CleanFleet

FINAL REPORT

December 1995

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FUEL ECONOMY

Fuel economy estimates are provided for the CleanFleet vans operated for two years by FedEx in Southern California. Between one and three vehicle manufacturers (Chevrolet, Dodge, and Ford) supplied vans powered by compressed natural gas (CNG), propane gas, California Phase 2 reformulated gasoline (RFG), methanol (M-85), and unleaded gasoline as a control. Two electric G-Vans, manufactured by Conceptor Corporation, were supplied by Southern California Edison. Vehicle and engine technologies are representative of those available in early 1992. A total of 111 vans were assigned to FedEx delivery routes at five demonstration sites. The driver and route assignments were periodically rotated within each site to ensure that each vehicle would experience a range of driving conditions. Regression analysis was used to estimate the relationships between vehicle fuel economy and factors such as the number of miles driven and the number of delivery stops made each day. The energy adjusted fuel economy (distance per energy consumed) of the alternative fuel vans operating on a typical FedEx duty cycle was between 13 percent lower and 4 percent higher than that of control vans from the same manufacturer. The driving range of vans operating on liquid and gaseous alternative fuels was 1 percent to 59 percent lower than for vans operating on unleaded gasoline. The driving range of the electric G-Vans was less than 50 miles. These comparisons are affected to varying degrees by differences in engine technology used in the alternative fuel and control vehicles. Relative fuel economy results from dynamometer emissions tests were generally consistent with those obtained from FedEx operations.

Introduction

Fuel economy estimates were obtained from statistical analyses of fuel consumption records kept on 111 CleanFleet vans while being operated by FedEx in normal package delivery service over the two-year demonstration period ending in September 1994. The fuels tested were compressed natural gas (CNG), propane gas, California Phase 2 reformulated gasoline (RFG), methanol (M-85), electricity, and unleaded gasoline as a control. Each alternative fuel was demonstrated at one of five sites in the Los Angeles basin. At each of four sites, either 20 or 21 vans provided by one to three vehicle manufacturers (Chevrolet, Dodge, and Ford) were operated using one of the liquid or gaseous alternative fuels. Three control vehicles from each manufacturer were also included at each of these sites. Two electric vehicles (EVs) with lead-acid and with nickel-cadmium batteries on G-Van platforms were operated at the fifth site. Relative fuel economy, compared to unleaded gasoline, was determined for each combination of alternative fuel and vehicle manufacturer. The results are compared with relative fuel economy estimates determined from the CleanFleet dynamometer emissions tests[1,2,3].

VEHICLE FUEL ECONOMY

Vehicles Tested

The vehicles that were used in the CleanFleet project represented a range of technologies that were available in 1992 and could be put into the rigors of daily commercial delivery service. As such, the degree to which engine and fuel system technologies were optimized for alternative fuels varied among fuel types and vehicle manufacturers. Relevant characteristics of the vans are listed in Table 1. Further details on vehicle specifications are provided in Volume 2: Project Design and Implementation[4].

Table 1. Characteristics of CleanFleet Vehicles

Vehicle Manufacturer	Fuel[a]	Engine: Displacement (L)	Engine: Type[b]	Engine: Compression Ratio	Fuel Delivery	Weight (lbs)
Ford	M-85	4.9	I6	8.8	SMPI[c]	5,530
	Propane Gas	4.9	I6	8.8	TB[d]	5,340
	CNG	4.9	I6	11	SMPI	5,780
	RFG/UNL	4.9	I6	8.8	MPI	5,520
Dodge	CNG	5.2	V8	9.08	SMPI	5,120
	RFG/UNL	5.2	V8	9.08	SMPI	4,820
Chevrolet	Propane Gas	5.7	V8	8.6	TB[d]	5,130
	CNG	5.7	V8	8.6	TB[d]	5,460
	RFG/UNL	4.3	V6	8.6	TBI[e]	4,970
G-Van	Electric	-	-	-	-	7,760

[a] CNG = Compressed natural gas, RFG = Phase 2 reformulated gasoline, UNL = Unleaded gasoline (industry average RF-A gasoline was used for the emissions tests on control vans).
[b] I6 = Inline, 6 cylinder.
[c] MPI = Multiport electronic fuel injection, SMPI = sequential MPI.
[d] TB = Throttle body. IMPCO ADP and AFE systems provide fuel to the engine through the throttle body.
[e] TBI = Throttle body fuel injection.

Fuels Tested

The alternative fuels used on the CleanFleet project were chosen to represent the fuels which would be available to a fleet operator in the 1996 time frame. A brief description of these fuels is presented below. The selection criteria and detailed specifications of the fuels used in CleanFleet are provided in Volume 2: Project Design and Implementation[4].

Natural Gas. Pipeline quality natural gas was delivered to the Irvine demonstration site by Southern California Gas Company.

Propane Gas. HD-5 grade propane gas was delivered by a local propane vendor out of their regular supply.

Reformulated Gasoline. A gasoline blended to meet specifications for California Phase 2 reformulated gasoline was used. This fuel was blended and stored by Phillips Petroleum in Borger, TX and delivered as needed to an underground storage tank at the demonstration site.

Methanol M-85. The M-85 was 85 percent methanol from the California methanol reserve, splash blended with 15 percent Phase 2 reformulated gasoline.

Unleaded Gasoline. Regular grade, 87 octane, unleaded gasoline was purchased through normal FedEx channels.

VEHICLE FUEL ECONOMY

Methods

This section contains a summary of the methods used to estimate and compare the fuel economy of the CleanFleet vans. It includes a discussion of fuel economy measures, descriptions of data collection procedures, and a summary of the data analysis approaches.

Measures of Fuel Economy and Vehicle Range

Because this study involves liquid fuels, gaseous fuels, and electricity, fuel economy is reported in terms of distance travelled per unit of energy consumed. The units chosen for CleanFleet are miles per gasoline equivalent gallon (mi/GEQ), where a GEQ is the amount of fuel that has the same energy content as one gallon of a reference fuel. For CleanFleet, the reference fuel used in calculating fuel economy is the industry average unleaded gasoline, called RF-A, from the Auto/Oil Air Quality Improvement Research Program[5]. RF-A fuel has an energy content of 32.06 MJ/L or 121.3 MJ/gal. The methods for calculating the number of GEQs from fuel property measurements are discussed below along with the procedures used to collect data on fuel properties.

Vehicle range estimates are calculated from the energy storage capacity of the vehicles and their predicted energy consumption rates under typical FedEx driving cycles. Specific driving range estimates are calculated both on volumetric (miles per fuel tank volume) and gravimetric (miles per fuel tank mass) bases.

Data Collection

The data collected on fleet operations include vehicle activity (mileage and route information), fuel consumption, and fuel properties (heating value and density). The emissions fuel economy analysis is based on dynamometer emission test results provided by the California Air Resources Board (ARB). The data collection and management methods are discussed below.

Vehicle Activity. One of the distinct advantages of having FedEx as a host fleet operator for the CleanFleet demonstration was that FedEx employees do an excellent job of reporting their daily activities. Thus, it was possible to use an existing FedEx activity reporting system to monitor the activity of CleanFleet vehicles. The daily activity data include driver identification number, route number, vehicle mileage, and number of delivery stops. These data were used initially to assign vehicles to specific routes; then, periodically reassign them to different routes in order to even-out vehicle mileage and the distribution of duty cycles within each demonstration site. The degree to which the vehicle rotation plan achieved these goals was discussed in the Vehicle Activity section of Volume 2: Project Design and Implementation[4]. Each van was driven on three to five different routes during the two-year demonstration. Because of their limited range, the electric vehicles were assigned to specific routes of less than 25 miles in length. They were not included in the vehicle rotation plan. However, at various times during the demonstration they were assigned to different routes, ranging from nine to 21 miles in length.

Vehicle activity data, including the route/driver rotation schedule, were used in the statistical analysis of vehicle fuel economy data. As shown in Figure 1, vehicle duty cycles can have a significant impact on fuel economy. The dashed line in Figure 1 is a seven-day moving average of the daily mileage from one of the Dodge CNG vans. The solid line is the seven-day moving average of vehicle fuel economy, measured in mi/GEQ. Both are plotted against total vehicle miles. This particular van was scheduled for five rotations, approximately every 5,000 miles. Notice how the fuel economy varied from seven to ten mi/GEQ as the daily mileage varied from 20 to 90 miles per day.

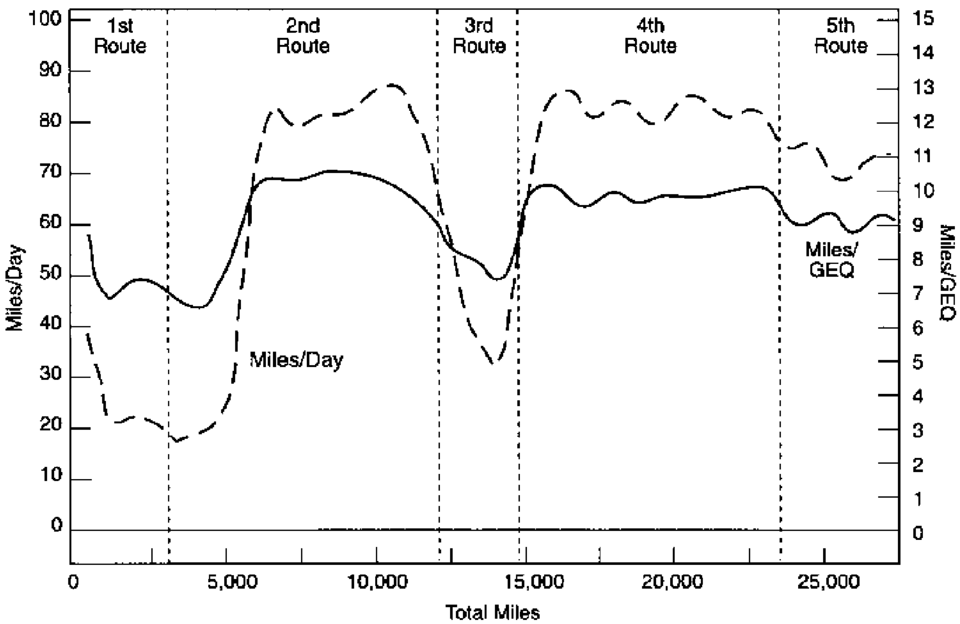

Figure 1. Example of Vehicle Activity/Fuel Economy Profile

Fuel Properties. Each month samples of all fuels used in the CleanFleet project were collected and sent to a laboratory for analysis[4]. Along with other properties, the energy content (MJ/kg for CNG and MJ/L for the liquid fuels) of each fuel was monitored for consistency. As long as there were no systematic changes in the fuel properties, the average energy content was used to convert the amount of fuel dispensed (gallons or kg) to the amount of energy consumed. As shown in Table 2, there were no systematic changes in the energy content of the CNG or M-85 during the CleanFleet demonstration. However, there was a change in the supply of propane gas after the third month of the project which resulted in a 3.1 percent increase in the volumetric energy content (MJ/L) of propane gas dispensed. Also, the second batch of RFG delivered after the sixth month of the project had an energy content that was 2.5 percent less than the initial batch. The unleaded gasoline used as a control fuel is whatever FedEx purchased as part of their routine operations. Thus, there were systematic changes associated with variations in and summer grade gasolines that are sold in the South Coast Air Basin. The energy contents of the fuels during the periods shown in Table 2 were used to determine energy consumption of the CleanFleet vehicles. For the liquid fuels, the number of GEQs per fuel unit is equal to the relative volumetric energy.

Table 2. Energy Content of CleanFleet Fuels

Fuel Type	Period[a]	No. of Months	Lower Heating Value (MJ/kg)	Density (kg/L)	Energy per Volume (MJ/L)	Fuel Units	GEQs per Fuel Units[b]
CNG	9/92 - 9/94	25	47.3	-	-	kg	0.3896
Propane Gas	9/92 - 11/92 12/92 - 9/94	3 22	45.7 46.4	0.493 0.502	22.56 23.27	gal gal	0.7038 0.7257
M-85	9/92 - 9/94	25	23.5	0.787	18.49	gal	0.5767
RFG	9/92 - 2/93 3/93 - 8/94	6 18	43.3 42.0	0.736 0.739	31.83 31.03	gal gal	0.9927 0.9678
Unleaded	Summer Winter	11 8	42.9 42.4	0.753 0.743	32.26 31.45	gal gal	1.0064 0.9810
RF-A[c]	--	--	42.8	0.749	32.06	gal	1.0000

(a) Energy content of each fuel was considered to be constant over the specified periods.
(b) Relative to RF-A, the auto/oil industry average unleaded gasoline.
(c) Reference: SAE 920324, Auto/Oil RF-A Fuel Analysis[5]

content of the fuel used compared to RF-A. The CNG conversion factor is the relative energy content of one kilogram of natural gas compared to that of one gallon of RF-A. For electric vehicles, the conversion factor relating energy consumed in kWh to GEQ units is based on 121.3 MJ = 33.7 kWh.

Fuel Consumption. Fuel consumption was recorded manually each time a vehicle was refueled, usually daily. Consumption of liquid fuels (propane gas, M-85, RFG, and unleaded gasoline) was recorded in gallons. The dispensing unit for CNG measured mass but reported the amount dispensed in nominal therms using a constant conversion factor (4.61 lbs/therm). Electricity was measured in kWh from separate meters assigned exclusively to the two charging systems.

Fuel consumption data were stored in a central database. As new data were entered they were checked for accuracy and consistency against historical data. Data completeness, measured by the percent of miles with valid refueling data, was 96 percent for the alternative fuel vehicles (AFVs) and 87 percent for the controls.

Calibration of Fuel Dispensers. Each alternative fuel dispenser used on the CleanFleet project, as well as each of the regular unleaded dispensers used at the CleanFleet demonstration sites, was either sealed by the local weights and measures department or calibrated to weights and measures standards. For the liquid fuels, standard weights and measures calibration procedures were used. For propane gas, the delivery truck was sealed by the local weights and measures department. For compressed natural gas, Southern California Gas Company performed regular dispenser calibration checks by weighing a test cylinder before and after filling.

Emissions. Emissions tests were performed on three vehicles from each of the twelve fleets representing different combinations of fuel type and vehicle manufacturer[1,2,3]. Fuel economy was calculated for each emissions test using the measured carbon content of the fuel and the observed quantity of emission components containing carbon; namely CO, CO_2, and total hydrocarbons (THC).

The emissions tests were performed by the ARB at their dynamometer testing facility in El Monte, California. Each vehicle was tested at three different mileage levels. Duplicate testing resulted in an average of 5.6 tests on each of 36 vehicles tested. Except for the control vehicles, the fuels used in the dynamometer tests were those used in normal fleet operations. The control vehicles were tested using the industry average unleaded gasoline (RF-A) supplied by the ARB. As shown in Table 2, the RF-A fuel has nearly the same energy content as the summer grade of unleaded used by FedEx in normal operations. This approach was taken to ensure a consistent baseline for comparing results with the alternative fuels.

Data Analysis Approach

Operations Data. As illustrated in Figure 1, fuel economy can vary significantly as the vehicle is driven over different routes. For the most part, FedEx delivery routes do not change very much over time. Many routes involve a daily schedule of pickup and delivery to the same businesses or to residences and businesses within a fixed geographic area. Also, most FedEx couriers are assigned to specific routes. Therefore, the CleanFleet vehicles experienced a fairly constant duty cycle with the same driver for a period of time. The vehicle rotation plan attempted to even-out the distribution of duty cycles among vehicles, both AFVs and controls, within each demonstration site. These duty cycles are best characterized by the number of miles driven per day and the number of delivery stops. Generally, fuel economy improves as the vehicle is driven over longer routes with fewer stops. This was demonstrated in the statistical analysis of the data. The purpose of this analysis was to account for the systematic effect of duty cycles (route length and number of stops) when comparing fuel economy among different vehicle fleets.

The data used in the statistical analysis consisted of the total miles driven, total energy consumed, average daily mileage, and the average number of delivery stops for each vehicle rotation period. An average of 4.5 rotations were performed on each of the 109 liquid and gaseous fueled vehicles. The statistical model is

$$\text{mi/GEQ} = F + \beta_1 \bullet \text{Dmiles} + \beta_2 \bullet \text{Dstops} + \text{error},$$

where F is a constant for each fleet (combination of fuel type and vehicle manufacturer at a given location), Dmiles is the average daily mileage of the route, and Dstops is the average number of daily delivery stops. The error term is due to unexplained differences among vehicles and drivers, variations in the routes over time, and measurement error. The parameters β_1 and β_2 represent the marginal effects of daily mileage and the number of delivery stops.

Weighted least squares regression was used to fit various forms of the above model to the data. The model that fit best assumes a different mileage effect for each demonstration site, but the same effect for fleets within a site. Also, because there were no statistically significant differences in the effect of delivery stops across sites or fleets within sites, the model assumes that this effect is constant. Other factors that often affect fuel economy include total vehicle miles, season of the year, and vehicle-to-vehicle differences. These factors were evaluated, but they were not included because they did not significantly improve the model fit. The validity of the model was verified using standard residual analysis. The R-squared correlation was 71 percent.

Emissions Data. Fuel economy estimates and their associated standard errors were obtained using the same mixed-modal analysis of variance approach that was used in presenting the emissions results(1,2,3). It was determined, however, that mileage accumulation during the two-year demonstration did not have a statistically significant effect on fuel economy. Approximate 95 percent confidence intervals on the estimated relative fuel economy (alternative fuel versus RF-A) were calculated using the propagation of errors method.

Results

Operational Fuel Economy

Figures 2a through 2i are plots of the fuel economy of individual vehicles versus the average daily mileage on the route driven. Each figure displays the data from the alternative fuel and control vehicles of the same manufacturer at a single demonstration site. Depending on the number of vehicle rotations performed, the fuel economy of each vehicle on three to five different routes is shown. The least squares regression lines, representing the predicted fuel economy as a function of average daily mileage, for the alternative fuel and control fleets from the same manufacturer are also displayed. They were calculated using the average number of delivery stops at the demonstration site. The slope of the regression lines, representing the marginal effect of increasing daily mileage for a fixed number of delivery stops, varied from site to site. At Rialto, site of the propane gas demonstration, fuel economy increased at a rate of 0.24 mi/GEQ for each additional 10 miles of daily route length. The routes at Rialto vary from 30 to 130 miles in length. Thus, the differences in duty cycles at this site account for a 2.4 mi/GEQ variation in fuel economy. Duty cycles have the greatest effect on fuel economy at Santa Ana. A ten mile per day increase in route length increases fuel economy for both the M-85 and control vans by nearly 0.5 mi/GEQ. An increase of ten delivery stops per day reduces fuel economy by 0.2 mi/GEQ. This effect was constant across demonstration sites.

Energy consumption data from the two electric G-Vans are listed in Table 3. Both were introduced to the demonstration in April of 1992 and began normal package delivery service on routes averaging 17 to 21 miles per day. Initially, both were powered by lead acid batteries. At the end of the first year both were taken out of service to receive new battery packs. One of the vans, ELG2, received a new lead-acid battery pack and it was returned to service on a shorter route in early 1993. The other van received a new nickel-cadmium battery pack, and it was returned to service a year later. Figure 3 contains plots of the daily mileage and fuel economy (kWh/mi) of the nickel-cadmium powered van. It averaged 1.9 kWh/mi on daily routes of 10 to 30 miles per day. Using a separate DC meter mounted on the vehicle, the average fuel economy was 1.55 kWh/mi. But this does not include the energy consumed by the charging unit.

The average fuel economy of all CleanFleet vehicles is presented in Table 4. Results are presented in mi/GEQ. Reporting fuel economy in units of mi/GEQ effectively places each fleet on the same basis for energy provided to the vans. Differences in mi/GEQ, therefore, reflect the efficiencies of the vehicles in converting the energy of the fuel into miles driven. In the table, the unadjusted fuel economy is simply the ratio of distance travelled to energy consumed. It does not account for differences in duty cycles. On the other hand, the adjusted fuel economy, based on the regression model, estimates fuel economy under comparable conditions. This value represents the predicted fuel economy on a typical duty cycle of 40 miles per day and an average number of stops. The adjusted estimates are subject to a possible statistical error of less than ± 0.3 mi/GEQ (±0.5 mi/GEQ for the control vans) at the 95 percent confidence level. Comparisons between the alternative fuel and control vehicles are presented as percent differences in the adjusted estimates. The reported percent differences are subject to a statistical error (at the 95 percent confidence level) of less than ±5.8 percent.

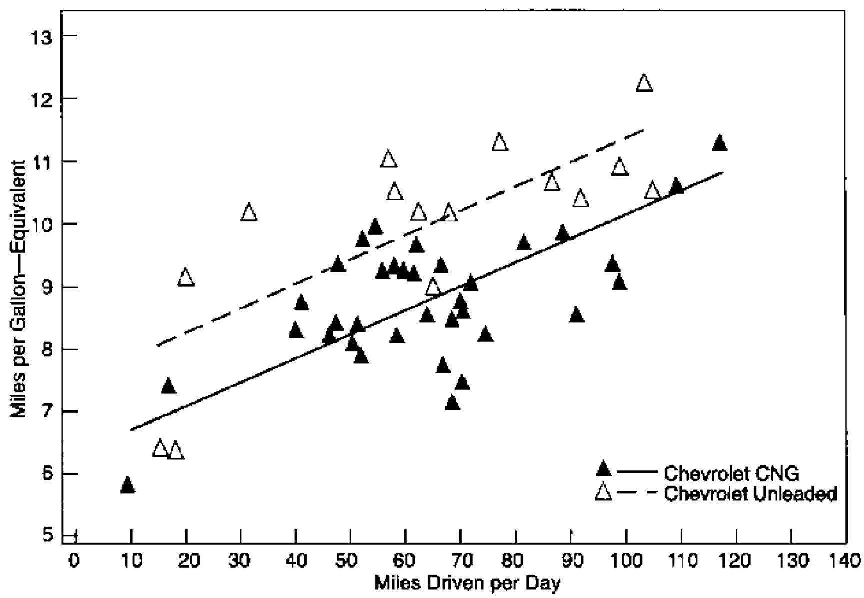

Figure 2-a. Chevrolet CNG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

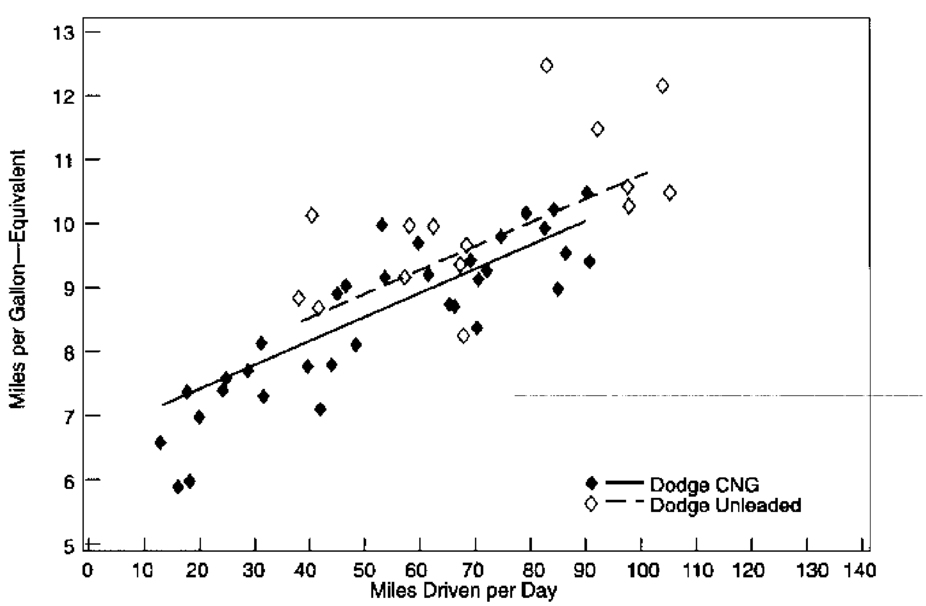

Figure 2-b. Dodge CNG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

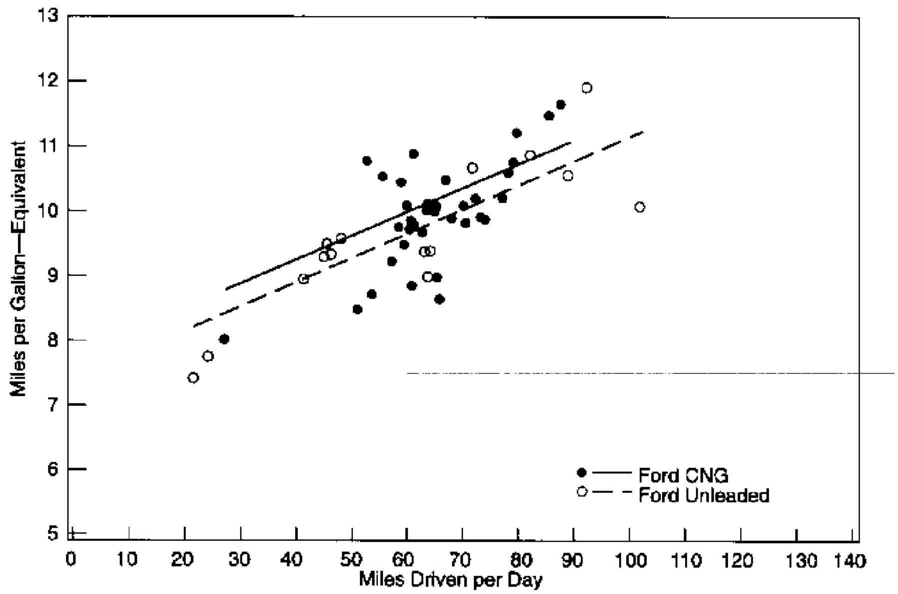

Figure 2-c. Ford CNG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

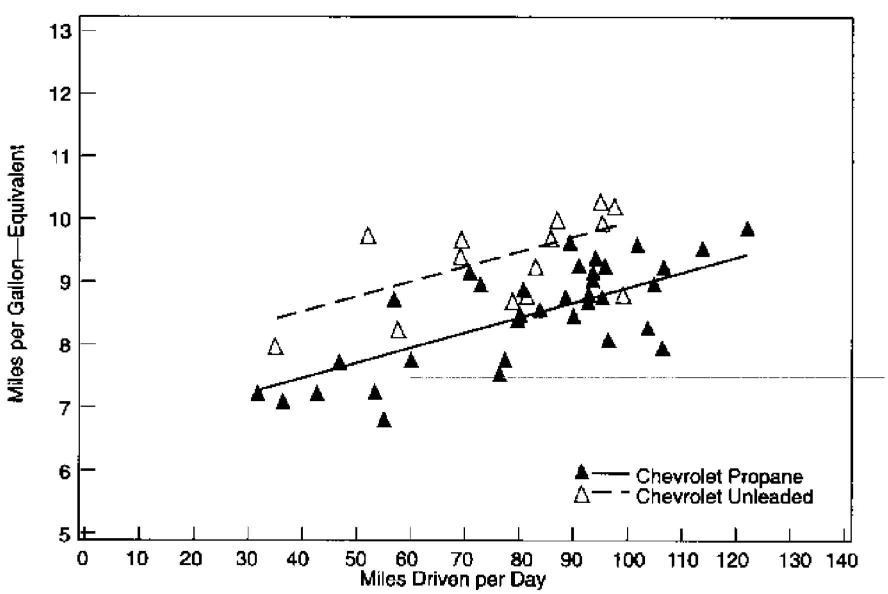

Figure 2-d. Chevrolet Propane Gas and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

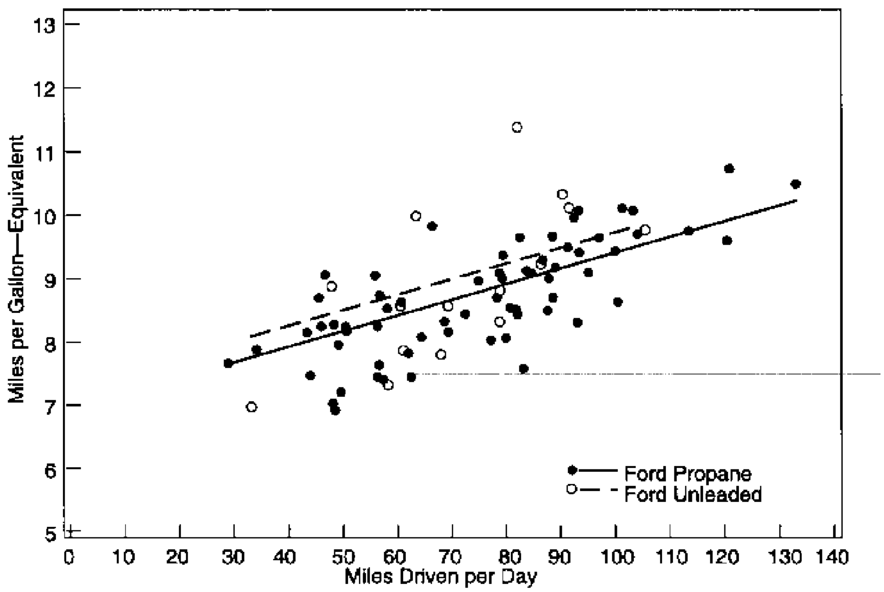

Figure 2-e. Ford Propane Gas and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

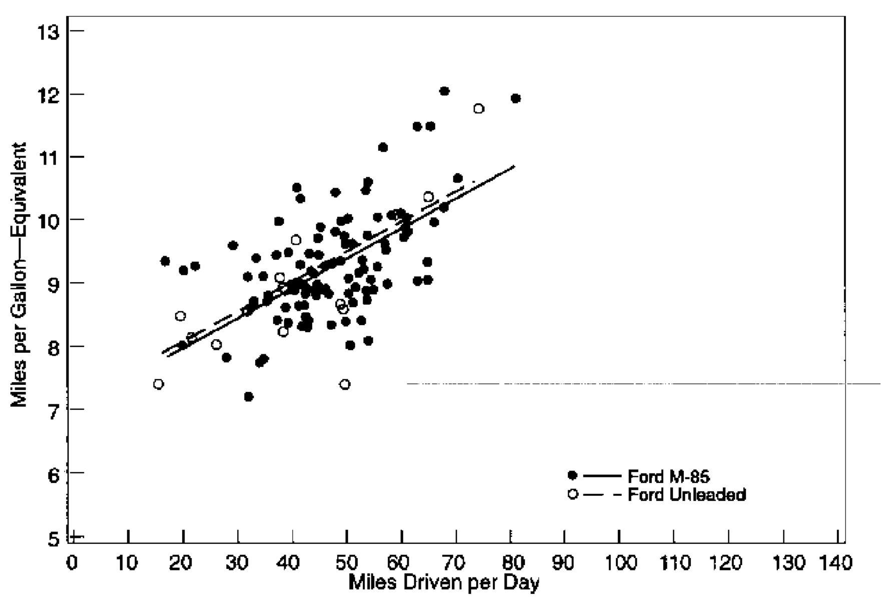

Figure 2-f. Ford M-85 and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

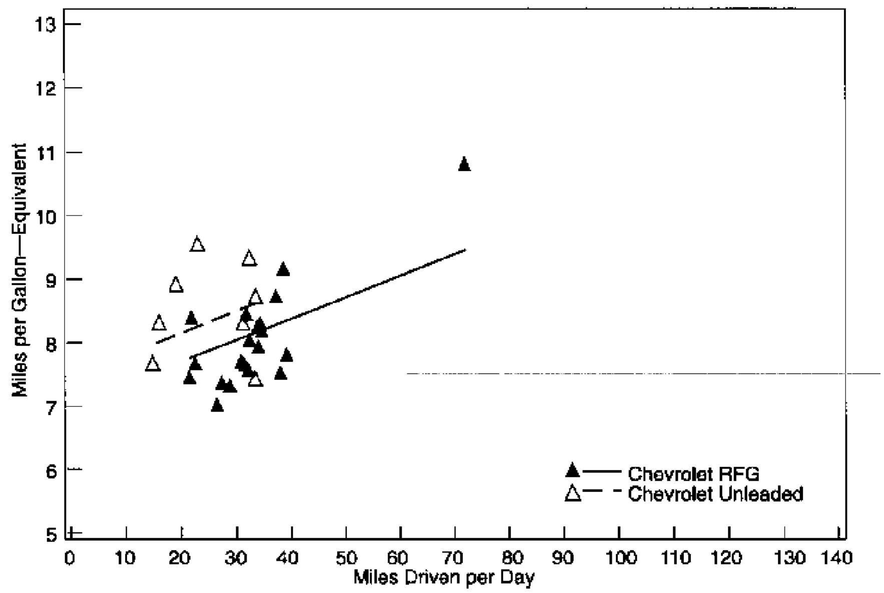

Figure 2-g. Chevrolet RFG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

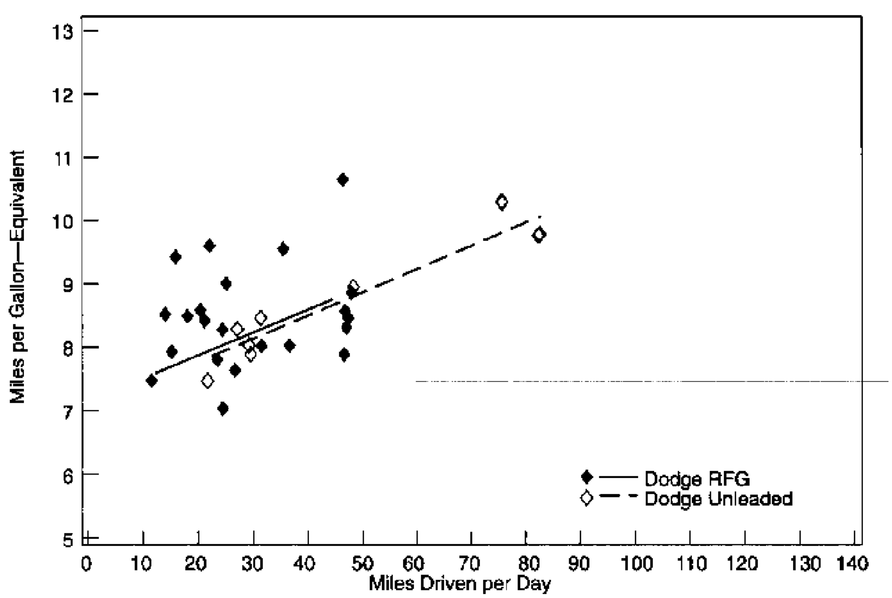

Figure 2-h. Dodge RFG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

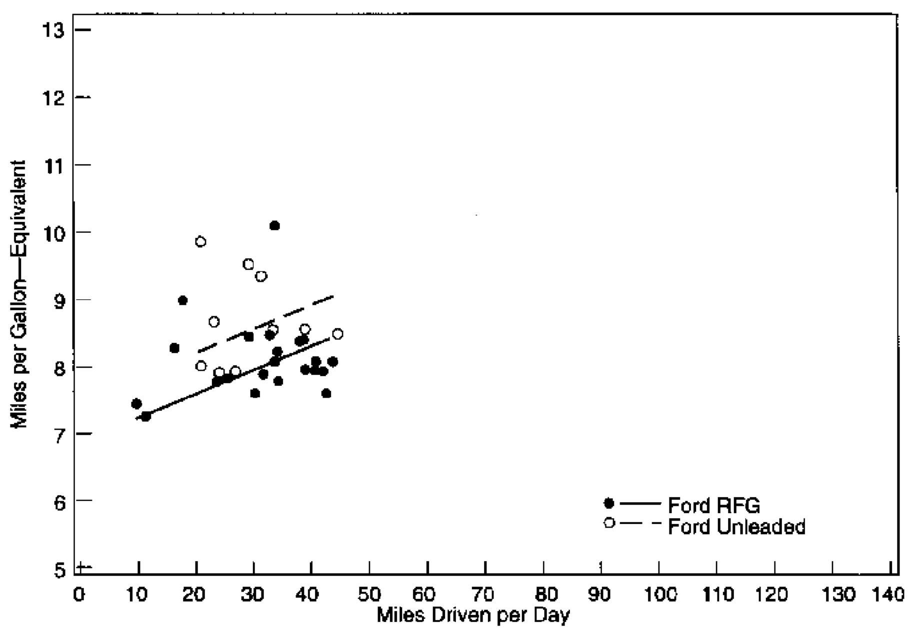

Figure 2-i. Ford RFG and Unleaded Vehicle Fuel Economy versus Average Miles Driven per Day

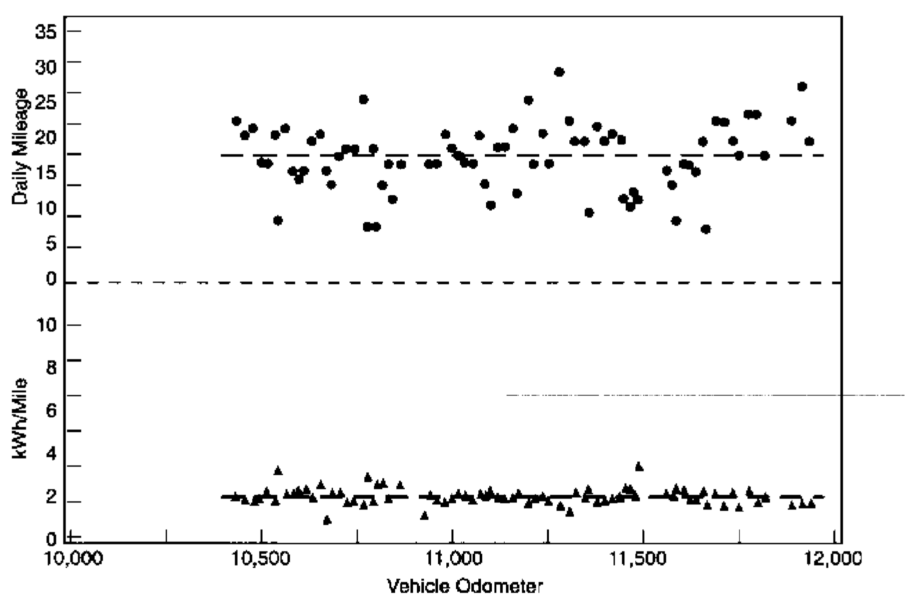

Figure 3. Electric Vehicle Daily Mileage and Fuel Economy (Nickel-Cadmium Batteries)

Table 3. Electric Vehicle Fuel Economy

Vehicle	Service Dates	Total Miles	Service Days	Mi/Day	kWh/mi
Lead-Acid					
ELG1	5/92 - 10/92	1,612	92	17	2.2
ELG2	5/92 - 12/92	2,056	98	21	2.2
ELG2	12/92 - 4/94	1,544	168	9	2.4
		5,212	358	14.6	2.3
Nickel-Cadmium					
ELG1	11/93 - 4/94	1,406	76	18	1.9

Three alternative fuel fleets had adjusted fuel economies that were at least 5.8 percent less than their respective control fleets: Chevrolet CNG, Chevrolet propane gas, and Ford RFG. It's important to point out, however, that the CNG and propane gas vans provided by Chevrolet were powered by 5.7 liter V8 engines while the control vans had 4.3 liter V6 engines. In the 1992 time frame, these vehicles represented the options that a fleet operator, such as FedEx, would have selected from this vehicle manufacturer. The RFG and control vans from the same manufacturer are identical.

The results presented thus far describe the fuel economy of full size cargo vans in routine FedEx operations. Differences among the five demonstration sites as well as the range of duty cycles observed within the same site helped to demonstrate how fuel economy is affected by variations in duty cycles. The results are likely to represent the fuel economy that would be achieved under similar daily delivery operations.

Emissions Fuel Economy

In addition to the in-use fuel economy results presented in the previous section, fuel economy estimates were obtained from the emissions tests performed by the ARB. Table 5 contains the fuel economy estimates obtained from these emissions tests. Notice that these estimates are as much as 50 percent higher than the corresponding estimates (See Table 3.) of fuel economy on a typical 40 mile per day FedEx duty cycle. This is likely due to the fact that the 40 mile per day duty cycle involves more city driving and more starts and stops than the Federal Test Procedure (FTP) duty cycle simulated in the dynamometer emissions tests. Despite these differences, the dynamometer tests provide an opportunity to compare the fuel economy of alternative fuel and control vans under identical driving conditions. Table 5 lists the percent difference in fuel economy of each alternative fuel vehicle compared with the corresponding control vehicle from the same manufacturer. These estimates are subject to a possible statistical error of less than $\pm$ 3.0 percent at the 95 percent confidence level. Thus, differences of more than 3 percent are statistically significant. The fuel economy of the Chevrolet and

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Dodge CNG vans were estimated to be 16.1 percent and 9.4 percent worse than their respective unleaded control vans. Both propane gas vans also experienced poorer fuel economy.

Table 4. Vehicle Fuel Economy from CleanFleet Field Operations

Location	Fuel Type	Vehicle Manufacturer	Unadjusted Fuel Econ (mi/GEQ)[a]	Adjusted[b] Fuel Econ (mi/GEQ)[a]	Percent Difference[c]
Irvine	CNG	Chevrolet	8.8	7.8	-12.8
		Dodge	8.7	8.2	-4.3
		Ford	10.0	9.3	3.6
	Control	Chevrolet	10.4	9.0	
		Dodge	10.4	8.5	
		Ford	9.9	8.9	
Rialto	Propane Gas	Chevrolet	8.7	7.7	-11.8
		Ford	9.0	8.2	-3.9
	Control	Chevrolet	9.5	8.8	
		Ford	9.2	8.6	
Los Angeles	RFG	Chevrolet	8.1	8.4	-5.2
		Dodge	8.3	8.4	1.0
		Ford	8.1	8.2	-7.0
	Control	Chevrolet	8.5	8.9	
		Dodge	8.8	8.3	
		Ford	8.6	8.8	
Santa Ana	M-85	Ford	9.3	8.6	-1.1
	Control	Ford	9.1	8.7	
Culver City	Elec[d]	G-Van	14.1	N/A[f]	N/A
	Elec[e]	G-Van	17.0	N/A	N/A

[a] A gasoline equivalent gallon (GEQ) in a unit of energy equal to 121.3 MJ
[b] Adjusted fuel economy based on typical duty cycle of 40 miles per day. Statistical error less than ± 0.3 mi/GEQ (± 0.5 for control) at 95 percent confidence level.
[c] Percent difference relative to unleaded control fuel. Statistical error less than ± 5.8 percent at 95 percent confidence level. Shaded boxes indicate statistically significant differences.
[d] Lead-acid batteries (9 to 21 miles per day).
[e] Nickel-cadmium batteries (18 miles per day).
[f] N/A = Not applicable

Table 5. Vehicle Fuel Economy from Emissions Dynamometer Tests

Fuel Type	Manufacturer	Fuel Economy (mi/GEQ)[a]	Percent Difference[b]
CNG	Chevrolet	11.3	-16.1
	Dodge	12.1	-9.4
	Ford	13.5	-2.1
Propane Gas	Chevrolet	12.0	-10.7
	Ford	13.0	-5.9
RFG	Chevrolet	13.5	0.9
	Dodge	13.0	-2.7
	Ford	13.5	-2.0
M-85	Ford	13.6	-1.7
RF-A (Control)	Chevrolet	13.4	
	Dodge	13.4	
	Ford	13.8	

[a] Estimates subject to statistical error of less than ± 0.3 mi/GEQ at 95 percent confidence level.
[b] Percent difference relative to RF-A control fuel. Estimates are subject to statistical error of less than ± 3.0 percent at 95 percent confidence level. Shaded boxes indicate statistically significant differences.

The ARB also tested the two G-Vans on the dynamometer using the federal urban driving schedule (FUDS) of the FTP emissions test. The vans were driven until they ran out of power. The G-Van powered by the nickel-cadmium batteries was driven 54 miles and achieved a fuel economy of 1.0 kWh/mi. The test on the van with lead-acid batteries was aborted after 18 miles due to battery pack failure. After installing a new battery pack, the van was retested and was driven for 34 miles and achieved a fuel economy of 1.2 kWh/mi.

Comparisons

Figure 4 compares the estimates of percent relative difference (AFV-Control) obtained from the field operations with those obtained from the emissions tests. The bars represent 95 percent confidence interval. The results are statistically consistent. That is, for each alternative fuel and vehicle make, the estimates of relative fuel economy obtained from operations and emissions test agree within the statistical uncertainty of the data. However, there does appear to be a systematic difference in the relative fuel economy estimates obtained from the operations and emissions tests for the CNG vans. The relative fuel economy estimates for the CNG vans from the emissions test are 4 percent to 5 percent lower than the corresponding estimates from the operations tests. This may be caused by the differences in relative effects of the FTP and typical FedEx duty cycles on vehicle fuel economy. Another possibility is that there may be a bias in the CNG tank calibration procedures performed by Southern California Gas Company.

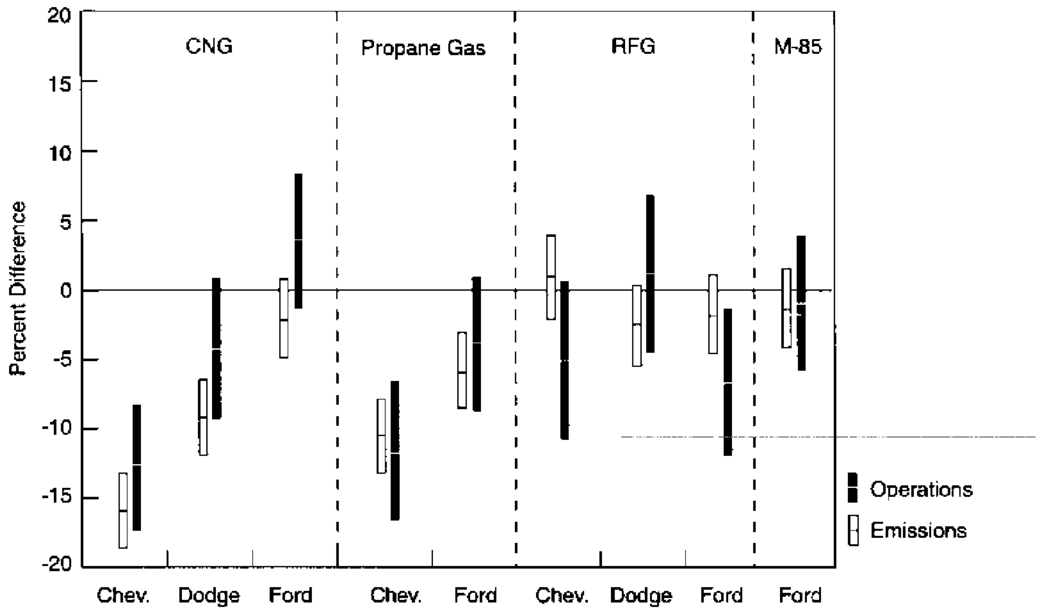

Figure 4. Comparison of Relative Fuel Economy Estimates from Field Operations (Table 4), and Emissions Tests (Table 5) on an Energy Equivalent Basis. Bars Represent 95 percent Confidence Intervals.

Fuel Capacity and Driving Range

The driving range of a vehicle depends on the amount of energy that can be stored on board between refuelings and the efficiency of the vehicle to convert energy into miles driven. For liquid fuels the volume of the fuel tank and the volumetric energy content of the fuel determine the on-board energy storage capacity. Pressure is also a factor for CNG vans. Energy storage for an electric vehicle is determined by the size and type of battery as well as operational factors such as the rate of recharge, amount of prior discharge, temperature, and general history and condition of the battery.

The energy efficiency of the vehicles depends on many factors including engine design, fuel characteristics, vehicle usage (e.g., duty cycle, driving style, total miles), vehicle characteristics (e.g., weight, aerodynamics), and weather. Some of these factors were accounted for in the design of the study through the selection of fuels, vehicles, sites, and routes; others were evaluated through the statistical treatment of the data. Estimates of fuel efficiency (mi/GEQ) on a typical FedEx duty cycle were obtained for each fuel (except electric) using statistical regression analysis, as discussed earlier.

Figure 5 shows the relative volumetric energy content of the liquid and gaseous fuels used in CleanFleet compared to the RF-A reference gasoline. Notice that there was about a 3 percent difference between the energy content of the winter and summer unleaded control gasolines. Total energy supplies on the vans, as shown in Figure 6, were then calculated using the known fuel tank volumes[4]. For CNG these estimates were calculated assuming 3,000 psi pressure in the fuel tanks. Dodge vans can hold 3,600 psi natural gas. Thus, their energy capacity and estimated driving range would be 14 percent higher at 3,600 psi. Figure 7 shows the estimated driving range using the fuel economy estimates (as shown in Table 4) based on a typical FedEx duty cycle of 40 miles per day. The estimated driving ranges for the electric vans were based on the maximum observed range while in service at FedEx.

Figure 8 shows the estimated specific driving ranges for the CleanFleet vans on volumetric and gravimetric bases. The volumetric range is the estimated maximum range (in miles) divided by the volume (in gallons) of the fuel tank. The gravimetric range is the estimated maximum range divided by the mass (in pounds) of the fuel tank

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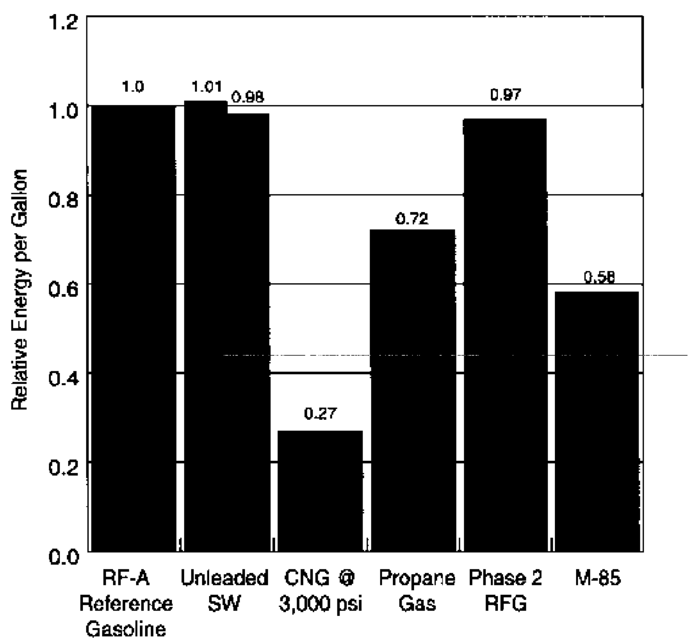

Figure 5. Relative Energy Content (Volume Basis) of CleanFleet Fuels

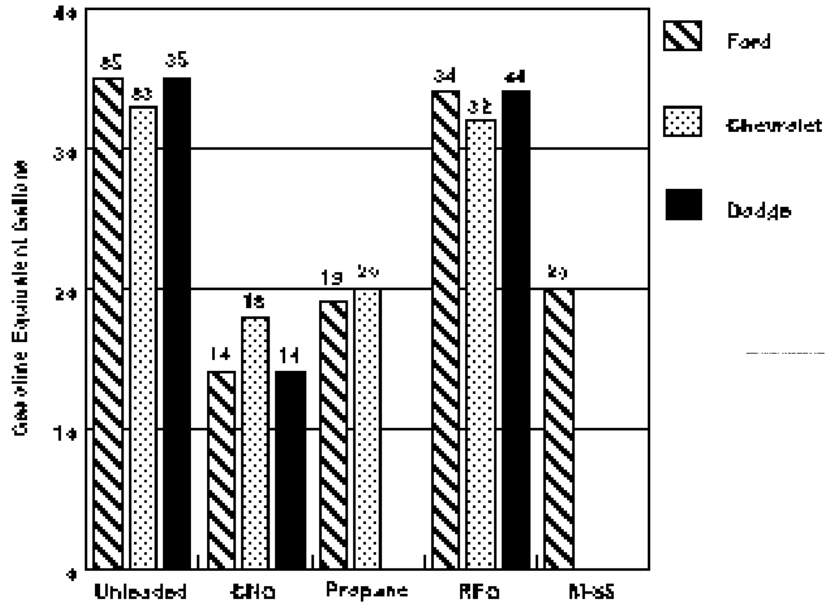

Figure 6. Energy Supply on CleanFleet Vans

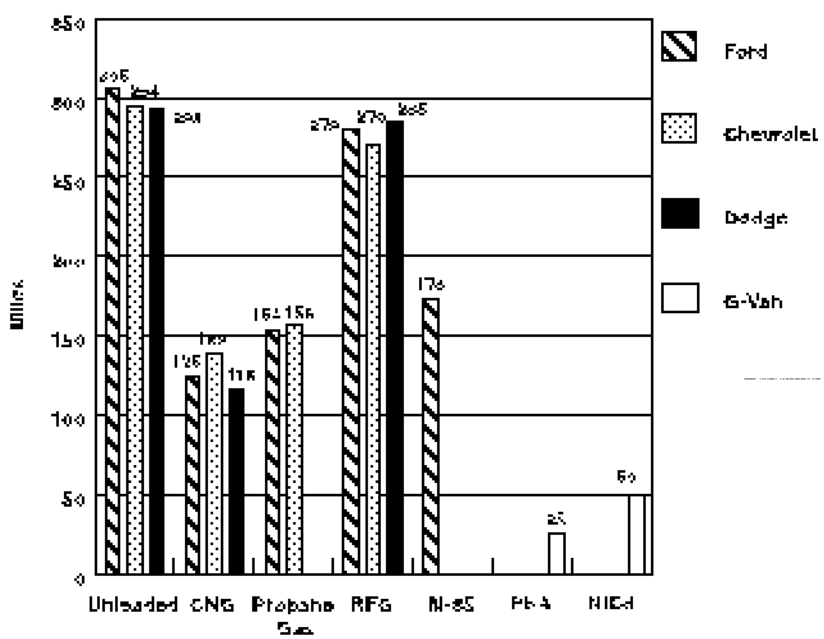

Figure 7. Driving Range of CleanFleet Vans (on Typical FedEx Duty Cycle at 40 Miles per Day)

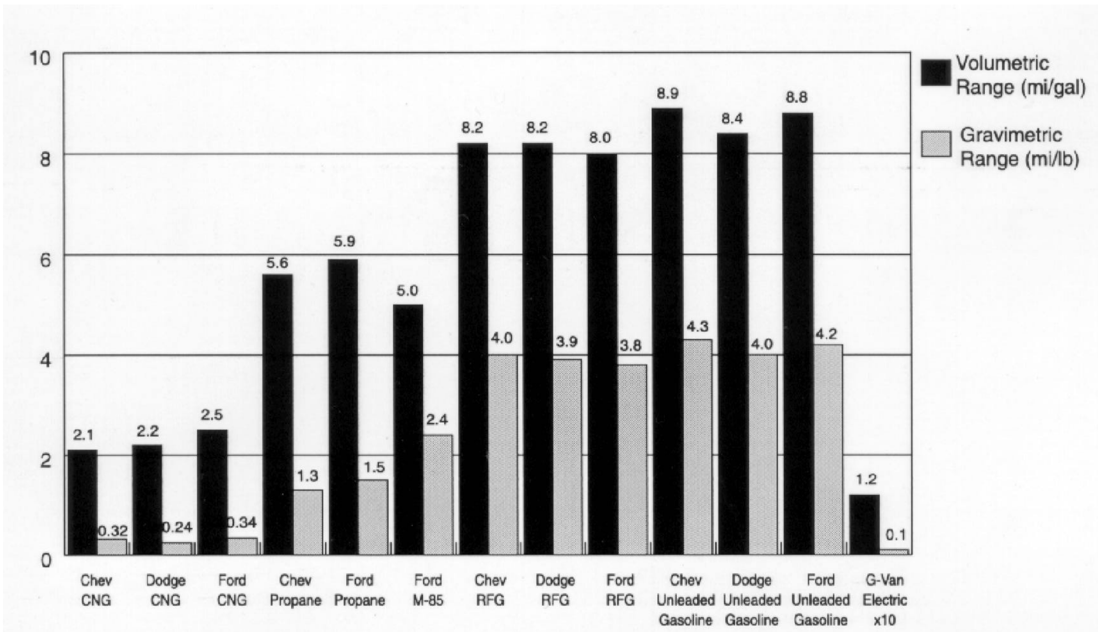

Figure 8. Estimated Specific Driving Range

Discussion

Fuel economy estimates for the liquid and gaseous alternative fuel vehicles were obtained while the vehicles were used in routine FedEx delivery operations. The estimates were compared to those obtained for control vehicles, using unleaded gasoline and operated on the same set of delivery routes. Rotation of the vehicles among route assignments at each demonstration site ensured that the alternative fuel and control vehicles were operated in a similar manner during the two-year demonstration. Regression analysis was used to model fuel economy as a function of duty cycle characteristics; namely daily mileage and number of delivery stops. Using a common duty cycle (40 miles per day), comparable estimates were obtained for fleets operating at different sites.

Fuel economy estimates from the CleanFleet emissions tests provided a second way to compare the fuel economy of alternative fuel and control vehicles. These estimates were obtained while the vehicles were operating in a dynamometer test facility under the FTP test cycle. The relative differences in fuel economy between the alternative fuel and control vehicles from the same manufacturer, as determined in the emissions tests, compared quite favorably with the relative differences obtained from FedEx operations during the two-year demonstration.

In interpreting these results, there are many factors to consider, including the following:

- The vehicles tested were those that were available from original equipment manufacturers in 1992. They represent a range of technologies, but not all technologies that will become available in the years to come.

- FedEx operations are fairly typical of pick-up and delivery services. However, the results achieved by FedEx should not be generalized to all types of fleet operations. Applications that involve heavier payloads or other types of duty cycles could produce different results.

- The degree to which the vehicle/engine technology was optimized for the alternative fuels varied considerably among fuel types and vehicle manufacturers. In some cases, the only major difference between the alternative fuel and control vehicles was in the fuel delivery system. However, for CNG and propane gas, the Chevrolet vans used 5.7L V8 engines while the Chevrolet control vans had 4.3L V6 engines. Also, the Ford CNG vans had a higher compression ratio than the Ford unleaded vans.

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