.593  | 0.73   |       |
|         |            |            |          | <b>STD*</b>    | 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   |       |
|         |            |            |          |                | <b>Count</b>   | 3               | 3     | 3               | 3      | 3      | 3      | 3     |
|         |            |            |          |                | <b>Average</b> | 11.407          | 0.050 | 8.453           | 771.20 | 0.377  | 3.557  | 0.428 |
|         |            |            |          |                | <b>STD*</b>    | 0.042           | 0.009 | 1.177           | 4.934  | 0.148  | 0.375  | 0.158 |

**Table A6 – Dedicated CNG - Detailed Round 2 Tests**

| Cold CO | Vehicle ID | Test Date  | Odometer | Fuel           | MPG            | CH <sub>4</sub> | CO    | CO <sub>2</sub> | NMHC   | NOx   | THC   |       |
|---------|------------|------------|----------|----------------|----------------|-----------------|-------|-----------------|--------|-------|-------|-------|
|         | 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  |       |
|         |            |            |          | <b>Count</b>   | 3              | 3               | 3     | 3               | 3      | 3     | 3     |       |
|         |            |            |          | <b>Average</b> | 10.41          | 0.337           | 0.707 | 615.63          | 0.027  | 0.577 | 0.363 |       |
|         |            |            |          | <b>STD*</b>    | 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 |       |
|         |            |            |          |                | <b>Count</b>   | 3               | 3     | 3               | 3      | 3     | 3     | 3     |
|         |            |            |          |                | <b>Average</b> | 10.747          | 0.334 | 6.847           | 586.65 | 0.043 | 1.250 | 0.377 |
|         |            |            |          | <b>STD*</b>    | 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 <sub>4</sub> | CO      | CO <sub>2</sub> | NMHC   | NOx    | THC    |       |
|-------------|----------------|------------|------------|----------------|----------------|-----------------|---------|-----------------|--------|--------|--------|-------|
|             | <b>Cold CO</b> | 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    |       |
|             |                |            |            | <b>Count</b>   | 3              | 3               | 3       | 3               | 3      | 3      | 3      |       |
|             |                |            |            | <b>Average</b> | 9.91           | 0.563           | 6.667   | 636.97          | 0.039  | 2.4    | 0.603  |       |
|             |                |            |            | <b>STD*</b>    | 0.181          | 0.081           | 2.492   | 8.011           | 0.012  | 0.121  | 0.090  |       |
|             |                |            |            |                |                |                 |         |                 |        |        |        |       |
| <b>US06</b> | 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 |       |
|             |                |            |            |                | <b>Count</b>   | 3               | 3       | 3               | 3      | 3      | 3      | 3     |
|             |                |            |            |                | <b>Average</b> | 9.87            | 0.862   | 22.437          | 614.32 | 0.094  | 3.757  | 0.957 |
|             |                |            |            |                | <b>STD*</b>    | 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 <sub>4</sub> | CO       | CO <sub>2</sub> | NMHC    | NOx    | THC    |       |
|-------------|----------------|------------|------------|----------------|----------------|-----------------|----------|-----------------|---------|--------|--------|-------|
|             | <b>Cold CO</b> | 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   |       |
|             |                |            |            | <b>Count</b>   | 3              | 3               | 3        | 3               | 3       | 3      | 3      |       |
|             |                |            |            | <b>Average</b> | 10.673         | 0.063           | 8.257    | 800.50          | 0.695   | 1.373  | 0.757  |       |
|             |                |            |            | <b>STD*</b>    | 0.110          | 0.006           | 0.630    | 8.215           | 0.050   | 0.379  | 0.045  |       |
|             |                |            |            |                |                |                 |          |                 |         |        |        |       |
| <b>US06</b> | 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   |       |
|             |                |            |            |                | <b>Count</b>   | 3               | 3        | 3               | 3       | 3      | 3      | 3     |
|             |                |            |            |                | <b>Average</b> | 10.83           | 0.159    | 87.538          | 687.378 | 0.701  | 1.623  | 0.859 |
|             |                |            |            |                | <b>STD*</b>    | 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        |
|            |                |              |
|            | <b>Count</b>   | 3            |
|            | <b>Average</b> | 0.040        |
|            | <b>STD*</b>    | 0.022        |
|            |                |              |
| SS231GFC   | RFA            | 0.186        |
| SS232GFC   | RFA            | 0.049        |
| SS233GFC   | RFA            | 0.306        |
|            |                |              |
|            | <b>Count</b>   | 3            |
|            | <b>Average</b> | 0.180        |
|            | <b>STD*</b>    | 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        |
|            |                |              |
|            | <b>Count</b>   | 3            |
|            | <b>Average</b> | 27.20        |
|            | <b>STD*</b>    | 15.75        |
|            |                |              |
| SS239CF    | RFA            | 0.348        |
| SS241CF    | RFA            | 0.096        |
| SS242CF    | RFA            | 0.128        |
|            |                |              |
|            | <b>Count</b>   | 3            |
|            | <b>Average</b> | 0.191        |
|            | <b>STD*</b>    | 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**

| Vehicle ID | % CNG use by volume |      |      |      |      |
|------------|---------------------|------|------|------|------|
|            | 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

| REPORT DOCUMENTATION PAGE  |   |  | Form Approved<br>OMB NO. 0704-0188                                     |  |
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