CleanFleet

FINAL REPORT

December 1995

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GLOSSARY

A	=	Amperes
AC	=	Alternating current
Acet	=	Acetaldehyde
ACGIH	=	American Conference of Government and Industrial Hygienists
ADP	=	Adaptive digital processor
AFE	=	Advanced fuel electronic
ATA	=	American Trucking Associations
AFV	=	Alternative fuel vehicle
ARB	=	California Air Resources Board
Benz	=	Benzene
Buta	=	1,3-butadiene
CH_4	=	Methane
CNG	=	Compressed natural gas
CO	=	Carbon monoxide
CO_2	=	Carbon dioxide
Control vehicle	=	A CleanFleet van using regular unleaded gasoline for daily operations or RF-A gasoline for emissions tests. Control vehicles are the baseline for the CleanFleet project
EGR	=	Exhaust gas recirculation
EPA	=	U.S. Environmental Protection Agency
EV	=	Electric vehicle
FID	=	Flame ionization detector
FFV	=	Flexible fuel vehicle
Fleet	=	A unique combination of vehicle manufacturer and fuel in the CleanFleet project

GLOSSARY
(Continued)

GEQ	=	Gasoline equivalent gallons
GVWR	=	Gross vehicle weight rating
h	=	Hour
kg	=	Kilograms
kWh	=	Kilowatt hour
LEV	=	Low emission vehicle (LEV emission standard)
M-85	=	Fuel consisting of 85 percent methanol and 15 percent RFG by volume
mi	=	Mile
MTBE	=	Methyl-tert-butyl ether
NGV	=	Natural gas vehicle
NMHC	=	Nonmethane hydrocarbons
NMOG	=	Nonmethane organic gases
NO_x	=	Nitrogen oxides (sum of nitric oxide and nitrogen dioxide)
O&M	=	Operation and maintenance
OEM	=	Original equipment manufacturer
OMHCE	=	Organic material hydrocarbon equivalent
OSHA	=	Occupational Safety and Health Administration
Ozone reactivity	=	Estimate of grams of ozone generated in the atmosphere per mile of vehicle travel
ppm	=	Parts per million
PRO	=	Propane gas or liquefied petroleum gas
psi	=	Pounds per square inch

GLOSSARY
(Continued)

RAF	=	Reactivity adjustment factor
RF-A	=	Unleaded gasoline used in CleanFleet control vans only for the emissions tests to serve as a baseline. RF-A is an industry average gasoline
RFG	=	California Phase 2 reformulated gasoline blended for the CleanFleet project
RO	=	Repair order
RSD	=	Relative standard deviation
SHED	=	Sealed housing for evaporative determination
TBN	=	Total base number
THC	=	Total hydrocarbons
TLEV	=	Transitional low emission vehicle
TLV	=	Threshold limit value
ULEV	=	Ultra-low emission vehicle
UNL	=	Regular unleaded gasoline sold commercially and used to power CleanFleet control vans in daily operations
ZEV	=	Zero-emission vehicle

SUMMARY

The South Coast Alternative Fuels Demonstration, called CleanFleet, was conducted in the Los Angeles area from April 1992 through September 1994. The demonstration consisted of 111 package delivery vans operating on five alternative fuels and the control fuel, unleaded gasoline. The alternative fuels were propane gas, compressed natural gas, California Phase 2 reformulated gasoline (RFG), methanol with 15 percent RFG (called M-85), and electricity. This volume of the eight volume CleanFleet final report is a summary of the project design and results of the analysis of data collected during the demonstration on vehicle maintenance and durability, fuel economy, employee attitudes, safety and occupational hygiene, emissions, and fleet economics.

Introduction

Alternative motor fuels are viewed by some policy makers as potentially viable options for addressing two problems facing the transportation sector of the United States economy. First, they are said by some to be “clean burning” fuels and, as such, they might be used to achieve significant reductions in emission levels from vehicles optimized to operate on them. Dramatic reductions in emissions are being mandated in urban areas across the nation that are not in compliance with the health-based national ambient air quality standard for ozone. Standards for carbon monoxide and concerns about greenhouse gases and “air toxic” emissions also must be addressed. Second, alternative fuels that are derived from domestic, non-petroleum sources could provide more diversity for energy sources and reduce the country’s dependence upon foreign oil.

Need for the Project

In spite of the potential offered by alternative fuels, in the early 1990s a dearth of objective, practical information existed on the operational, emissions, and economic effects of using the leading alternative fuel options.

Introducing alternative motor fuels into the economy requires the availability of reliable supplies of fuels and vehicles built to use them. Also, both fleet operators and individuals must have confidence in the safety, reliability, and performance of the vehicles. In the 1990 time frame when the CleanFleet project was developed, the requisite conditions cited above did not exist; several critical gaps existed in the information base available to policy makers, fleet operators, vehicle manufacturers, and fuel suppliers. Among these gaps were the following:

- Objective, comparable data on operations, emissions, and economics of several alternative fuel technologies
- Comprehensive data on operational impacts and speciated emissions from a significant number of vehicles over a sufficient period of time to provide meaningful results

- Consistent information on employee acceptance, training requirements, and safety practices; and on local building code requirements and fire marshall practices.

Project Objective

To address these needs, the CleanFleet project was designed to demonstrate and document the operational, emissions, and economic status of alternative fuel, commercial fleet delivery vans in the early 1990s for meeting air quality regulations in the mid to late 1990s. The project was designed to provide information on "daily, real-world, commercial operations" using alternative fuel vehicle technologies that could be put into FedEx delivery service for a two-year period.

Sponsors

The CleanFleet project was sponsored by a group of major public and private sector organizations (see Table 1). Major vehicle manufacturers and fuel organizations participated, giving the demonstration technical credibility. Government agencies at the local, state, and federal levels participated giving the demonstration relevance to existing and emerging regulations. Representatives of these organizations composed a steering committee or "Working Group" to guide the project. Battelle led this Working Group to provide technical integration, objectivity, and independence.

Table 1. CleanFleet Sponsors

Organization	Role
South Coast Air Quality Management District	Host, Project Oversight
U.S. DOE/National Renewable Energy Laboratory	Federal Demonstration Oversight
U.S. Environmental Protection Agency	Technical Oversight — Emissions
California Energy Commission	Vehicle Financial Support
California Air Resources Board	Vehicle Emission Measurements
California Mobile Source Air Pollution Reduction Review Committee	Emissions
FedEx	Fleet Operator
Chevrolet Motor Division	Vehicles
Chrysler Corporation	Vehicles
Ford Motor Company	Vehicles
American Methanol Institute	Methanol
ARCO Products Company Chevron U.S.A. Products, Inc.	Reformulated Gsoline

Organization	Role
LP Gas Clean Fuels Coalition Gas Processors Association National Propane Gas Association Western Liquid Gas Association	Propane Gas
Southern California Gas Company	Compressed Natural Gas
Southern California Edison	Electric Vehicles

Topics Addressed

The scope of the project encompassed fleet operations, vehicle emissions, and fleet economics. The topics that were addressed are listed in Table 2.

Table 2. Topics Addressed in the CleanFleet Project

Fleet Operations	Vehicle Emissions	Fleet Economics
Vehicle	Regulated Emissions	Infrastructure Costs
Maintenance	Ozone Precursors	Owning Costs
Reliability	Air Toxics	Operating Costs
Fuel Economy	Greenhouse Gases	
Durability		
Safety		
Facilities		
Fueling		
Vehicle Housing		
Employee Attitudes		
Training		
Occupational Hygiene and Safety		
Operational Impacts		

SUMMARY OF CLEANFLEET FINDINGS

Contents of Final Report

The CleanFleet Final Report or "Findings" is an eight-volume report. This volume, Volume 1, is a summary of the findings. Appendix A contains a list of publications on the project. The volumes in the report are:

Volume 1	Summary
Volume 2	Project Design and Implementation
Volume 3	Vehicle Maintenance and Durability
Volume 4	Fuel Economy
Volume 5	Employee Attitude Assessment
Volume 6	Occupational Hygiene
Volume 7	Vehicle Emissions
Volume 8	Fleet Economics.

Overview of the Project

Prior to summarizing the findings from the project for each fuel, an overview of the project describing the fuels and vehicles, the experimental design, and fleet economics is provided.

Fuels and Vehicles

To draw valid and useful conclusions from the demonstration, the fuels and vehicles need to be seen together as systems, not separately. Optimizing fuel storage and delivery to engines, combustion, and exhaust gas treatment all combine to match vehicle technology to the properties of the fuel being used. The fuels and vehicles tested in CleanFleet represented various levels of optimization.

Five fuels were selected as alternative fuels for the CleanFleet project. These fuels, shown in Table 3, were judged by the Working Group to represent energy sources that offered potential environmental benefits and could be used in commercial delivery vans in daily service in the 1992 time frame. Ethanol and ethyl tertiary-butyl ether blends with reformulated gasoline were included in the planning phase of the project, but the ethanol fuel organizations decided not to participate in the demonstration.

Table 3. CleanFleet Fuels and Number of Vehicles

	Vehicle Manufacturer				
Fuel	**Ford**	**Chevrolet**	**Dodge**	**Other**	**Total**
Compressed Natural Gas	7	7	7	—	21
Propane Gas	13	7	—	—	20
Reformulated[(a)] Gasoline	7	7	7	—	21
M-85[(b)]	20	—	—	—	20
Unleaded Gasoline	12	9	6	—	27
Electricity	—	—	—	2	2
TOTAL	59	30	20	2	111

[(a)] California Phase 2 reformulated gasoline (RFG).
[(b)] M-85 was 85 percent methanol and 15 percent RFG.

As shown in Table 3, 111 vehicles were involved in the project: 84 vehicles operating on the alternative fuels and 27 vehicles operating on regular unleaded gasoline as a baseline (i.e., control vehicles) for comparison.

All vans were full-size panel vans equipped with communications equipment needed by FedEx for its business. A picture of a typical van is shown in Figure 1.

SUMMARY OF CLEANFLEET FINDINGS

Figure 1. CleanFleet vans were full-size panel vans outfitted for FedEx operations.

Experimental Design

The experimental design for the demonstration addressed several important factors. For fleet operations, they are (1) geographic centralization of vehicles operating on each alternative fuel, (2) number of vehicles, (3) control fleets, (4) treatment of electric vans (EVs), (5) time frame, and (6) treatment of variables. For emission tests, they are the substances measured, number of vans tested, effect of mileage, and baseline fuel.

Fleet Operations. The geographic extent of the demonstration is shown in Figure 2. CleanFleet vehicles were operated by FedEx throughout the four counties composing the South Coast Air Quality Management District. Each fuel was headquartered at a single FedEx location: compressed natural gas (CNG) in Irvine, propane gas in Rialto, reformulated gasoline (RFG) in south central Los Angeles, M-85 in Santa Ana, and EVs in Culver City. The restrictions of demonstrating only one alternative fuel per site and only one site per alternative fuel were forced principally by limitations on funding available for the fueling infrastructure and the need to simplify business operations for FedEx while conducting the project.

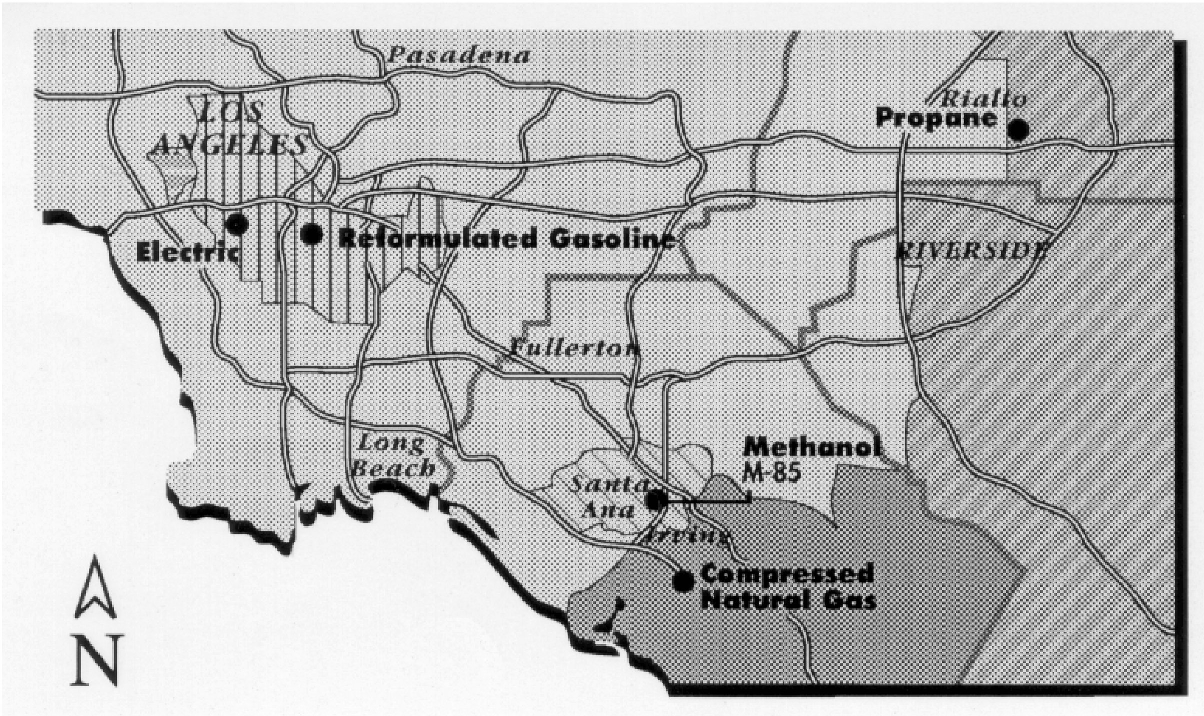


Figure 2. CleanFleet vehicles operated in the South Coast Air Quality Management District.

The experimental design called for demonstrating a sufficient number of vehicles to achieve statistical credibility for the project's findings. In addition, all three major domestic vehicle manufacturers, which had ongoing dealings with FedEx, were invited to participate. The statistical design called for a minimum of seven identical liquid or gaseous fueled vans from each participating original equipment manufacturer (OEM).

Along with the liquid and gaseous alternative fuel vans from each OEM, control fleets (a fleet is defined in this report as a group of vans from a particular OEM operating on a particular fuel at a particular site) of three standard gasoline vans were used at each site for each OEM to provide a baseline for comparison. The principal comparisons in evaluating results of operations, emissions, and economics were to compare individual alternative fuel fleets to their counterpart control fleets.

Because of the early development status of EVs (the vans themselves, as well as their chargers) and their cost, only two EVs were evaluated in CleanFleet. Control vans were not used in the study of EVs. Rather the EV demonstration was designed to provide information on how well early prototype EVs could meet the needs of a fleet operator in the delivery service business.

All CleanFleet vans were evaluated over a 24-month period between April 1992 and September 1994. The various fleets were phased into operation as the vehicles and fuels became available. This period of time was judged sufficient to provide credible information from the project. During this period, information was gathered on operations, emissions, and economics.

Finally, the experimental design addressed the variables that would affect project results. Principal variables studied were (1) fuels, (2) vehicle technologies, and (3) effects of daily use (with distance traveled, or mileage, as the indicator of vehicle use). Ancillary variables included effects of site location (e.g., different FedEx practices or delivery and pickup route structures), routes and drivers, baseline fuel for emissions measurements, and weather.

Site location was one ancillary variable to be dealt with. Because each alternative fuel was demonstrated at only one site, differences in site characteristics (including FedEx operational practices) could confound comparisons among fuels or even make the project results site-specific. These potential effects were ameliorated by three factors. First, FedEx's uniform business practices across the sites and by use of control vans. Second, results for the control vans were compared across sites to investigate the possible influence of site characteristics. Third, the principal comparisons were designed to be between alternative fuel fleets and their control fleets at a particular site, not between alternative fuel fleets at different sites.

The effects of different driving routes and drivers were expected to be a significant ancillary variable. The experimental design called for rotating the liquid and gaseous fuel vans among delivery routes and drivers at each demonstration site throughout the 24-month demonstration. This was done to even out differences in the effects of different duty cycles on the vans. Each van was driven by from three to six drivers on different routes during the demonstration.

The baseline fuel was regular unleaded gasoline purchased according to normal FedEx practice. This fuel varied seasonally, by supplier, and also changed as oxygenate was added to gasoline sold in Los Angeles during the project. The use of this fuel as a "baseline" reflects the practical nature of the project.

Weather affected operation of vehicles as a result of varying ambient temperatures. For example, of the five demonstration sites, only the vans at Rialto were equipped with air conditioning. Also, different grades of gasoline are sold in summer and winter months. Daily temperatures and precipitation across the South Coast Air Basin were documented daily from published information in *The Los Angeles Times*. By demonstrating the vehicles over a 24-month period, two annual cycles of weather were encountered. This was sufficient to document any important effects of weather on the project results.

Emission Tests. The emission tests were designed to provide information on emissions from in-use vehicles as the vehicles accumulated mileage during the course of the demonstration. Four classes of emissions were measured in vehicle exhaust and evaporative emissions: regulated emissions, ozone precursors, air toxics, and greenhouse gases. These measurements provided a comprehensive data set on emissions from all liquid and gaseous fuel fleets. Because EVs are classified as zero-emission vehicles, they were not tested for emissions. Three vans from each fleet were tested in three rounds as the vans accumulated mileage. As noted earlier, regular unleaded gasoline was used in daily operations for the baseline fuel. While this variability was deemed acceptable for daily operations, the project sponsors recognized that a more steady baseline would be needed to evaluate changes in emissions from vans over time. Consequently, a standard fuel was selected to be used in the control vans for emissions measurements. This fuel was the industry average fuel (designated as RF-A) used in the Auto/Oil Air Quality Research Improvement Program. It is also the standard gasoline used by the California Air Resources Board (ARB) for emission measurements. The alternative fuel vehicles (AFVs) were tested with the same alternative fuels used in daily operations.

Fleet Economics

Using the CleanFleet experience as a starting point, an assessment was made of the costs that fleet operators might face if they implemented alternative fuels into a commercial fleet in the 1996 time frame. The factors listed in Table 4 were identified as having the potential to affect the costs of implementing alternative fuels. A case study was developed from the fleet operator's perspective. The baseline case was a package delivery operation in Los Angeles with 150 vans operating out of a single site. The case study assumed that, in 1996, 50 of the vans would be replaced with new vans that operated on one of the five alternative fuels studied in CleanFleet. The vans would be brought indoors for package loading and storage and fueled on site. Because production EVs would not be available in 1996, an estimate of costs in the 1998 time frame was made for EVs. The case study provided results both before and after corporate income tax.

Table 4. Cost Factors for the Fleet Economics Assessment

Infrastructure Costs	Owning Costs	Operating Costs
Personnel Training	Base Vehicle Price	Fuel Cost
Fueling Facility	Modification Cost	Refueling Labor
Inside Vehicle Storage	Residual Value	Maintenance
Maintenance Facility		Insurance
Mixed Fleet Complexity		Cost Incentives

Presentation of Data and Findings

In this section, the format of the presentation is described, followed by a perspective on use of the information.

Presentation Format

Data and findings for each fuel are presented in the following sections for operations, emissions, and fleet economics. The presentation format is tailored to each of these topics.

Fleet Operations. Data and experience are presented in three categories: fuel economy, motor oil, and vehicle maintenance.

Fuel Economy. Two results are presented in the summaries of fuel economy findings: (1) the efficiency of the AFVs in using the energy of the fuel compared to the efficiency of the control vehicles and (2) the driving range experienced in the CleanFleet project. The relative efficiency is specific to the type of vehicles and fuels involved but not to their application (i.e., FedEx operations). In contrast, the driving range is specific to both types of vehicles and fuels and the application.

Fuel economy, expressed in distance traveled per unit of fuel (e.g., miles/gallon), depends upon many factors. These include the energy content of the fuel and the efficiency of the vehicle in transforming the energy of the fuel into distance traveled. Fuel economy expressed in these units is specific to the duty cycle of the vehicles, which includes driving habits, cargo weight, terrain, and number of stops and starts. A key parameter upon which fuel economy depends was the length of the route driven each day. Factors such as this were accounted for in characterizing the relative efficiency of operation. For example, the average efficiency of a fleet of AFVs is expressed as a percentage higher or lower than the average efficiency of the control fleet. Appropriate adjustments were made to account for differences in route lengths. In addition, fuel economy was also determined from the emissions measurements (which use a standard driving cycle).

Detailed results on fuel economy in distance/quantity of fuel (e.g., miles/gallon) and on an energy equivalent basis among the fuels are presented in Volume 4. In this volume, the relative energy efficiency of the vans is summarized along with the fuel economy on an energy equivalent basis to a gallon of reference unleaded gasoline. By this means, the various operational factors are accounted for on a relative basis in the comparison. To place the results in perspective, information is provided on the driving range of the vans in the FedEx application.

To illustrate the practical constraints of using various fuels, data are presented in terms of the driving range experienced by specific fleets in FedEx operations. Results are presented in miles of driving range for a full tank(s) of fuel or full charge of electrical energy. These results depend upon the amount of fuel that can be stored onboard the vehicles, the duty cycle of the vehicles, and their efficiency in using the stored energy in the fuel. To make the results consistent, the reported driving ranges were normalized to a FedEx route length of 40 miles per day and an average number of stops and starts.

Results are also presented for specific driving range. This is the driving range on a full load of fuel divided by the volume of fuel storage (miles/gallon capacity) or the weight of the fuel system (miles/pound). These data illustrate differences among the fuels in terms of useful output (miles driven) to the constraints of volume and weight necessary in the fuel system on the vans.

Motor Oil. Each time motor oil was changed in the vans, samples of used oil were collected and analyzed to determine the properties of the oil and the concentration of engine wear metals. The oil properties that were evaluated are listed below, along with their relevance as indicators of engine durability:

Total base number	—	a measure of alkaline reserve in the lubricant for neutralizing acidic combustion products
Oxidation	—	a measure of lubricant breakdown
Nitration	—	a measure of blow-by contamination
Viscosity	—	a measure of the ability to maintain hydrodynamic oil films in journal bearings.

In the following sections, information on total base number, nitration, and viscosity is summarized for each fleet. Normalized relative differences in these parameters are presented for used oil after each 3,000 miles of vehicle use. For example, the average level of total base number (TBN) in a Chevrolet CNG van is compared to that observed in the Chevrolet control vans. The comparison is made at a 3,000-mile interval because the oil change intervals for all fleets permit valid comparisons at this mileage interval.

In reviewing these results, the significance of the three parameters needs to be remembered. TBN is a measure of the amount of overbase additives present in the engine oil. A decline in TBN occurs as the overbase in the oil is consumed to neutralize acidic combustion products that enter the oil sump. In general, the longer the oil has been in use, the higher the amount of combustion products that have been neutralized, thereby reducing the TBN. Thus, higher TBN is generally a good sign for used oil. Nitration is related to TBN. As TBN decreases, nitration of the oil from acidic combustion products should increase. Thus, lower nitration levels are generally a good sign in used oil. Viscosity of the oil is an important property characterizing the ability of the oil to lubricate the engine. Constant viscosity of the oil over time in use is a good sign.

The concentration of nine metals in used motor oil is also presented. The percent difference in metal accumulation in oil (AFVs compared to the control vans) is estimated at 10,000 and 20,000 total miles. The elements and their significance are listed below:

Engine Metals	Possible Source of Engine Metals
Iron	shafts, cylinder liners, piston rings, valve train parts (e.g., cam lobes and followers)
Chromium	piston rings
Nickel	certain kinds of valve and valve guides
Aluminum	pistons, aluminum bearings or bushings
Lead	bearing babbitt or bronze bushings
Copper	bearing babbitt or bronze bushings
Tin	bearing babbitt or bronze bushings
Molybdenum	piston rings
Antimony	bearing babbitt

The rate of engine metal removal can be affected by many different factors. These include fuel and oil properties and vehicle and engine specifications such as size and type of engine, number of cold starts, and choice of materials and anti-wear treatments for key engine parts. Vehicle duty cycles and preventive maintenance practices can also affect wear rates. These factors are often confounded, so it is usually difficult to isolate their effects. Nevertheless, the results from CleanFleet provide some useful insight into the accumulation of engine metals in the motor oil.

Vehicle Maintenance. Information on vehicle maintenance and reliability are summarized in two forms. First, the average number of unscheduled repair orders per vehicle per 100 days for selected vehicle systems is plotted for each fleet. The systems covered are those vehicle systems that relate to the fuel such as the powertrain, fuel delivery systems, and associated hardware. These systems were defined by a group of ATA (American Trucking Associations) codes that designate components of vehicles. In Volume 3 of the CleanFleet findings on vehicle maintenance, information is also provided on labor hours required for maintenance and estimated maintenance costs. Because many of the alternative fuel fleets in the demonstration were not production vans, the labor hours required to repair them and the associated costs for parts were difficult to establish on a consistent basis. Consequently, these results must be interpreted in the context of a detailed discussion of maintenance. To provide a brief summary of the relative frequency of unscheduled repairs on the vans, the simple metric of number of repair orders per 100 days of fleet operations is presented in this summary.

Second, the availability of the vans is summarized. Availability was defined as the percent of normal operations time that a vehicle is available for use, regardless of whether it is actually used.

Emissions. Measurement of tailpipe emissions from CleanFleet vans provided data on emission levels as a function of mileage. For detailed information on emission levels in units of g/mi as a function of odometer reading, consult Volume 7, Vehicle Emissions. To summarize the wealth of information in these data, a single parameter was calculated for eight compounds (or classes of compounds) for each fleet. The parameter presented in this summary is the mass of the compound emitted per van over a defined mileage range. The mileage range of 5,000 to 25,000 miles was selected because all fleets had vans tested for emissions over that range. This summary of the emissions results provides a measure of the quantity of emissions reductions achieved by the demonstration vans compared to the control vans operating on unleaded gasoline.

Emissions are summarized for (1) regulated compounds—carbon monoxide (CO), nonmethane organic gases (NMOG), and nitrogen oxides (NO_x); (2) ozone-forming potential of the exhaust (using the

ARB's reactivity computation); air toxics—benzene, formaldehyde, acetaldehyde, 1,3-butadiene; and greenhouse gases—carbon dioxide (CO_2) and methane (CH_4). For each compound in the first three classes (the greenhouse gas results are not plotted but are summarized), the average mass emissions (or ozone-forming potential of exhaust) for the three vans tested in each fleet are plotted as a horizontal bar, along with the 95 percent confidence interval about the mean (the vertical extent of the bar containing the mean). Results are provided in units of kg of species emitted for regulated compounds and ozone-forming potential and in grams for the four air toxics. In the figures that display the data, the carbon monoxide results are in the top chart on a different scale than are the NO_x, NMOG, and ozone-forming potential. On the bottom chart, benzene is displayed on a different scale than are the results for formaldehyde, acetaldehyde, and 1,3-butadiene.

Fleet Economics. Results of the fleet economics assessment are presented in bar charts that show the cost to a fleet operator in units of cents/mile. The total cost is broken down into three components—infrastructure, owning, and operating costs. For the liquid and gaseous fuels, with the assumption of 50 AFVs travelling 20,000 miles annually, each cent per mile is equivalent to $10,000 per year. The plots present results before corporate income tax and without tax incentives. The detailed report on fleet economics (Volume 8) presents results both before and after income tax, with and without incentives.

Use of the Data and Findings

It is important to keep in mind the differences in vehicle technologies that were tested to draw valid, useful conclusions from the data and findings of the project. The conceptual design of the CleanFleet project called for demonstrating a variety of OEM-supported vehicles on the five alternative motor fuels. Vehicle technologies that were available in 1992 and that could be subjected to the rigors of daily commercial fleet operations were demonstrated. In 1992 few production vans were designed and optimized to take advantage of the inherent characteristics of alternative fuels. Most AFVs were designed to operate on gasoline and modified to accept alternative fuels. The breadth of available technology for CleanFleet provides various practical options to fleet operators who plan to use alternative motor fuels. These differences need to be taken into account when comparing data on operations, emissions, or economics from the various fleets.

The three principal factors to be kept in mind when evaluating the results are that they are collected from vans that represent:

- Different levels of optimization across fuels for fuel storage and delivery of fuel to the engine, combustion, and emission control
- Different technologies for the four systems cited above
- A snapshot of technologies that were available in 1992 during a decade in which technological improvements are being made each year.

CleanFleet was not designed to compare the alternative fuels demonstrated. Rather, vans from a particular manufacturer operating on a particular fuel were to be compared to control vans from the same manufacturer operating on unleaded gasoline. Therefore, care must be taken in comparing data or findings on a fuel-by-fuel basis and ascribing relative benefits or drawbacks to the fuels themselves because the data result from the particular combinations of fuel and vehicle technology being tested. In the same manner, care needs to be exercised in comparing data on the basis of vehicle technology (e.g., Ford vs. Chevrolet vs. Dodge).

The 1992 CleanFleet technologies do not, of course, represent the more advanced alternative fuel technologies that are anticipated to be available at the end of the decade. Nevertheless, they do provide an important benchmark.

Compressed Natural Gas

Findings from the CNG portion of the project are summarized in five parts. The basis for the demonstration and findings is summarized first. Then findings on operations are presented in two sections (data and experience). This is followed by a summary of findings on emissions and fleet economics.

Basis for Demonstration and Findings

The basis for the CNG demonstration is summarized in five parts: vehicle technologies, fuel properties, fueling facility, building facility, and vehicle activity.

Vehicle Technologies. The 21 CNG vans [or natural gas vehicles (NGVs)] represented three levels of CNG vehicle technology development. The seven Dodge CNG vans were OEM production vans. The Ford vans may be called OEM-modified vans. They were modified by Roush Technologies under contract to Ford to operate on CNG before they were delivered to FedEx. The Chevrolet CNG vans may be called after-market vans, because they were modified to operate on CNG by a third-party organization after the vans had been purchased by FedEx as gasoline vans. The control vans operating on unleaded gasoline were all standard model year 1992 OEM production vans.

Ford. The Ford CNG vans were built especially for CleanFleet. They featured a 4.9-liter, in-line, six-cylinder engine having a limited calibration of a sequential, multiport, electronic fuel injection system (see Table 5). The compression ratio was 11:1 compared to a value of 8.8:1 for gasoline Ford vans.

Fuel capacity was 188 liters in three steel gas cylinders. This fuel storage capacity was equivalent to 14 gallons of unleaded gasoline on an energy equivalent basis. The Ford CNG vans weighed, on average, about 133 kg (292 pounds) more than the Ford gasoline control vans.

The Ford CNG vans were equipped with a standard gasoline catalyst system. The vehicles were operated under an experimental permit from the California ARB.

Chevrolet. The Chevrolet vans were built originally to operate on gasoline, although they featured V8, 5.7-liter gaseous fuel compatible engines in anticipation of their use. Subsequently, these vans were modified to operate on CNG using IMPCO Technologies Inc.'s advanced fuel electronic (AFE) system. This is a microprocessor-based engine management system that controls fuel flow and mixture, spark advance, and exhaust gas recirculation (EGR) functions to provide optimum engine performance. AFE's operational functions interact with the vehicle's OEM on-board computer. The AFE strategy allows the OEM on-board diagnostic routines to remain operational at all times. Fuel was provided to the engine through a gas ring just upstream of the throttle body (see Table 5). The compression ratio was not changed during the modification process; it remained at 8.6:1.

Table 5. Characteristics of the CNG and Control Vans

Vehicle Component	Ford CNG	Ford Control	Chevrolet CNG	Chevrolet Control	Dodge CNG	Dodge Control
Chassis Model	E250	E250	G30	G30	B350	B350
Engine Displacement (L) Type Compression Ratio	4.9 I6 11	4.9 I6 8.8	5.7 V8 9.6	4.3 V6 8.6	5.2 V8 9.08	5.2 V8 9.08
Fuel Delivery[a]	SMPI	MPI	TB	CPI	SMPI	SMPI
Fuel Capacity (L)	188	132	249	125	198[c]	132
Fuel Capacity (GEQ)[b]	14	34.9	18.1	33.0	14.4[c]	34.9
Vehicle Weight (kg)	2,623	2,490	2,478	2,248	2,323[c]	2,183
Engine Classification[d]	MD	MD	HD	HD	MD	MD
Catalyst[e]	G	G	NG	G	NG	G

(a) TB = Fuel provided through a gas ring upstream of the throttle body, CPI = Central port injection, MPI = Multiport electronic fuel injection, SMPI = Sequential MPI.
(b) GEQ = Gasoline equivalent gallons on an energy equivalent basis.
(c) Values reflect the addition of a fourth fuel cylinder to the van.
(d) MD = Vans in California medium-duty class. HD = Engines in heavy-duty class.
(e) Three-way catalyst optimized for exhaust from the fuels listed. G = Gasoline, NG = Natural gas.

Fuel capacity was 249 liters in three aluminum, fiber glass-wrapped cylinders. This fuel storage capacity was equivalent to 18 gallons of unleaded gasoline on an energy equivalent basis. On average, the Chevrolet CNG vans equipped with 5.7-liter V8 engines weighed about 230 kg (482 pounds) more than the Chevrolet control vans equipped with 4.3-liter V6 engines.

The Chevrolet CNG vans were equipped with Engelhard catalysts that had been chosen for use with natural gas exhaust. These vans were operated on experimental permits from the ARB.

Dodge. The Dodge CNG vans were among the first production CNG vans offered for sale by Dodge. They employed sequential, multi-port fuel injection to the 5.2-liter, V8 engine.

Fuel was stored in three fully wrapped (Fiberglas), aluminum gas cylinders in the production vans for an equivalent storage capacity of 11 gasoline equivalent gallons (GEQ) at 3,000 psig. These cylinders were capable of storing CNG at 3,600 psig, but fuel was stored at 3,000 psig for CleanFleet. This permitted the natural gas fuel compressor and dispenser to operate at the same pressure for vehicles from all three OEMs. On average, the Dodge production vans with three gas cylinders weighed about 163 pounds more than the Dodge control vehicles. Because these vans were found to have a driving range in FedEx operations of only about 80 miles, a fourth fuel storage cylinder was added with Chrysler's approval (see Table 5).

The Dodge CNG vans had a catalyst tailored for natural gas exhaust. These vans were certified to California model year 1992 emission standards. A year later the same technology was certified to California's low emission vehicle (LEV) standards.

Fuel Properties. Pipeline quality natural gas was compressed for use in the CleanFleet CNG vans. Over the course of the demonstration, the composition of the natural gas was very stable. As shown in Table 6, the average methane content of natural gas was 94.62 percent, with a relative standard deviation (RSD) of 1.49 percent. The net heating value had an RSD of 1.28 percent over the course of the demonstration.

Table 6. Average Characteristics of Natural Gas

Parameter	Units	Mean	Relative Standard Deviation (%)[a]
Methane	Vol %	94.62	1.49
Ethane	Vol %	2.09	NR
Propane	Vol %	0.48	NR
n-butane	Vol %	0.11	NR
Isobutane	Vol %	0.10	NR
Pentanes	Vol %	0.06	NR
Hexanes	Vol %	0.07	NR
Nitrogen	Vol %	1.39	NR
CO_2	Vol %	1.08	NR
Heating Value, net	MJ/kg	47.3	1.28
Density	kg/m^3	0.722	1.36
Specific Gravity [b]		0.589	2.52
Wobbe Index[c]	MJ/m^3	44.4	1.13

[a] Relative standard deviation is reported for major components and parameters. NR means not reported.
[b] With respect to air.
[c] Calculated from heating value and specific gravity.

Fueling Facility. Southern California Gas Company installed a fueling station on FedEx property for the demonstration. Shown in Figure 3, the station consisted of a dedicated gas meter, a natural gas compressor, a cascade, and a fuel dispensing unit. For increased reliability, the compressor station utilized two Ariel compressors, each with a capacity to compress 25 L/s (50 cubic feet per minute) of natural gas to a pressure of 20 megapascal (3,600 psi). The cascade system of storage cylinders had a capacity of 450 normal cubic meters. The dispenser was equipped with a mass flow meter and electronic processing to provide an output in nominal energy units.

SUMMARY OF CLEANFLEET FINDINGS

Figure 3. The natural gas fueling facility was on site at FedEx.

Building Facility. The building into which FedEx vehicles were brought was a mixed use facility having both a package sorting and loading area and offices. Building codes applicable to bringing CNG-powered vehicles into such a building were not found. Working with the code officials and the fire marshall, the following modifications to the building were implemented:

- Increased the ventilation rate to five air changes per hour.
- Reversed the air flow pattern with exhaust out the top of the building and the supply close to the ground.
- Installed 24 flammable gas detectors near the ceiling.
- Linked the gas detector system to the ventilation system to provide automatic activation if flammable gas was detected by any sensor at a level exceeding 20 percent of the lower flammability limit.
- Disconnected the pre-existing open-flame unit heaters near the ceiling.

- Heated incoming ventilation air.
- Installed an auxiliary heater for the mechanics' area to provide heat during night hours when the mechanics worked with building doors open.
- Unrelated to CNG and at the direction of the fire marshall, installed a timer to periodically sweep carbon monoxide out of the building.

Vehicle Activity. Over the course of the demonstration, the CNG vans, on average, logged between 23,000 and 30,000 miles compared to the control vans with 39,000 to 43,000 miles (see Table 7). The higher mileage for the control vans was mostly due to their earlier introduction into service compared to the NGVs. The Dodge vans had the lowest average daily mileage because FedEx requested that the vans not be assigned to the longer routes out of Irvine until a fourth fuel tank was added. After the additional cylinder was installed, the Dodge vans began to operate on longer routes.

Table 7. Summary of Vehicle Activity for the CNG Fleet

Type of Fuel	Vehicle Manufacturer	Average Number of Service Days	Average Total Miles Per Vehicle	Average Miles Per Day
CNG	Ford	455	29,533	65
	Chevrolet	441	26,812	61
	Dodge	460	22,639	49
Control	Ford	630	39,439	63
	Chevrolet	573	39,663	69
	Dodge	544	42,685	78

Figure 4 demonstrates how the vehicle rotation plan achieved its goal of equalizing the distribution of duty cycles among fleets. The "box and whisker" plots describe the distribution of average daily miles traveled by vans within a rotation cycle. For example, each of the seven Chevrolet CNG vans were assigned to five different routes during the demonstration—a total of 35 route assignments. The "box" indicates that 50 percent of the daily routes assigned to the Chevrolet CNG vans averaged between 50 and 70 miles per day. The median value is indicated by the bar in the middle of the box. The ends of the "whiskers" indicate that the minimum route length was 10 miles per day and the maximum was 120 miles. Overall, the distribution of average miles per day for the CNG and control vans overlap.

Operations Data

Operations data for the natural gas portion of the demonstration are summarized for vehicle fuel economy, motor oil, and vehicle maintenance.

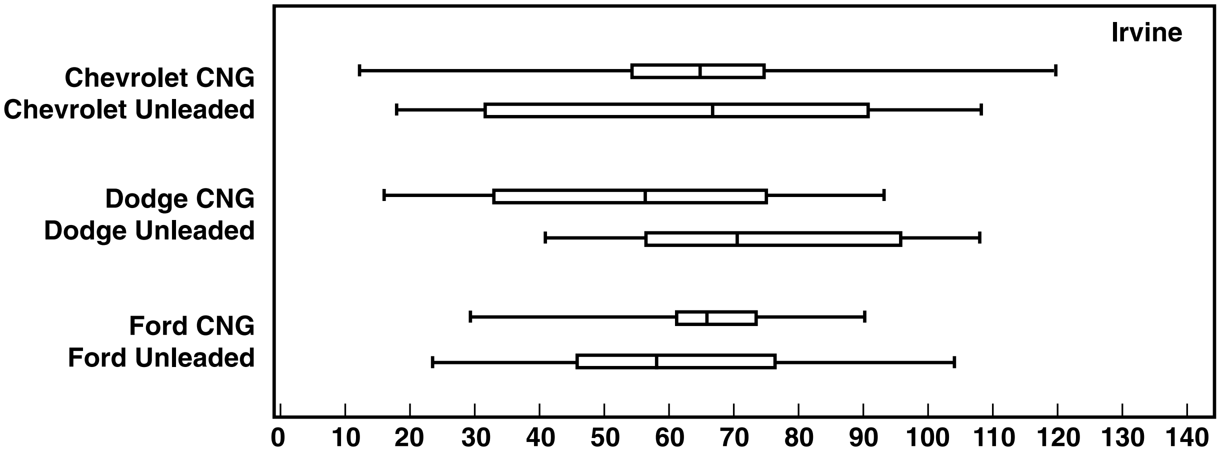


Figure 4. The distribution of the average miles that CNG and control vehicles traveled each day overlaps, providing comparable routes.

Fuel Economy. The mean efficiencies of the Ford, Chevrolet, and Dodge NGVs compared to their control fleets are shown in Figure 5. The mean efficiencies from operational data were 3.6, -12.8, and -4.3 percent different for these alternative fuel fleets compared to their gasoline controls. The corresponding mean relative efficiencies from the emissions chassis dynamometer were -2.1, -16.4, and -9.4 percent. The higher relative efficiency for the Ford vans may reflect the higher compression ratio in the Ford CNG vans compared to the control engines. The low efficiency for the Chevrolet NGVs reflects the different engines (5.7-liter V8 CNG vs. 4.3-liter V6 gasoline control), as well as limited optimization of the Chevrolet NGVs compared to their gasoline controls. As shown by the 95 percent confidence intervals, the mean efficiency of the Ford NGVs is not different from the control vans on a statistically significant basis. Mixed results are shown for the Dodge vans. The efficiency of Chevrolet NGV fuel use was significantly less than the gasoline control vans.

The average fuel economy of the vans on an energy equivalent basis was 9.3, 7.8, and 8.2 miles/GEQ for the Ford, Chevrolet, and Dodge NGV fleets. The corresponding fuel economy of the control vans was 8.9, 9.0, and 8.5 miles/GEQ.

The quantity of fuel stored on the vans, the energy content of the fuel, and the efficiency of the vehicle in using the fuel combine to yield an estimate of the driving range of the CleanFleet vans. Results are shown in Figure 6.

The specific driving range was computed as the ratio of driving range to either the volume of fuel storage capacity or the weight of the fuel system on the vehicles. Results are shown in Table 8.

Motor Oil. Figure 7 provides information on the properties of used motor oil from the NGVs. In general, the oil in the NGVs retained levels of TBN that were higher than the oil in the control vans, and these differences were statistically significant. Levels of nitration in the used oil were significantly less. Viscosity of the oil was either not statistically different (Ford and Dodge) or slightly less. Findings for these three oil properties were positive for the NGVs with respect to the gasoline control vans.

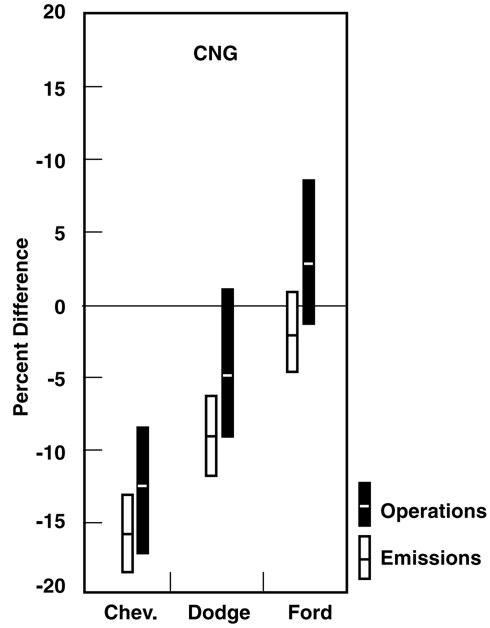


Figure 5. Relative fuel economy (efficiency) for CNG vans was compared to the control vehicles.

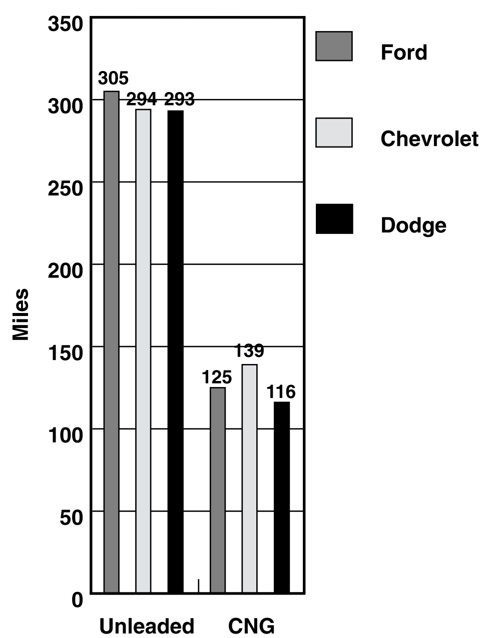


Figure 6. The driving range of CNG and control vans (on a typical FedEx duty cycle at 40 miles per day) was estimated.

Table 8. Specific Driving Range of CNG and Control Vans

Vehicle Manufacturer	Miles Per Gallon Capacity		Miles Per Pound	
	CNG[a]	Control	CNG	Control
Ford	2.5	8.8	0.34	4.2
Chevrolet	2.1	8.9	0.32	4.3
Dodge	2.2	8.4	0.24	4.0

[a] At 3,000 psig.

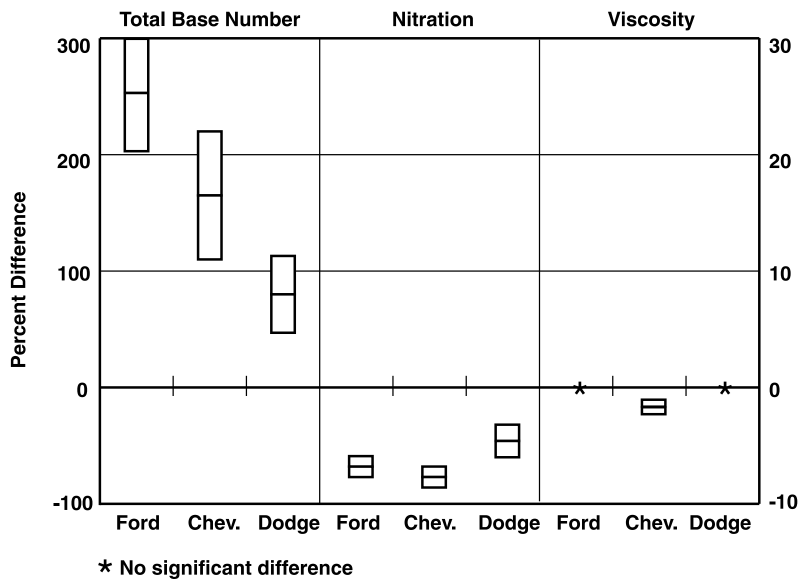


Figure 7. Relative differences in total base number, nitration, and viscosity of used motor oil after 3,000 miles were normalized for CNG and control vans.

Table 9 contains information on the accumulation of metals in engine oil after 10,000 and 20,000 total miles. With the exception of copper in the oil from the Dodge NGVs, all results were either statistically insignificant in terms of metal removal rate or less than the control vehicles.

Table 9. Average Percent Difference in Accumulation of Engine Metals in Motor Oil for the CNG and Control Vans at 10,000 and 20,000 Miles

Metal	Mileage (Thousands)	Ford	Chevrolet	Dodge	
Iron	10	--[a]	--	--	
	20	--	--	--	
Chromium	10	--	--	--	
	20	--	--	--	
Nickel	10	--	--	-57	
	20	--	-50	-65	
Aluminum	10	-50		-31	--
	20	-38	-21	--	
Lead	10	--	-53	--	
	20	-31	-51	-23	
Copper	10	--	--	--	
	20	--	--	+75	
Tin	10	-39	-89	-37	
	20	-44	-90	--	
Molybdenum	10	--	-95	-78	
	20	--	-94	--	
Antimony	10	--	--	--	
	20	--	--	--	

[a] Indicates that the difference was not statistically significant at the 0.6 percent level. This is an overall error rate for all nine comparisons of five percent (i.e., 95 percent confidence level).

Vehicle Maintenance. Maintenance requirements for the NGVs reflected the development status of the vans. The Dodge NGVs experienced two minor leaks at fittings and problems with two pressure regulators. The fuel gauges did not adequately measure the fuel remaining. With the exception of the fuel gauges, few problems occurred with these production vans. The Ford NGVs, which were specially built for the project, experienced some minor hardware problems. The main issue for FedEx was the fuel gauges; the drivers did not trust the readings. In contrast, the Chevrolet NGVs, equipped with IMPCO's AFE system, experienced hardware and software problems throughout the project. These problems were consistent with the developmental nature of the AFE system as applied to NGVs. The fuel gauges on the Chevrolet NGVs were also a problem for FedEx drivers.

As one measure of maintenance requirements, the number of repair orders (ROs) per 100 days of service is plotted in Figure 8 for the whole vehicle and for the fuel-related systems (light shading). In all cases, the NGVs experienced more ROs per 100 days than did the control vans. Comparing the figures for NGVs versus control vans, the relative percent difference in ROs per 100 days for the fuel-related systems was 183, 64, and 86 percent higher for the NGVs for Chevrolet, Dodge, and Ford vans, respectively. In each case, these differences were statistically significant with 95 percent confidence.

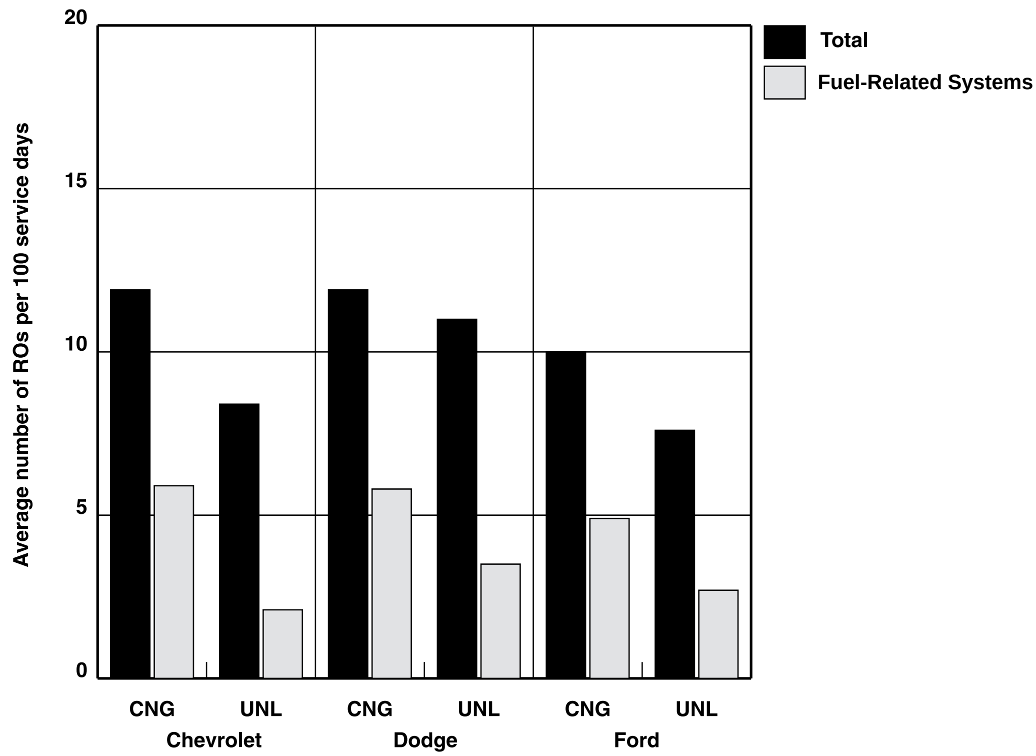


Figure 8. The number of repair orders per 100 days of service for the total van and fuel-related systems is compared for CNG and control vans.

The availability of the NGVs and control vans is shown in Figure 9. Average availability of the Chevrolet, Dodge, and Ford fleets was 94, 93, and 94 percent. The corresponding availability of the control vans was 95, 91, and 98 percent.

Operations Experience

Safety. FedEx experience related to safety in CNG operations is summarized in two parts: (1) potential exposure of employees to natural gas during fueling and to formaldehyde from vehicle exhaust and (2) incidents such as fuel leaks and vehicle accidents.

A limited number of measurements were made of natural gas concentrations in the breathing zone of employees during refueling. The principal components of natural gas, methane and ethane, are considered “simple asphyxiants.” Simple asphyxiants are toxic only at levels where the gas builds up in concentration to an extent that insufficient oxygen is available for breathing. Considering these and other components of natural gas, the measured concentrations in air during refueling were at least an order of magnitude below applicable limits. Under these conditions no adverse health effects would be anticipated.

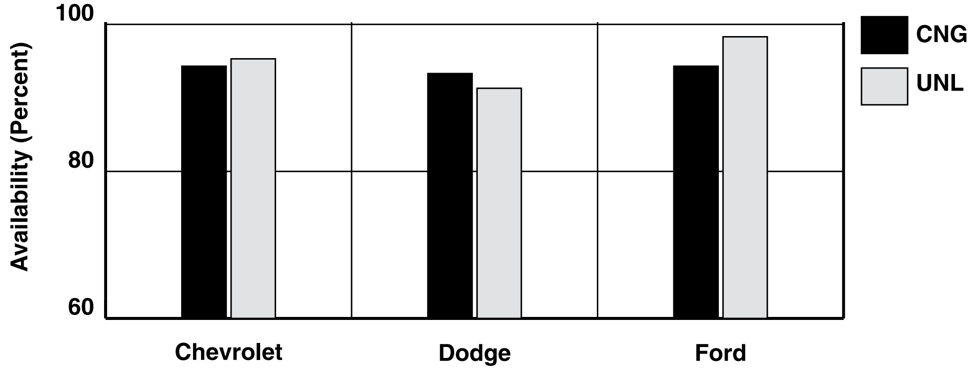


Figure 9. The availability of CNG and control vans is shown.

Formaldehyde concentrations were measured in the FedEx building as the vans were started and pulled out in the morning. Formaldehyde is found in the exhaust of NGVs, and both Occupational Safety and Health Administration (OSHA) and the American Conference of Government and Industrial Hygienists (ACGIH) have established limits for formaldehyde concentrations. Measured levels of formaldehyde were below these levels.

During the course of the demonstration, leaks of natural gas occurred from fittings on tubes in vehicles and the outdoor compressor and cascade storage. The leaks were easily repaired, and no injury or property damage occurred. One NGV was in a traffic accident; the fuel system on the van was not a factor in the accident, and it was not damaged.

FedEx operations were conducted in a safe manner. No safety incidents associated with natural gas resulted in personal injury or property damage.

Employee Attitudes. FedEx employees who participated in the demonstration of NGVs had a uniformly positive attitude about using a “clean-burning” fuel to reduce vehicle emissions and improve air quality. They were proud to be driving the NGVs and reported positive response from FedEx customers who noticed the CleanFleet markings on the vans.

Ninety-four percent of the study group perceived no health problems associated with the use of CNG. The new indoor ventilation that was installed in the FedEx building contributed to this perception because employees believed that the combination of the ventilation system and clean CNG exhaust improved air quality. (Early in the demonstration, the new ventilation system was operated continuously; later a timer was installed, and the system was automatically operated to purge CO from the building. The requirement for the timer was not directly related to the use of natural gas itself as a fuel).

The majority of the study group (75 percent) believed that they experienced no personal safety problems. However, drivers were concerned about poor vehicle acceleration and more stalling than for the control vans. To them this represented a greater potential for a traffic accident. Nevertheless, a positive shift in attitude about the safety of CNG occurred during the demonstration as experience was gained with the previously “unknown” fuel.

Attitudes about NGV performance were mixed. Only four percent of the study group believed that the NGV performance was superior to that of the controls; 58 percent believed that performance was about the same. Consensus was that the NGVs had less horsepower and only marginally acceptable driving range. The drivers believed that they couldn't rely on the fuel gauges in any of the NGVs to provide information on remaining fuel on board and driving range. Considerable concern was raised about the NGVs' stalling (particularly those vans with IMPCO's AFE system).

When questioned about daily operations, fueling the NGVs emerged as a major concern. Problems cited were (1) inability of the compressor station to fuel all 21 vans to full capacity in rapid sequence and (2) the time required to fuel the 21 NGVs when the compressor/cascade system was fueling the last four to five vans.

In spite of their desire to improve air quality, the lack of health concerns, and the demonstrated ability to use CNG in fleet operations, about 56 percent of the study group at the CNG site did not believe that FedEx should convert the entire fleet operation at the site to CNG until vehicle performance and fueling issues were resolved.

Emissions

As the NGVs were used in daily FedEx operations, the mass of pollutants emitted into the atmosphere was significantly reduced. Results are shown in Figure 10 for selected pollutants over the odometer range 5,000 to 25,000 miles. For example, reductions in emission of CO from the Ford, Chevrolet, and Dodge fleets compared to their control fleets averaged 36, 160, and 106 kg per van. Estimates of the reduction in ozone formed in the atmosphere by emissions of NMOG and NO_x were 20, 38, and 29 kg per van for the same fleets. This represents over a 90 percent reduction in ozone-forming potential of exhaust from NGVs compared to gasoline vans. Reductions in air toxics were estimated to be 0.34, 0.87, and 0.59 kg. Reductions of CO_2 (not shown in Figure 10) averaged 3,020, 1,230, and 2,030 kg per van compared to their controls. Methane emissions increased by 50, 50, and 13 kg.

Fleet Economics

The estimated cost to a fleet operator to use CNG in 50 vans in the 1996 time frame is shown in Figure 11 for six options. Results are shown before corporate income tax or incentives and after tax and with incentives. Two basic cases are shown: (1) the four options on the left represent the case in which the fleet installs, owns, and operates the natural gas fuel station (compressor, cascade storage, dispenser), and (2) the two options on the right represent the case in which the fleet purchases the gas already compressed from a fuel station installed on site by a third party such as a gas utility.

The baseline case on the left represents operations that are the closest to FedEx operations in CleanFleet: redundancy of the compressor (i.e., two compressors in the event one of them was not working), rapid fueling of the entire fleet (i.e., all NGVs within 3 to 4 hours), and vehicles stored indoors. The total estimated annual cost to the fleet is 45.9 cents per mile. The first option, listed as a single compressor with longer fueling time for the fleet (i.e., about six hours) requires a smaller capital investment in the fuel station (in this case, $300,000 compared to $450,000), and the result is a reduction of 1.6 cents per mile in total estimated annual costs for the fleet. The next option includes the first option plus an estimate of reduced operation and maintenance (O&M) costs for the fuel station. The

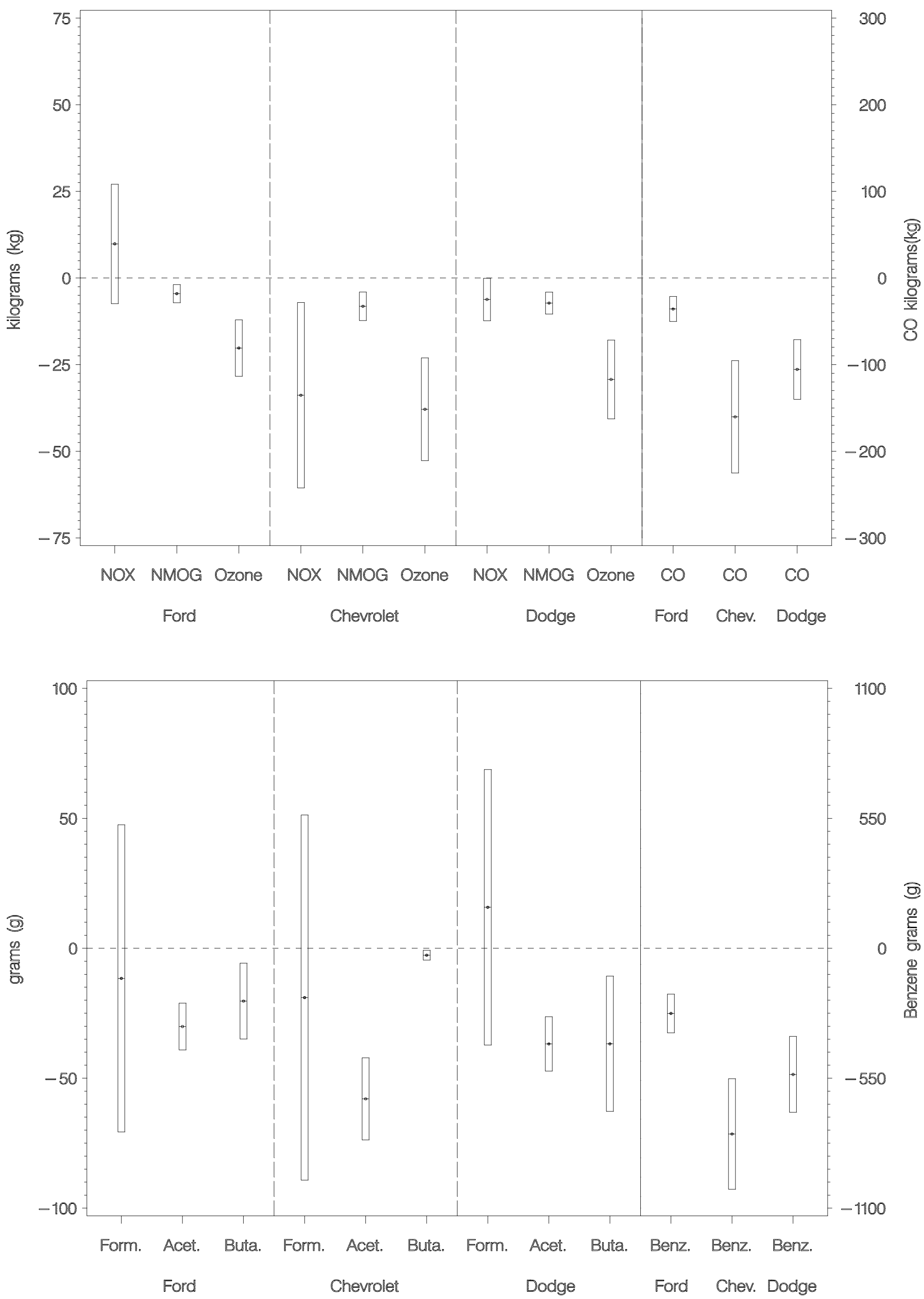


Figure 10. Estimated differences in selected emissions from CNG vehicles compared with control vehicles are shown over the range 5,000 to 25,000 miles.

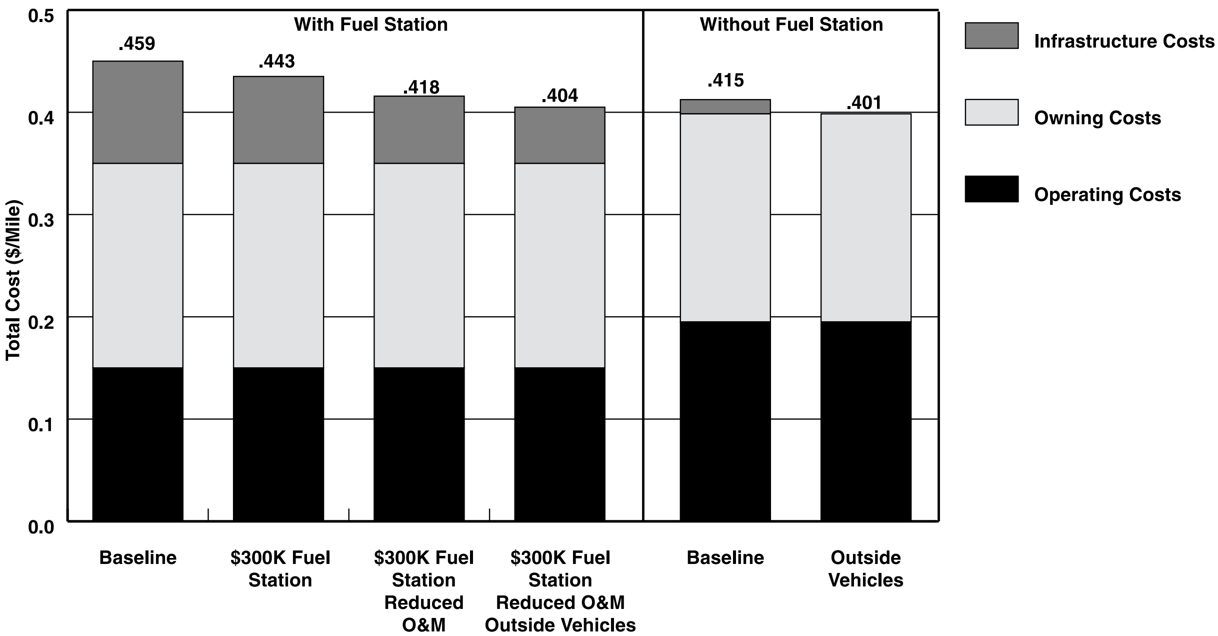


Figure 11. Costs were estimated for a CNG fleet in a 1996 economic case study.

O&M costs in CleanFleet were substantial. Scaling them from the 21-van fleet in the project to the 50-van fleet for the case study yielded O&M costs of 38 cents per GEQ. A reasonable lower estimate of O&M costs for 1996 technology and operations was 16 cents per GEQ, yielding a total cost per mile for the fleet of 41.8 cents per mile. Finally, if the vans were not brought indoors and the buildings were not modified, the estimated total cost to the fleet is 40.4 cents per mile.

Two cases are provided for the option in which the fleet purchases natural gas already compressed. The baseline case for this option differs from the baseline case on the left only in the investment costs for the fuel station, O&M costs for the fuel station, and the price of the natural gas. The total estimated cost per mile is 41.5 cents per mile. If the vans are stored outside, the total cost drops to 40.1 cents per mile.

Table 10 summarizes the results before and after income taxes, with the effect of incentives included in the after-tax estimates.

Table 10. Estimated Total Costs (cents/mi) for a CNG Fleet Before and After Income Tax

Option	Before Income Tax Without Incentives (cents/mi)	After Income Tax With Incentives (cents/mi)
Fleet Owns Fuel Station		
Baseline	45.9	29.0
Single Compressor Longer Fueling	44.3	27.9
Plus Reduced O&M Costs	41.8	26.4
Plus Vans Stored Outside	40.4	25.3
Fleet Buys Compressed Gas		
Baseline	41.5	25.9
Vans Stored Outside	40.1	24.8

Propane Gas

Findings from the propane gas portion of the project are summarized in five parts. The basis for the demonstration and findings is summarized first. Then findings on operations are presented in two sections (data and experience). This is followed by a summary of findings on emissions and fleet economics.

Basis for Demonstration and Findings

The basis for the propane gas demonstration is summarized in five parts: vehicle technologies, fuel properties, fueling facility, building facility, and vehicle activity.

Vehicle Technologies. The 20 propane gas vans were all after-market modifications to gasoline vans from Ford and Chevrolet that had been built with engines that were compatible with gaseous fuels (see Table 11). Two generations of IMPCO fuel system technology were used on the vans. The Ford vans were equipped with IMPCO's adaptive digital processor (ADP) system, and the Chevrolet vans were equipped with IMPCO's AFE system (which was the same engine management system used on the Chevrolet CNG vans).

Ford. The 13 Ford propane gas vans had 4.9-liter, in-line, six-cylinder engines that had been prepared for use with a gaseous fuel (Ford's "LP prep package"). IMPCO's ADP system was added to these vans. The ADP system is a stand-alone system with an alternative fuel, electronic, closed-loop feedback controller.

The Ford propane gas vans were equipped with one steel tank for fuel storage providing 19 GEQ of storage capacity at 85 percent of gross tank volume. On average, these vans weighed about 153 pounds less than the Ford control vans. The catalyst on board these vans was a standard 1992 gasoline catalyst system for California. These vans were operated on permits for the ARB-certified ADP system.

Chevrolet. The seven Chevrolet propane gas vehicles were all 5.7-liter, V8 engines. IMPCO's AFE system was added to these vehicles during the after-market modification. The AFE system is a microprocessor-based engine management system that controls fuel flow and mixture, spark advance, and EGR functions to provide optimum engine performance. AFE's operational functions interact with the vehicle's OEM on-board computer. The AFE strategy allows the OEM on-board diagnostic routines to remain operational at all times. Fuel was provided to the engine through a gas ring just upstream of the throttle body (see Table 11). The compression ratio was not changed during the modification process; it remained at 8.6:1.

The Chevrolet vans had twin steel fuel tanks providing 21 GEQ of storage capacity at 85 percent of gross tank volume. On average, these vans, with 5.7-liter engines, weighed about 172 pounds more than the Chevrolet control vans with 4.3-liter engines. The Engelhard catalyst was chosen specifically for treating exhaust from propane gas. These vans were operated on experimental permits granted by the ARB.

Table 11. Characteristics of the Propane Gas and Control Vans

Vehicle Component	Ford		Chevrolet	
	Propane Gas	Control	Propane Gas	Control
Chassis Model	E250	E250	G30	G30
Engine				
Displacement (L)	4.9	4.9	5.7	4.3
Type	I6	I6	V8	V6
Compression Ratio	8.8	8.8	8.6	8.6
Fuel Delivery[(a)]	TB	MPI	TB	TBI
Fuel Capacity (L)	98	132	105	125
Fuel Capacity (GEQ)[(b)]	18.7	34.9	20.1	33.0
Vehicle Weight (kg)	2,421	2,490	2,326	2,248
Engine Classification[(c)]	MD	MD	HD	HD
Catalyst[(d)]	G	G	PRO	G

(a) TB = Fuel provided through the throttle body, TBI = TB injection, MPI = Multiport electronic fuel injection, SMPI = Sequential MPI.
(b) GEQ = Gasoline equivalent gallons on an energy equivalent basis.
(c) MD = Vans in California medium-duty class. HD = Engines in heavy-duty class.
(d) Three-way catalyst optimized for exhaust from the fuels listed. G = Gasoline, PRO = Propane gas.

Fuel Properties. Propane gas (or liquefied petroleum gas) was delivered to the FedEx demonstration site in Rialto about once a week for use by the CleanFleet propane gas vans. The project specification for propane gas was HD-5, i.e., the concentration of propene was to be less than five percent by volume. The composition of the propane gas was more variable over the first three months of the demonstration than during the succeeding months. As shown in Table 12, the average propane content of propane gas was 91.88 percent, with an RSD of 4.86 percent. The net heating value had an RSD of 0.49 percent over the course of the demonstration.

Fueling Facility. The propane industry installed a fueling station on FedEx property for the demonstration. Shown in Figure 12, the installation consisted of a 3,800-liter (1,000-gallon) storage tank, pump, and dispenser. Figure 12 shows delivery of propane gas to the storage tank. Note the asphalt pad near the tank that has markings painted on it. The grade at this location was not level, and initially when propane gas vans were fueled, the FedEx fueler was unable to fill the vans to the 85-percent full capacity; the quantity dispensed was 2 to 3 gallons short. This shortfall was caused by the angle of the vans parked at the tank for fueling. The float inside the fuel tank indicated a full load of fuel when more space was available. By leveling the area near the fuel tank with a new asphalt pad, a full load of fuel was delivered to the vans.

Table 12. Average Characteristics of Propane Gas

Parameter	Units	Mean	Relative Standard Deviation (%)[d]
Methane	Vol %	0.20	NR
Ethane	Vol %	5.43	NR
Propane	Vol %	91.88	4.86
Propene	Vol %	0.76	NR
Butanes	Vol %	1.48	NR
C5+[a]	Vol %	0.02	NR
Inerts[b]	Vol %	0.23	NR
Liquid density	kg/L	0.501	1.03
Heating Value, net	MJ/kg	46.3	0.49
Wobbe Index[c]	MJ/m^3	69.3	1.29

[a] C5+ is hydrocarbons with five or more carbon atoms.
[b] Inerts include nitrogen, oxygen, and carbon dioxide.
[c] Calculated from heating value and liquid density.
[d] RSD is reported for major components and parameters. NR means not reported.

Figure 12. Propane gas was delivered on site at FedEx.

SUMMARY OF CLEANFLEET FINDINGS

Building Facility. The building into which FedEx vehicles were brought was a mixed use facility having both a package sorting and loading area and office space. FedEx vans are being loaded in the building in Figure 13. Working with the code officials and the fire marshall, the following modifications to the building were implemented:

- Increased the ventilation rate to six air changes per hour.
- Extended the exhaust intake ducts to within 18 inches of the floor (because propane is heavier than air).
- Installed four flammable gas detectors near the floor along the sorting belt.
- Linked the gas detector system to the ventilation system to provide automatic activation if flammable gas was detected by any sensor at a level exceeding 20 percent of the lower flammable limit.

Vehicle Activity. Over the course of the demonstration, the propane gas vans, on average, logged between 36,000 and 40,000 miles compared to the control vans with 39,000 to 43,000 miles (see Table 13).

Figure 13. FedEx vans were brought into buildings each day for loading and unloading packages.

Table 13. Summary of Vehicle Activity for the Propane Gas Fleet

Type of Fuel	Vehicle Manufacturer	Average Number of Service Days	Average Total Miles Per Vehicle	Average Miles Per Day
Propane	Ford Chevrolet	522 432	39,521 35,519	76 82
Control	Ford Chevrolet	572 502	42,452 38,758	74 77

Figure 14 demonstrates how the vehicle rotation plan achieved its goal of equalizing the distribution of duty cycles among fleets at the propane gas site. Overall the distribution of average miles per day for the propane gas and control vans overlap.

Operations Data

Operations data for the propane gas portion of the demonstration are summarized for vehicle fuel economy, motor oil, and vehicle maintenance.

Fuel Economy. The mean efficiencies of the Ford and Chevrolet propane gas vans compared to their control fleets are shown in Figure 15. The mean efficiencies from operational data were -3.9 and -11.8 percent for these fleets. The corresponding mean efficiencies from the emissions chassis dynamometer were -5.9 and -10.7 percent. The low efficiency for the Chevrolet vans reflects the different engines (5.7-liter V8 CNG vs. 4.3-liter V6 gasoline control), as well as limited optimization of the Chevrolet propane gas vans compared to their gasoline controls. As shown by the 95 percent confidence intervals, the mean efficiency of the Ford vans determined from operations data is not different from the control vans on a statistically significant basis. However, the mean efficiency determined from the chassis dynamometer is significantly less. The Chevrolet propane gas van fuel use efficiency was significantly less than the gasoline control vans.

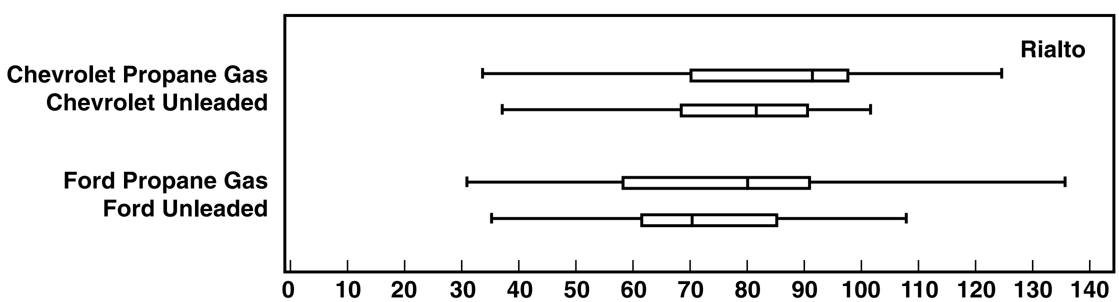


Figure 14. The distribution of the average miles that the propane gas and control vehicles traveled each day overlaps, providing comparable routes.

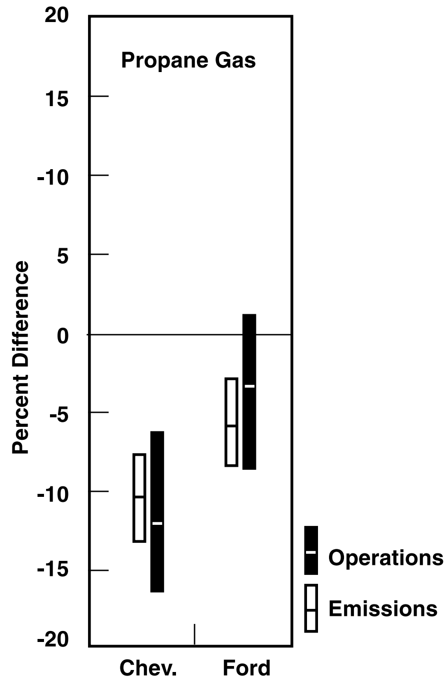


Figure 15. Relative fuel economy (efficiency) for propane gas vans was compared to the control vehicles.

The average fuel economy of the propane vans was 8.2 and 7.7 miles/GEQ for the Ford and Chevrolet fleets. The corresponding fuel economy for the control fleets was 8.6 and 8.8 miles/GEQ.

The quantity of fuel stored on the vans, the energy content of the fuel, and the efficiency of the vehicle in using the fuel combine to yield an estimate of the driving range of the CleanFleet vans. Results are shown in Figure 16.

The specific driving range was computed as the ratio of driving range to either the volume of fuel storage capacity or the weight of the fuel system on the vehicles. Results are shown in Table 14.

Motor Oil. Figure 17 provides information on the properties of used motor oil from the vans. The TBN levels in used oil were, on average, over 100 percent higher than the levels in oil from the control vans. Nitration levels showed mixed results, and viscosity was about the same as for the controls. For both the Ford and Chevrolet vehicles, viscosity for the propane gas and control vans was within normal range.

Table 15 contains information on the accumulation of metals in motor oil after 10,000 and 20,000 total miles. In all cases, the average accumulation of the nine metals from the propane gas engines was either less or the same as from the control vehicles within the statistical uncertainty. The Chevrolet vans showed the most difference; it is important to remember that the Chevrolet propane van engines were 5.7 liters versus 4.3 liters for the gasoline vans.

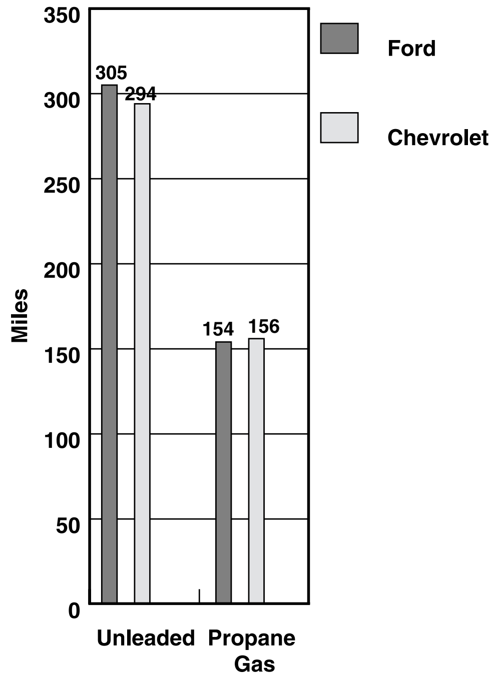


Figure 16. The driving range of propane gas and control vans (on a typical FedEx duty cycle at 40 miles per day) was estimated.

Table 14. Specific Driving Range of Propane Gas and Control Vans

Vehicle Manufacturer	Miles Per Gallon Capacity		Miles Per Pound	
	Propane	Control	Propane	Control
Ford	5.9	8.8	1.5	4.2
Chevrolet	5.6	8.9	1.3	4.3

Vehicle Maintenance. Maintenance requirements for the propane gas vans reflected the developmental status of the fuel kits used on the vans. The Ford vans had the more proven ADP system from IMPCO, and these vans experienced fewer maintenance requirements than did the Chevrolet vans with IMPCO's AFE system. Problems occurred with both hardware and software in the ADP and AFE systems. The fuel gauges on the propane gas vans were deemed unreliable by FedEx drivers.

As one measure of maintenance requirements, the number of ROs per 100 days of service is plotted in Figure 18 for the whole vehicle and for the fuel-related systems. In all cases, the propane gas vans experienced more ROs per 100 days than did the control vans. Comparing the figures for propane gas vans versus control vans, the relative percent difference in ROs per 100 days for the fuel-related systems (lightly shaded bars) was 54 and 21 percent higher for the Chevrolet and Ford propane gas

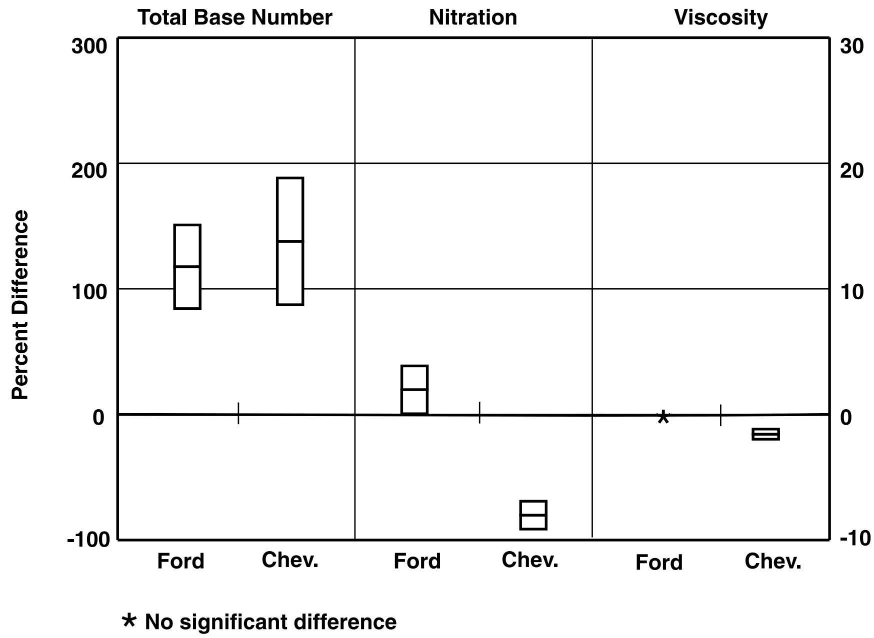


Figure 17. Relative differences in total base number, nitration, and viscosity of used motor oil after 3,000 miles were normalized for propane gas and control vans.

Table 15. Average Percent Difference in Accumulation of Engine Metals in Motor Oil for the Propane Gas and Control Vans at 10,000 and 20,000 Miles

Metal	Mileage (Thousands)	Ford	Chevrolet	
Iron	10 20	--[a] --	-- --	
Chromium	10 20	-- --	-- --	
Nickel	10 20	-- --	-56 -62	
Aluminum	10 20	-66 -58	 -67	-60
Lead	10 20	-- -27	-50 -52	
Copper	10 20	-- --	-- --	
Tin	10 20	-- -36	-92 -92	
Molybdenum	10 20	-- --	-95 -94	
Antimony	10 20	-- --	-- --	

[a] Indicates that the difference was not statistically significant at the 0.6 percent level. This is an overall error rate for all nine comparisons of five percent.

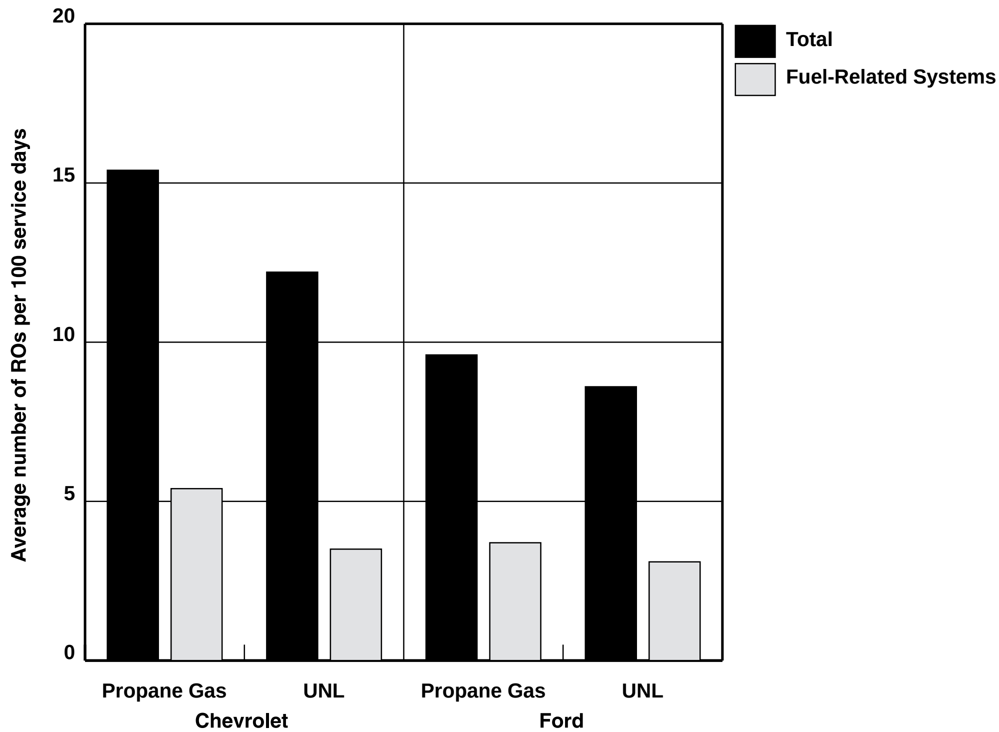


Figure 18. The number of repair orders per 100 days of service for the total van and fuel-related systems is compared for propane gas and control vans.

vans, respectively. The percent difference for the Chevrolet vans was statistically significant with 95 percent confidence. The difference for the Ford vans was not statistically significant.

The availability of the propane gas vans and control vans is shown in Figure 19. Average availability of the Chevrolet and Ford fleets was 88 and 96 percent. The corresponding availability of the control vans was 91 and 96 percent.

Operations Experience

Safety. FedEx experience related to safety in propane gas operations is summarized in two parts: (1) potential exposure of employees to propane gas during fueling and (2) incidents such as fuel leaks and vehicle accidents.

Limited measurements were made of propane gas concentrations in the breathing zone of employees during refueling. The principal component of the fuel is propane. Propane is considered to be an “asphyxiant” by the ACGIH. This means it is toxic only at a level where the air is diluted such that insufficient oxygen is available for breathing. The OSHA personal exposure limit, an 8-hour average, for propane is 1,000 ppm. Some of the observed propane concentrations exceeded 1,000 ppm for short

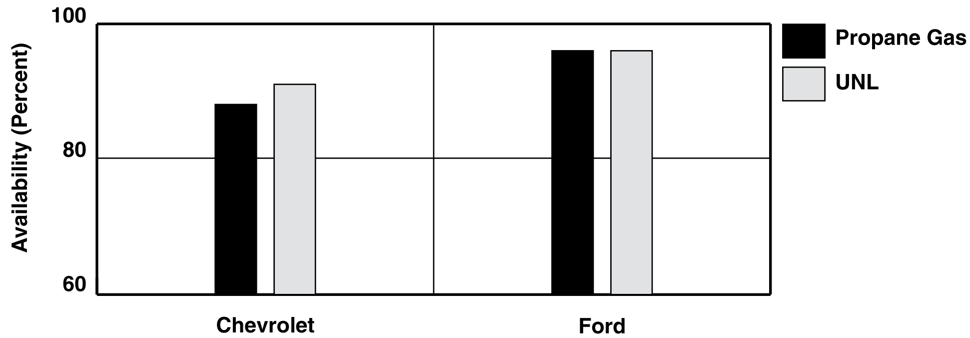


Figure 19. The availability of propane gas and control vans is shown.

periods of time—a few minutes. However, the overall time-averaged exposure of fuelers to propane vapor is estimated to have been much less than the OSHA limit.

During the course of the demonstration, leaks of propane gas occurred from fittings on the fuel system in the vehicles. The leaks were easily repaired, and no injury or property damage occurred.

FedEx operations were conducted in a safe manner. No safety incidents associated with propane gas resulted in personal injury or property damage.

Employee Attitudes. FedEx employees who participated in the demonstration of propane gas had a positive attitude about using a “clean-burning” fuel to reduce vehicle emissions and improve air quality. They reported positive response from FedEx customers who noticed the CleanFleet markings on the vans.

Eighty-eight percent of the study group perceived no health problems associated with use of propane gas.

About a third of the study group reported safety concerns, and these related to operation of the vans. Of those who reported such concerns, six percent of the study group were concerned about fuel leaks (fearing an explosion). Twenty-seven percent were concerned about stalling, lack of acceleration, and braking. The concerns about stalling and poor acceleration related to performance and reliability problems with the vans. As employees considered their attitudes about safety of propane gas before and near the conclusion of the demonstration, 39 percent reported no change in attitude and 46 percent reported a positive change in their attitude. Twelve percent were more concerned about safety compared to their initial attitudes.

Attitudes about vehicle performance were mixed. Only seven percent of the study group believed that the performance of the propane gas vans was superior to that of the controls; 59 percent believed that the performance was about the same. Mechanics were positive about the appearance of the used motor oil at each oil change. People reported initial problems with hard starting and stalling, but they believed that these problems had been fixed. Drivers believed that they couldn’t rely on the fuel gauges in either the Ford or Chevrolet propane gas vans to provide information on the remaining quantity of fuel and driving range.

When questioned about daily operations, 68 percent of the study group believed that they were able to meet their regular schedule without interruption; 10 percent had no opinion.

In spite of their desire to improve air quality, the majority opinion that health was not an issue, and the demonstrated ability to use propane gas in fleet operations, about 46 percent of the study group at the propane gas site did not believe that FedEx should convert the entire fleet operation at the site to propane gas; vehicle stalling issues and inaccuracy of the vehicle fuel gauges remained in their minds.

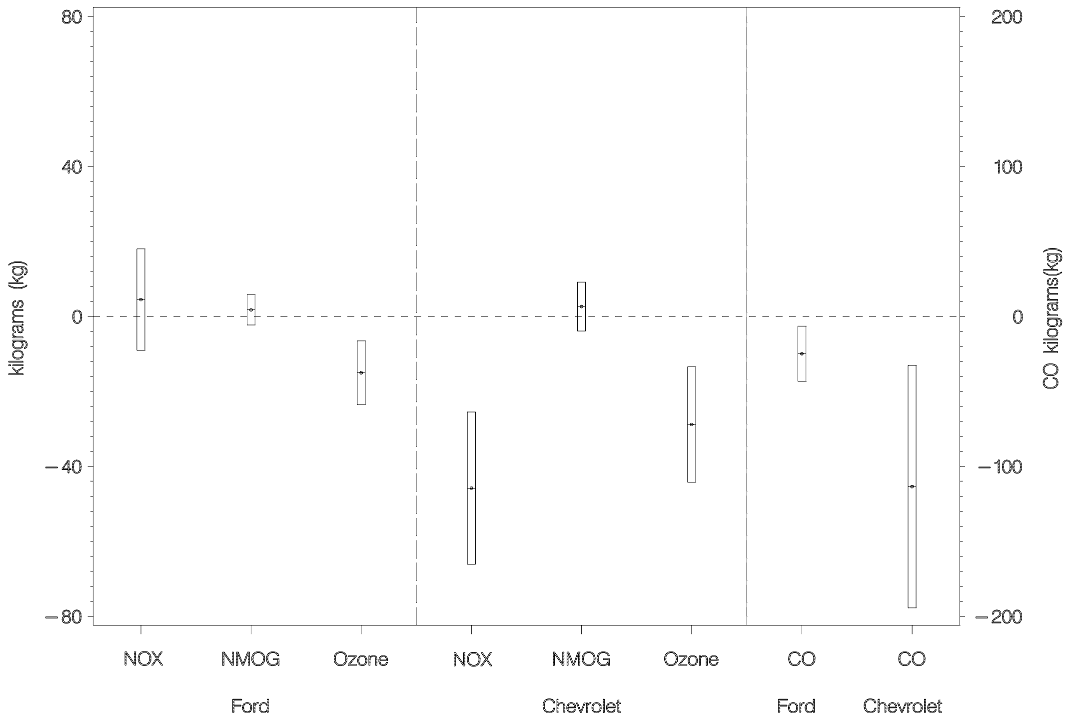
Emissions

As the propane gas vans were used in daily FedEx operations, the mass of most pollutants emitted into the atmosphere was significantly reduced. NMOG emissions (principally propane as unburned fuel) were higher than for the gasoline control vans. Results are shown in Figure 20 for selected pollutants over the odometer range 5,000 to 25,000 miles. For example, reductions in emission of CO from the Ford and Chevrolet fleets compared to their control fleets averaged 25 and 114 kg per van. Estimates of the reduction in ozone formed in the atmosphere by emissions of NMOG and NO_x were 15 and 29 kg per van for the same fleets. This represents more than a 50 percent reduction in ozone-forming potential of exhaust from propane gas vans compared to gasoline vans. Reductions in air toxics were estimated to be 0.34 and 0.86 kg. Reductions in CO_2 (not shown in Figure 20) averaged 900 and 230 kg per van compared to their controls. Methane emissions increased by 0.5 and 0.8 kg.

Fleet Economics

The estimated cost to a fleet operator to use propane gas in 50 vans in the 1996 time frame is shown in Figure 21 for three options. Results are shown before corporate income tax and without tax and other incentives. In the baseline option, vehicles are brought indoors, and a ventilation system linked to a group of flammable gas detectors is installed. The estimated total annual cost per mile of vehicle travel is 39.6 cents per mile. In the middle case, an array of flammable gas detectors is employed along with an alarm, but not an enhanced ventilation system. In this option, if the gas detection system sounds an alarm, the building would be evacuated; and people would need to wait until the concentration of flammable gas decreased (without automatic start-up of a ventilation system) before returning to work inside. Finally, if the vehicles were not brought indoors, building modifications would not be needed, dropping the annual cost to 38.2 cents per mile. In all cases, it is assumed that the fleet installs and pays for a propane fuel storage tank and dispenser on the property.

Table 16 summarizes the results before and after income taxes, with the effect of incentives included in the after-tax estimates.



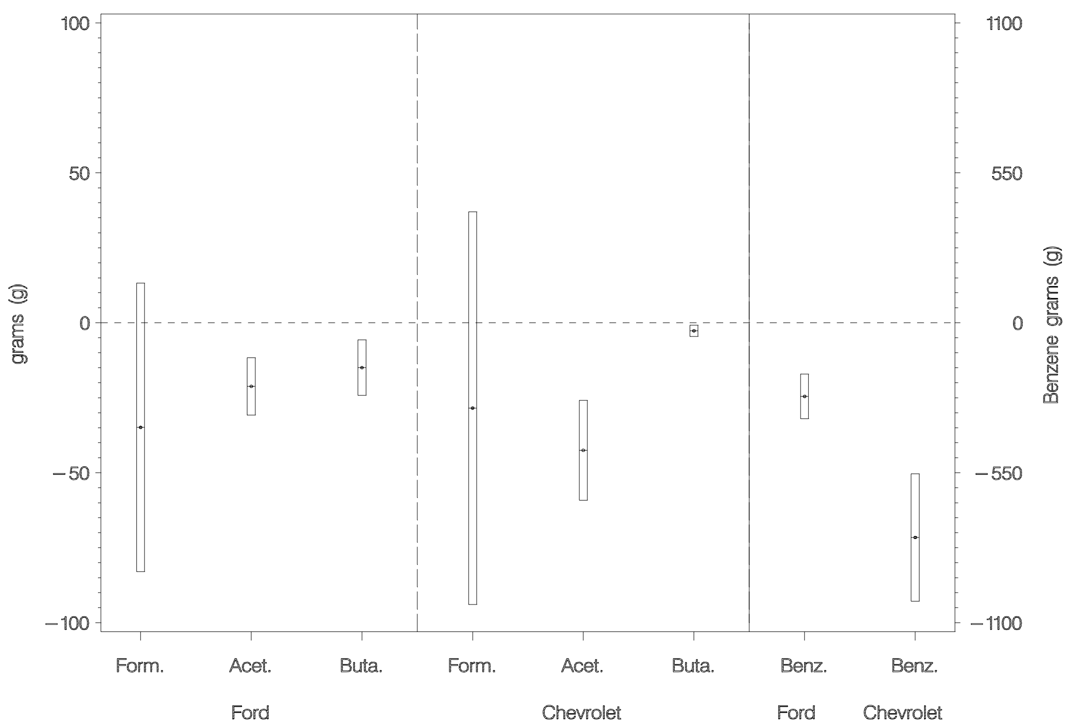


Figure 20. Estimated differences in selected emissions from propane gas vehicles compared with control vehicles are shown over the range 5,000 to 25,000 miles.

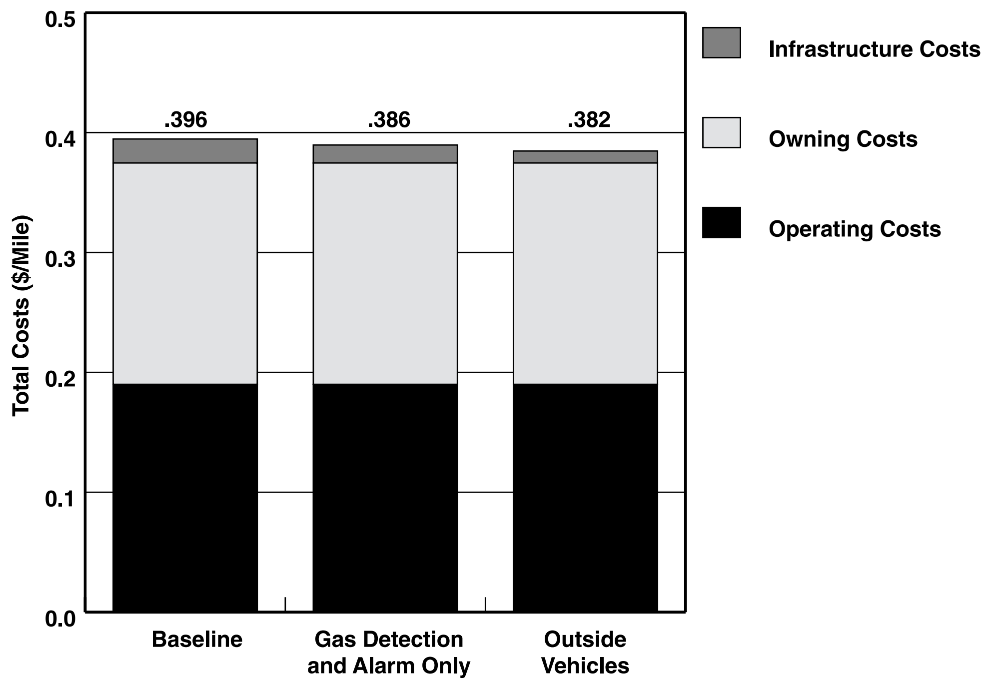


Figure 21. Costs were estimated for a propane gas fleet in the 1996 economic case study.

Table 16. Estimated Total Costs for a Propane Gas Fleet Before and After Income Tax

Option	Before Income Tax Without Incentives (cents/mi)	After Income Tax With Incentives (cents/mi)
Baseline	39.6	24.7
Gas Detection and Alarm Only	38.6	23.9
Vans Stored Outside	38.2	23.6

Reformulated Gasoline

Findings from the RFG portion of the project are summarized in five parts. The basis for the demonstration and findings is summarized first. Then findings on operations are presented in two sections (data and experience). This is followed by a summary of findings on emissions and fleet economics.

Basis for Demonstration and Findings

The basis for the RFG demonstration is summarized in five parts: vehicle technologies, fuel properties, fueling facility, building facility, and vehicle activity.

Vehicle Technologies. The vans operating on gasoline (both reformulated and baseline unleaded) were all standard model year 1992 production vans. Differences shown in actual weight between the RFG and control vans in Table 17 are indicative of the variability of the measurements, principally in upfitting FedEx equipment and supplies in the individual vans.

Table 17. Characteristics of the RFG and Control Vans

	Ford		Chevrolet		Dodge	
Vehicle Component	**RFG**	**Control**	**RFG**	**Control**	**RFG**	**Control**
Chassis Model	E250	E250	G30	G30	B350	B350
Engine						
Displacement (L)	4.9	4.9	4.3	4.3	5.2	5.2
Type	I6	I6	V6	V6	V8	V8
Compression Ratio	8.8	8.8	8.6	8.6	9.08	9.08
Fuel Delivery[a]	MPI	MPI	CPI	CPI	SMPI	SMPI
Fuel Capacity (L)	132	132	125	125	132	132
Fuel Capacity (GEQ)[b]	34.9	34.9	33.0	33.0	34.9	34.9
Vehicle Weight (kg)	2,516	2,490	2,259	2,248	2,189	2,183
Engine Classification[c]	MD	MD	HD	HD	MD	MD
Catalyst[d]	G	G	G	G	G	G

[a] TB = Fuel provided through the throttle body, CPI = Central port injection, MPI = Multiport electronic fuel injection, SMPI = Sequential MPI.
[b] GEQ = Gasoline equivalent gallons on an energy equivalent basis.
[c] MD = Vans in California medium-duty class. HD = Engines in heavy-duty class.
[d] Three-way catalyst optimized for exhaust from gasoline (G).

The catalysts on these vans were standard model year 1992 catalysts for California. The emission control systems on these vans were not optimized for future California LEV standards.

SUMMARY OF CLEANFLEET FINDINGS

Fuel Properties. Phase 2 RFG was blended in two batches for the project by Phillips Petroleum under contract to ARCO and Chevron. Although the RFG blends met California specifications for Phase 2 gasoline, they were not produced entirely from refinery streams expected to be used for production in 1996 and beyond. Consequently, some differences in effects of their use are possible. The two batches differed slightly in composition, but both batches met specifications for Phase 2 RFG. For example, toluene constituted about 14 percent by weight of batch 1 of RFG and 8.2 percent by weight of batch 2. The sulfur content of the two batches was 17 and 36 parts per million (ppm), within the 40 ppm specification. The T90 value was 143 C and 148 C. Over the course of the demonstration, the net heating value had an RSD of 1.73 percent (see Table 18).

Table 18. Average Characteristics of RFG

Parameter	Units	Mean	Relative Standard Deviation (%)
Density	kg/L	0.738	0.43
Methanol	Vol %	0.0	NR
Ethanol	Vol %	0.0	NR
MTBE[(a)]	Vol %	10.5	3.94
TBA[(b)]	wt %	0.0	NR
Carbon	wt %	83.9	1.19
Hydrogen	wt %	13.7	2.40
Heating Value, net	MJ/kg	42.3	1.73
Reid Vapor Pressure	kPa	47.5[(c)]	2.01

(a) MTBE is methyl tert-butyl ether.
(b) TBA is tert-butyl alcohol.
(c) 47.5 kPa = 6.89 psi.

Fueling Facility. FedEx made available an underground fuel storage tank of 20,000 liters capacity. Fuel was delivered to the site by tanker from bulk storage in Oklahoma.

Building Facility. No modifications were required to the FedEx building to bring RFG-fueled vans into it.

Vehicle Activity. Over the course of the demonstration, the RFG vans, on average, logged between 20,000 and 21,000 miles compared to the control vans with 16,000 to 26,000 miles (see Table 19).

Figure 22 demonstrates how the vehicle rotation plan achieved its goal of equalizing the distribution of duty cycles among the RFG fleets. Overall the distribution of average miles per day for the RFG and control vans overlap.

Table 19. Summary of Vehicle Activity for the RFG Fleet

Type of Fuel	Vehicle Manufacturer	Average Number of Service Days	Average Total Miles Per Vehicle	Average Miles Per Day
CNG	Ford	648	20,984	32
	Chevrolet	608	19,740	32
	Dodge	605	18,246	30
Control	Ford	647	18,944	29
	Chevrolet	660	16,176	24
	Dodge	607	25,697	42

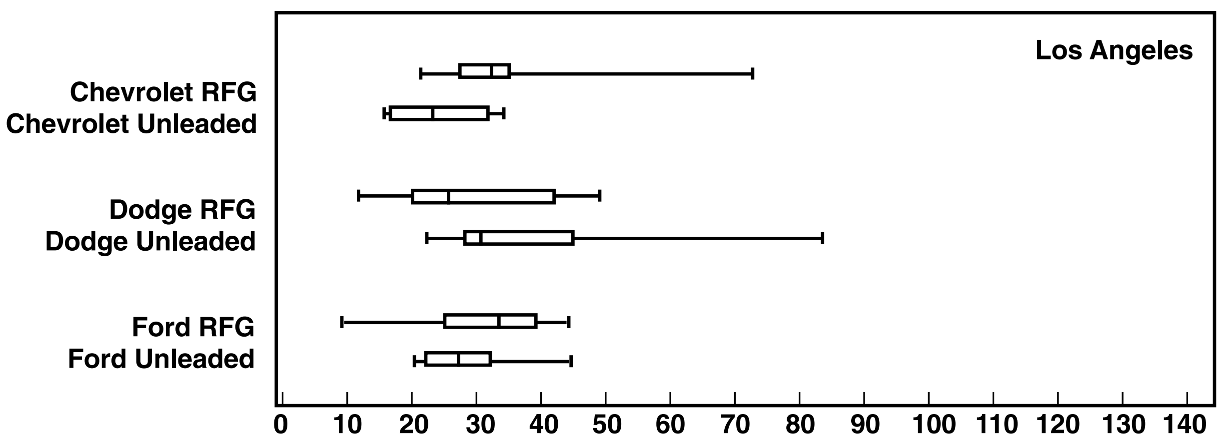


Figure 22. The distribution of the average miles that the RFG and control vehicles traveled each day overlaps, providing comparable routes.

Operations Data

Operations data for the RFG portion of the demonstration are summarized for vehicle fuel economy, motor oil, and vehicle maintenance.

Fuel Economy. The mean efficiencies of the Ford, Chevrolet, and Dodge RFG vans compared to their control fleets are shown in Figure 23. The mean efficiencies from operational data were -7.0, -5.2, and 1.0 percent different for the RFG fleets compared to their control fleets. The corresponding mean relative efficiencies from the emissions chassis dynamometer were -2.0, 0.9, and -2.7 percent. As shown by the 95 percent confidence intervals, only the mean relative efficiency for the Ford vans from the operational data is statistically significant. Given these results, it can be reasonably concluded that there was no difference in the efficiency of the vans using RFG compared to their controls.

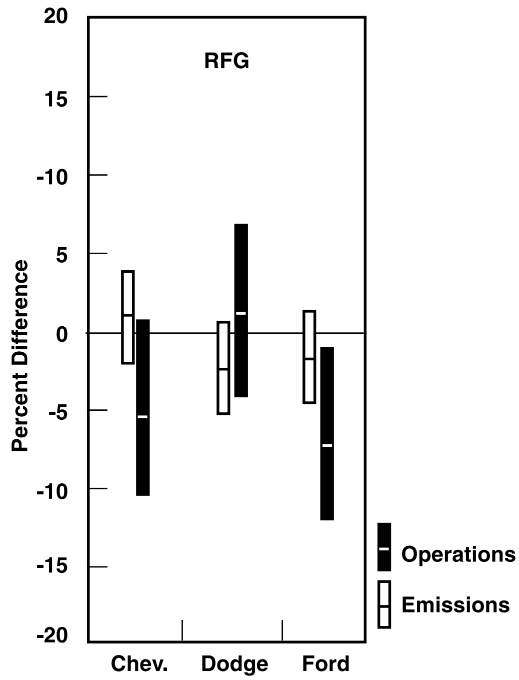


Figure 23. Relative fuel economy (efficiency) for RFG vans was compared to the control vehicles.

The average fuel economy of the RFG vans was 8.2, 8.4, and 8.4 miles/GEQ for the Ford, Chevrolet, and Dodge fleets. The corresponding fuel economy for the control fleets was 8.8, 8.9, and 8.3 miles/GEQ.

The quantity of fuel to be stored on the RFG vans, the energy content of the fuel, and the efficiency of the vehicle in using the fuel combine to yield an estimate of the driving range of the CleanFleet vans. Results are shown in Figure 24.

Specific driving range was computed as the ratio of driving range to either the volume of fuel storage capacity or the weight of the fuel system on the vehicles. Results are shown in Table 20.

Motor Oil. Figure 25 provides information on the properties of used motor oil from the vans. TBN levels in oil from the RFG vans were higher than from the control vans with 95 percent statistical confidence; nitration levels were less. Viscosity of the used oil was within normal range and about the same as the viscosity of the oil from the control vans.

Table 21 contains information on the accumulation of metals in motor oil after 10,000 and 20,000 total miles. The average metal removal rates of each of the nine metals from the RFG engines was for the most part not statistically different from the control engines. As observed in Table 21, some accumulations of metal in the engine were less for the RFG engines; none were greater.

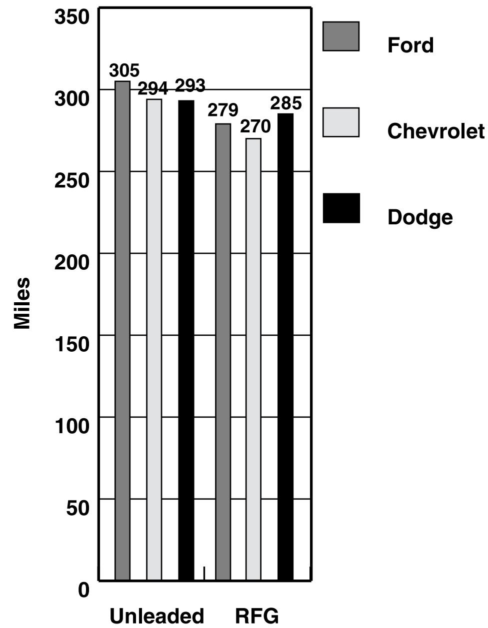


Figure 24. The driving range of RFG and control vans (on a typical FedEx duty cycle at 40 miles per day) was estimated.

Table 20. Specific Driving Range of RFG and Control Vans

	Miles Per Gallon Capacity		Miles Per Pound	
Vehicle Manufacturer	**RFG**	**Control**	**RFG**	**Control**
Ford	8.0	8.8	3.8	4.2
Chevrolet	8.2	8.9	4.0	4.3
Dodge	8.2	8.4	3.9	4.0

Vehicle Maintenance. Over the course of the two-year demonstration, no fuel-related maintenance was required on the RFG vans. As one measure of maintenance requirements, the number of ROs per 100 days of service is plotted in Figure 26 for the whole vehicle and for the potentially fuel-related systems. A finite number of potentially fuel-related system repairs is shown in Figure 26 because the values are based on a computer search of ATA codes that cover some non-fuel-related systems. Comparing the figures for RFG versus control vans, the relative percent difference in ROs per 100 days was for the fuel-related systems (lightly shaded bars) 16, 1, and -6 percent for the RFG vans

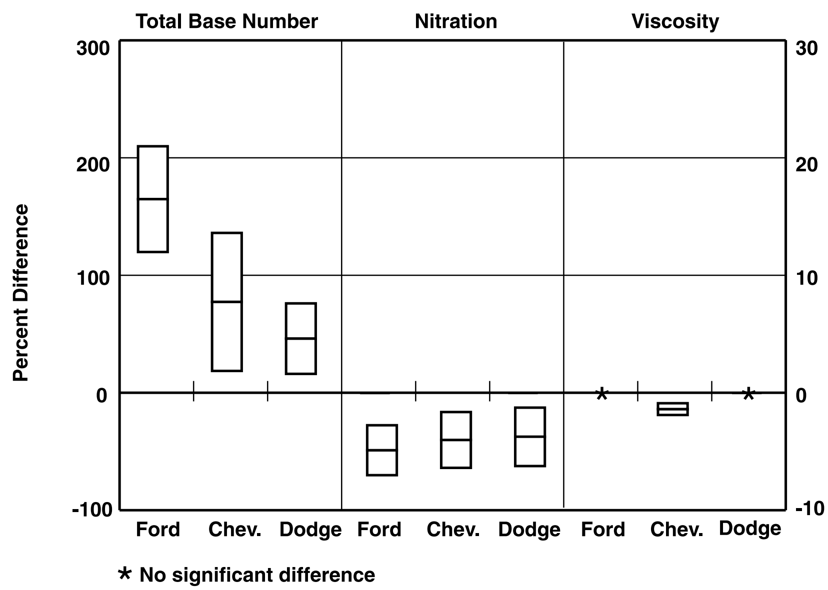


Figure 25. Relative differences in total base number, nitration, and viscosity of used motor oil after 3,000 miles were normalized for RFG and control vans.

Table 21. Average Percent Difference in Accumulation of Engine Metals in Motor Oil for the RFG and Control Vans at 10,000 and 20,000 Miles

Metal	Mileage (Thousands)	Ford	Chevrolet	Dodge
Iron	10 20	–[a] --	-46 --	-46 --
Chromium	10 20	-- --	-61 --	-- --
Nickel	10 20	-- --	-- --	-46 --
Aluminum	10 20	-41 --	-48 -32	-- --
Lead	10 20	-- --	-- --	-- --
Copper	10 20	--	--	--
Tin	10 20	-- --	-- --	-29 -37
Molybdenum	10 20	-- --	-62 -68	-- --
Antimony	10 20	-- --	-- --	-- --

[a] Indicates that the difference was not statistically significant at the 0.6 percent level. This is an overall error rate for all nine comparisons of five percent.

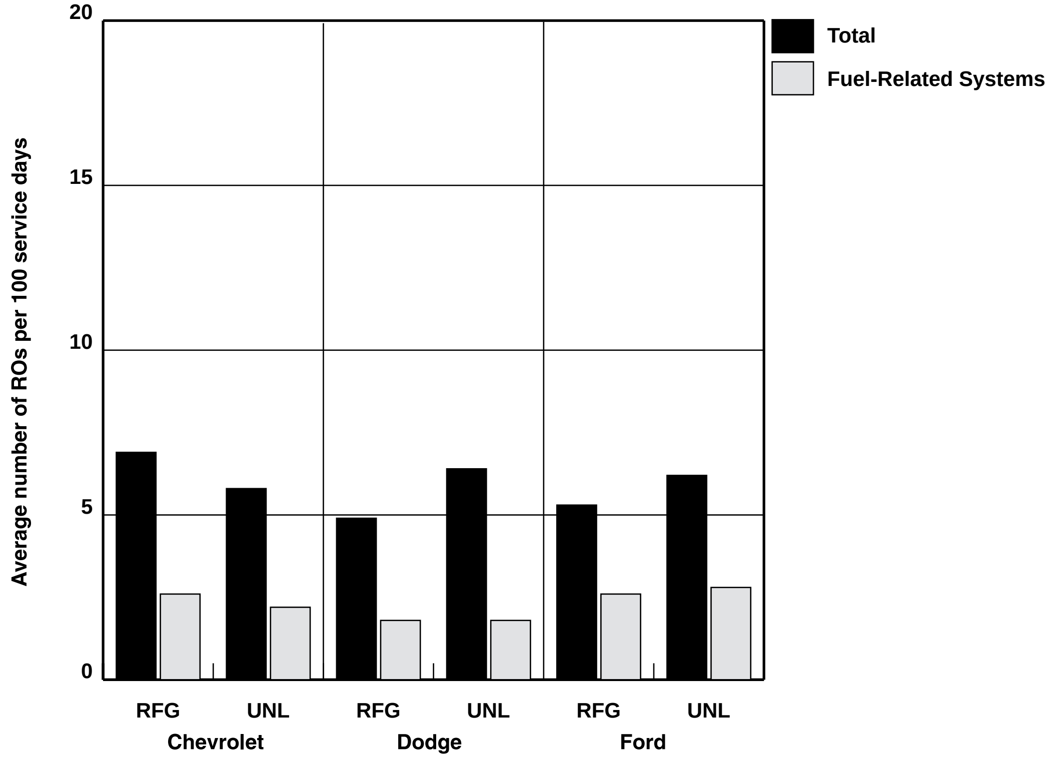


Figure 26. The number of repair orders per 100 days of service for the total van and fuel-related systems is compared for RFG and control vans.

for Chevrolet, Dodge, and Ford vans, respectively. In each case, these differences were not statistically significant with 95 percent confidence; maintenance requirements were about the same for the RFG and control vans.

The availability of the RFG and control vans is shown in Figure 27. Average availability of the Chevrolet, Dodge, and Ford fleets was each 98 percent. The corresponding availability of the control vans was 99, 99, and 98 percent. These values are essentially the same as the RFG values.

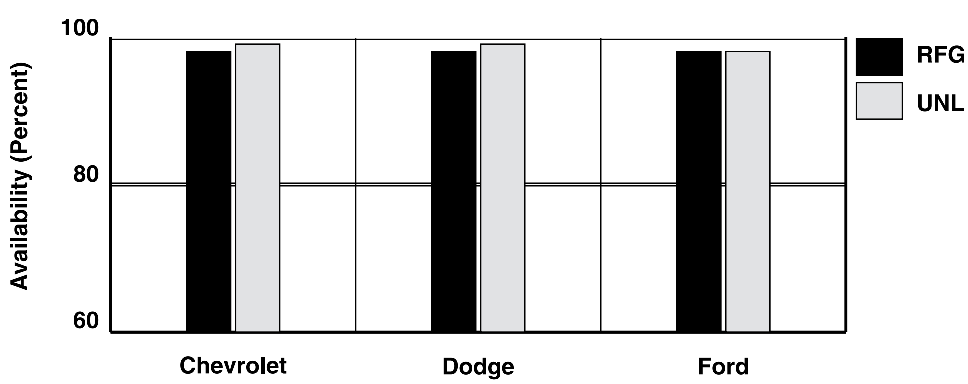


Figure 27. The availability of RFG and control vans is shown.

SUMMARY OF CLEANFLEET FINDINGS

Operations Experience

Safety. FedEx experience related to safety in RFG operations is summarized in two parts: (1) potential exposure of employees to RFG during fueling and (2) incidents such as fuel leaks and vehicle accidents.

Limited measurements were made of vapor concentrations in the breathing zone of employees during refueling with RFG and unleaded gasoline. Gasoline is a complex mixture of hydrocarbons, oxygenated organic compounds, and additives. To obtain an indication of the extent of exposure to gasoline vapors during refueling, octane was monitored as an indicator of the level of vapor concentrations. The oxygenate MTBE was also monitored. Measurements indicated that it is unlikely that the eight-hour threshold limit value (TLV) was exceeded for any of the paraffin hydrocarbon components for either the RFG or regular unleaded gasoline. Neither the ACGIH nor OSHA has established recommended limits for workplace exposure to MTBE. Concentrations of MTBE from RFG (oxygenated with 10.5 percent MTBE) were about an order of magnitude less than from the winter unleaded gasoline (oxygenated with 15 percent MTBE). A definitive explanation for this difference has not been found; vapor recovery equipment on the two pumps for the gasolines (which were about two meters apart) are believed to have been functioning properly.

FedEx operations were conducted in a safe manner. No safety incidents associated with RFG resulted in any personal or property damage.

Employee Attitudes. FedEx employees who participated in the demonstration of RFG-powered vehicles were positive about using a “clean-burning” fuel to reduce vehicle emissions and improve air quality. They were proud to be driving the RFG vans and reported positive response from FedEx customers who noticed the CleanFleet markings on the vans.

Attitudes about health problems were mixed for RFG. Thirty percent of the study group reported health-related problems and attributed them to vehicle exhaust; but, in the study group, as many people thought the exhaust from RFG vans was different from that of the control vans as did those who couldn’t remember any difference.

There were no safety concerns about using RFG. When queried about vehicle performance, 37 percent of the study population thought that the performance of the RFG vans was better than that of the control vans; 60 percent thought the performance was about the same.

When questioned about daily operations, the study group reported no effect of RFG on operations compared to using regular gasoline. The use of RFG was transparent.

Ten percent of the study population at the RFG site did not believe that FedEx should convert the entire fleet operation at the site to RFG, 30 percent had no opinion, and 50 percent believed that RFG should be used exclusively in place of regular gasoline.

Emissions

As the RFG vans were used in daily FedEx operations, the mass of pollutants emitted into the atmosphere was reduced. Results are shown in Figure 28. Although the mean mass of emissions from

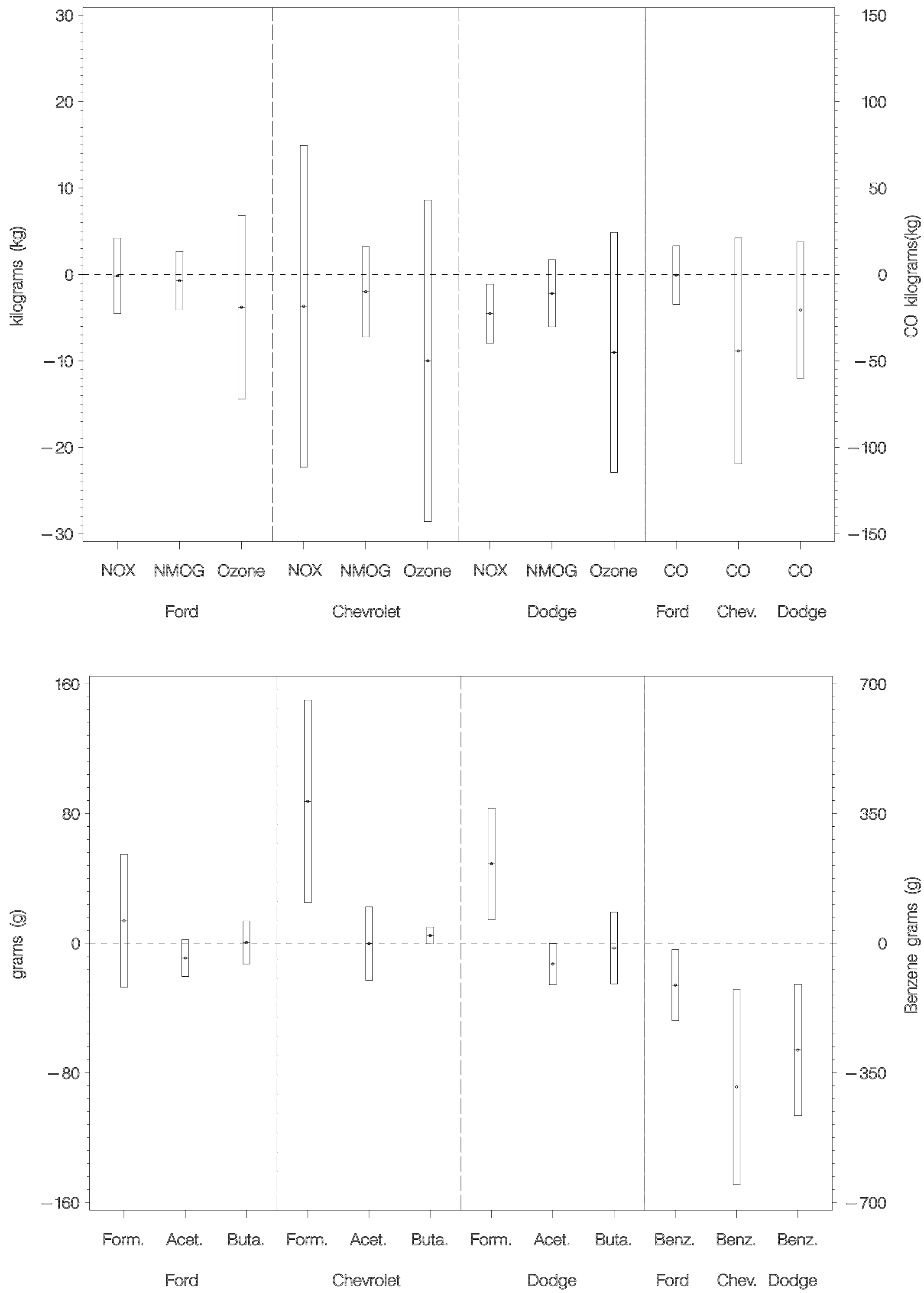


Figure 28. Estimated differences in selected emissions from RFG vehicles compared with control vehicles are shown over the range 5,000 to 25,000 miles.

RFG vans was less than from the control vans for all parameters shown except formaldehyde, many of these differences in emitted mass were not statistically significant (with 95 percent confidence).

For example, reductions in emission of CO from the Ford, Chevrolet, and Dodge fleets compared to their control fleets averaged 0.35, 44, and 21 kg per van. Estimates of the reduction in ozone formed in the atmosphere by emissions of NMOG and NO_x were 4, 10, and 9 kg. Estimated reductions in air toxics were 0.11, 0.30, and 0.26 kg. Reductions in CO_2 (not shown in Figure 27) averaged 260 kg for the Chevrolet vans. Increases averaged 68 and 310 kg per van for the Ford and Dodge vans. Methane emissions decreased by 0.1, 0.04, and 0.3 kg.

Fleet Economics

The estimated cost to a fleet operator to use RFG in 50 vans in the 1996 time frame is shown in Figure 29. Results are shown before corporate income tax and without tax and other incentives. Three cases are shown for the estimated price of RFG to a fleet in 1996 (f.o.b. California port). The estimated total annual cost for the three cases is 35.3, 35.7, and 36.1 cents per mile. It was assumed that the existing gasoline fuel storage tank at the site could be used for storing the RFG.

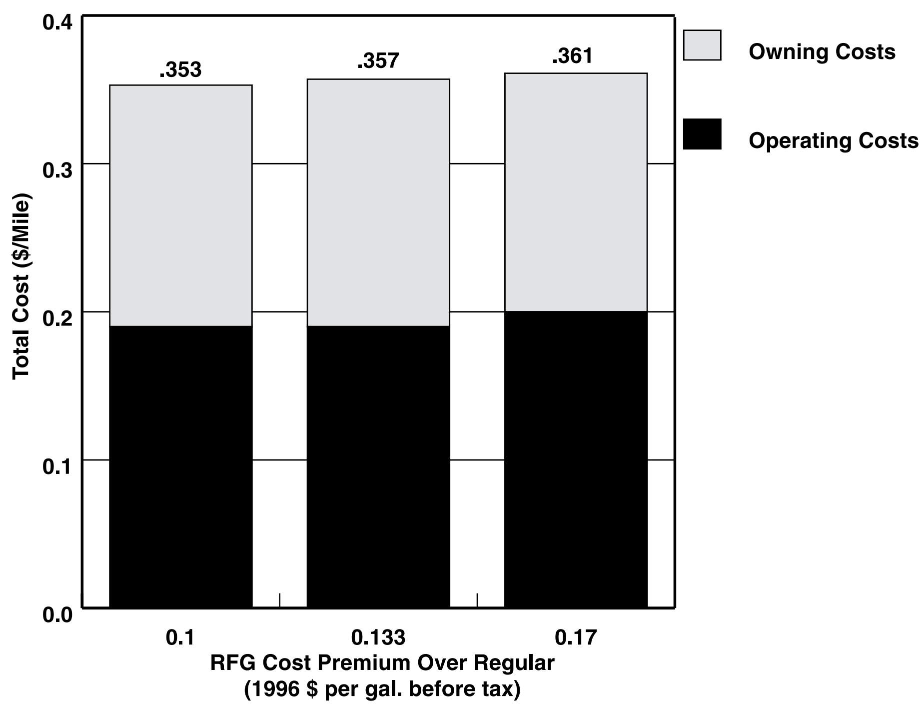


Figure 29. Costs were estimated for an RFG fleet in a 1996 economic case study.

Table 22 summarizes the results before and after income taxes, with the effect of incentives included in the after-tax estimates.

Table 22. Estimated Total Costs for an RFG Fleet Before and After Income Tax

RFG Cost Premium (cents/gallon)	Before Income Tax Without Incentives (cents/mi)	After Income Tax With Incentives (cents/mi)
10	35.3	21.8
13.3	35.7	22.0
17	36.1	22.3

M-85

Findings from the M-85 portion of the project are summarized in five parts. The basis for the demonstration and findings is summarized first. Then findings on operations are presented in two sections (data and experience). This is followed by a summary of findings on emissions and fleet economics.

Basis for Demonstration and Findings

The basis for the M-85 demonstration is summarized in five parts: vehicle technologies, fuel properties, fueling facility, building facility, and vehicle activity.

Vehicle Technologies. The 20 Ford M-85 flexible fuel vans were a portion of 200 such vans built by Ford for the California Energy Commission. They had 4.9-liter, in-line, six-cylinder engines (Table 23). As flexible fuel vehicles (FFVs), they could operate on a blend of methanol and gasoline ranging from 85 percent methanol by volume down to zero percent methanol, i.e., gasoline. For CleanFleet, they were operated on a steady supply of M-85 in which the gasoline component was the RFG used in this project.

These vans were built as gasoline vans, then modified in California to become FFVs. Changes to the vehicles included adding a sensor to monitor the alcohol content of the fuel, methanol-compatible materials in all portions of the vehicle exposed to fuel, larger fuel injectors, and a seventh “cold-start” fuel injector.

On average, the M-85 vans weighed about 36 pounds more than the Ford control vans. The catalysts on these vans were a standard model year 1992 catalyst for gasoline exhaust. A catalyst specifically designed to remove formaldehyde in exhaust during cold-start conditions was not used in these vans.

Fuel Properties. M-85 was produced by mixing appropriate quantities of methanol from the California Energy Reserve with RFG from the RFG demonstration site in a tank truck, which was driven to the M-85 site. Average parameters characterizing the M-85 over the course of the demonstration are shown in Table 24.

Fueling Facility. An above-ground, vaulted, 15,000-liter (4,000-gallon) fuel tank and dispenser were installed at the demonstration site (Figure 30). Significant permitting issues were faced to gain local approval to install the fuel tank. In addition to issues involving placement of the tank itself (e.g., appropriate setbacks), the local authorities required upgrading the property near the tank for aesthetic purposes. A concrete masonry wall and new sliding door for vehicle entry were required. This experience points out that, regardless of the fuel itself, necessary construction on a site may trigger a complete review of the property by local authorities.

Table 23. Characteristics of the M-85 and Control Vans

Vehicle Component	Ford	
	M-85	Control
Chassis Model	E250	E250
Engine		
Displacement (L)	4.9	4.9
Type	I6	I6
Compression Ratio	8.8	8.8
Fuel Delivery[a]	SMPI	MPI
Fuel Capacity (L)	132	132
Fuel Capacity (GEQ)[b]	20.1	34.9
Vehicle Weight (kg)	2,506	2,490
Engine Classification[c]	MD	MD
Catalyst[d]	G	G

[a] TB = Fuel provided through the throttle body, TBI = TB injection, MPI = Multiport electronic fuel injection, SMPI = Sequential MPI.
[b] GEQ = Gasoline equivalent gallons on an energy equivalent basis.
[c] MD = Vans in California medium-duty class. HD = Engines in heavy-duty class.
[d] Three-way catalyst optimized for exhaust from gasoline (G).

Table 24. Average Characteristics of M-85

Parameter	Units	Mean	Relative Standard Deviation (%)
Density	kg/L	0.787	0.27
Methanol	Vol %	85.4	1.27
Hydrogen[a]	wt %	12.7	0.40
Heating Value, net	MJ/kg	23.5	2.29
Reid Vapor Pressure	kPa	50.3	2.52
Particulate Loading	mg/L	0.373	NR

[a] Calculated from hydrogen content of pure methanol and the measured hydrogen content of RFG.

Figure 30. An above-ground tank was used to store M-85 at the demonstration site.

Building Site. No modifications were required for the building into which the vans were driven each day. The building was in compliance with requirements for gasoline-powered vans, which was adequate for M-85 vans.

Vehicle Activity. Over the course of the demonstration, the M-85 vans, on average, logged 25,000 miles compared to the control vans with 25,000 miles (see Table 25).

Table 25. Summary of Vehicle Activity for the M-85 Fleet

Type of Fuel	Average Number of Service Days	Average Total Miles Per Van	Average Miles Per Day
M-85	521	24,969	48
Control	595	25,221	42

Figure 31 demonstrates how the vehicle rotation plan achieved its goal of equalizing the distribution of duty cycles among fleets. Overall the distribution of average miles per day for the M-85 and control vans overlap.

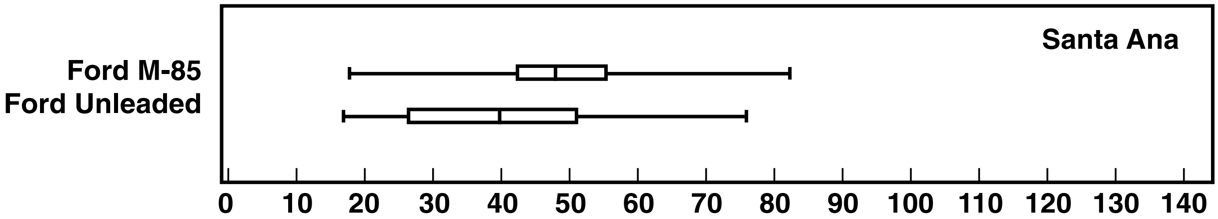


Figure 31. The distribution of the average miles that the M-85 and control vehicles traveled each day overlaps, providing comparable routes.

Operations Data

Operations data for the M-85 portion of the demonstration are summarized for vehicle fuel economy, motor oil, and vehicle maintenance.

Fuel Economy. The mean efficiencies of the M-85 vans (see Figure 32) compared to their controls were -1.1 and -1.7 percent from operational and chassis dynamometer data, respectively. These mean differences are not statistically significant (95 percent confidence); and, therefore, no difference in efficiency is attributed to the M-85 and control fleets.

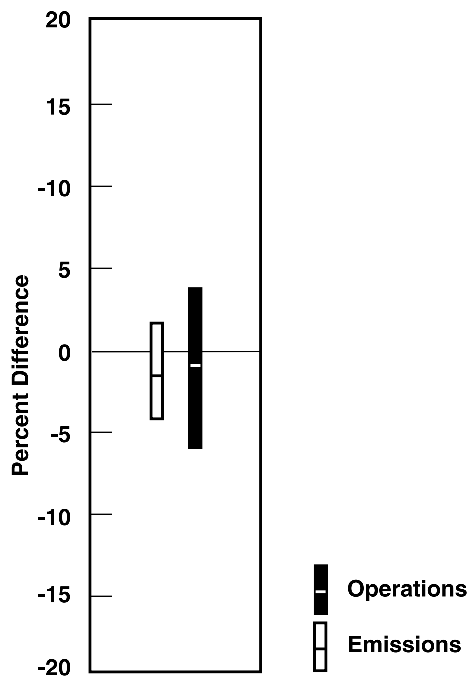


Figure 32. Relative fuel economy (efficiency) for M-85 vans was compared to the control vehicles.

The quantity of fuel stored on the vans, the energy content of the fuel, and the efficiency of the vehicle in using the fuel combine to yield an estimate of the driving range of the CleanFleet vans. Results are shown in Figure 33.

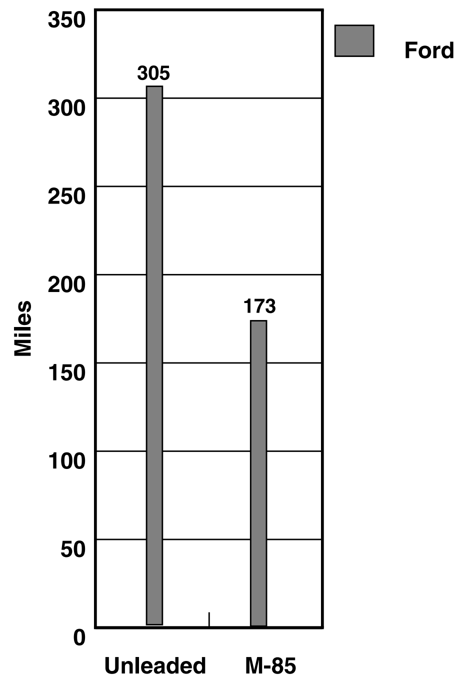


Figure 33. The driving range of M-85 and control vans (on a typical FedEx duty cycle at 40 miles per day) was estimated.

The specific driving range was computed as the ratio of driving range to either the volume of fuel storage capacity or the weight of the fuel system on the vehicles. Results are shown in Table 26.

Table 26. Specific Driving Range of M-85 and Control Vans

Miles Per Gallon Capacity		Miles Per Pound	
M-85	Control	M-85	Control
8.0	8.8	3.8	4.2

Motor Oil. Figure 34 provides information on the properties of used motor oil from the M-85 vans. Average TBN levels in the oil from the M-85 vans were more than twice the levels from the control vans; nitration levels were less. Viscosity was higher; however, the oil used in the M-85 vans was not the same as the oil used in the control vans. For example, it should be noted that the Lubrizol MFV 10W30 oil used in the M-85 vans had an initial TBN of 8.53, versus a value of 6.51 for the Chevron Delo 400 15W40 oil used in all other vans.

Table 27 contains information on the accumulation of metals in motor oil after 10,000 and 20,000 total miles. Metal removal rates for five of the nine elements were essentially the same for the M-85 and control engines. Iron and nickel rates were higher than the controls. A detailed analysis of engine wear, with before and after measurement of key parts, was beyond the scope of this project. A small sample of the various alternative fuel and control engines were, however, torn down for

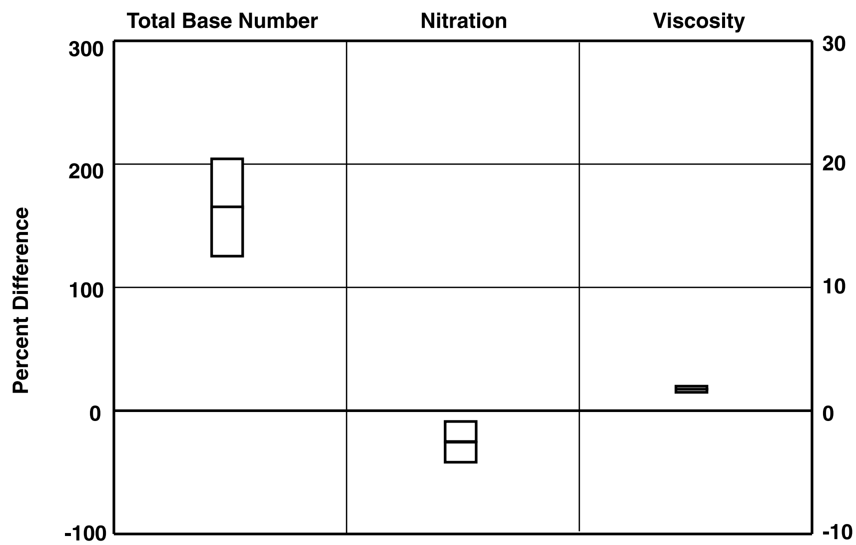


Figure 34. Relative differences in total base number, nitration, and viscosity of used motor oil after 3,000 miles were normalized for M-85 and control vans.

Table 27. Average Percent Difference in Accumulation of Engine Metals in Motor Oil for the M-85 and Control Vans at 10,000 and 20,000 Miles

Metal	Mileage (Thousands)	Average Percent Difference
Iron	10 20	+390 +530
Chromium	10 20	–[a] --
Nickel	10 20	+100 +240
Aluminum	10 20	-40 +51
Lead	10 20	-- --
Copper	10 20	-- --
Tin	10 20	-- +53
Molybdenum	10 20	-- --
Antimony	10 20	-- --

[a] Indicates that the difference was not statistically significant at the 0.6 percent level. This is an overall error rate for all nine comparisons of five percent.

inspection at the end of the demonstration to determine if there were any significant differences in wear or other degradation patterns that might have implications for long-term durability. In the case of the M-85 engines, candidate source(s) were sought for the high level of iron in the oil samples. The only iron/steel parts showing any significant distress that might account for the level of iron/steel found in the oil were the valve train rocker arms and rocker arm pivots. Cursory measurements of weight loss by these parts (12 each per engine) indicate that they might well account for the increase in the cumulative amount of 7.6 grams of iron found in the oil of the M-85 engines over that of the control engines. It is important to remember that the M-85 engines were not full production engines for methanol vans; they were demonstration vans. It could be expected that Ford (or another OEM with its demonstration vehicles) would uncover an issue with metal removal and correct it before mass production took place. In any event, during the demonstration, the engines operated satisfactorily and met FedEx's fleet needs.

Vehicle Maintenance. The M-85 vans experienced a few hardware problems characteristic of nonproduction vehicles. Fuel control modules, the cold start injectors, and some fuel pumps were replaced in the vans. The number of ROs per 100 service days are plotted in Figure 35 for the whole vehicle (dark shading) and fuel-related systems (light shading). The percent difference in ROs per 100 days for the fuel-related systems on the M-85 vans compared to their controls was 46 percent, which is statistically significant.

Availability of the M-85 vans averaged 97 percent (Figure 36). Availability of the control vans averaged 99 percent.

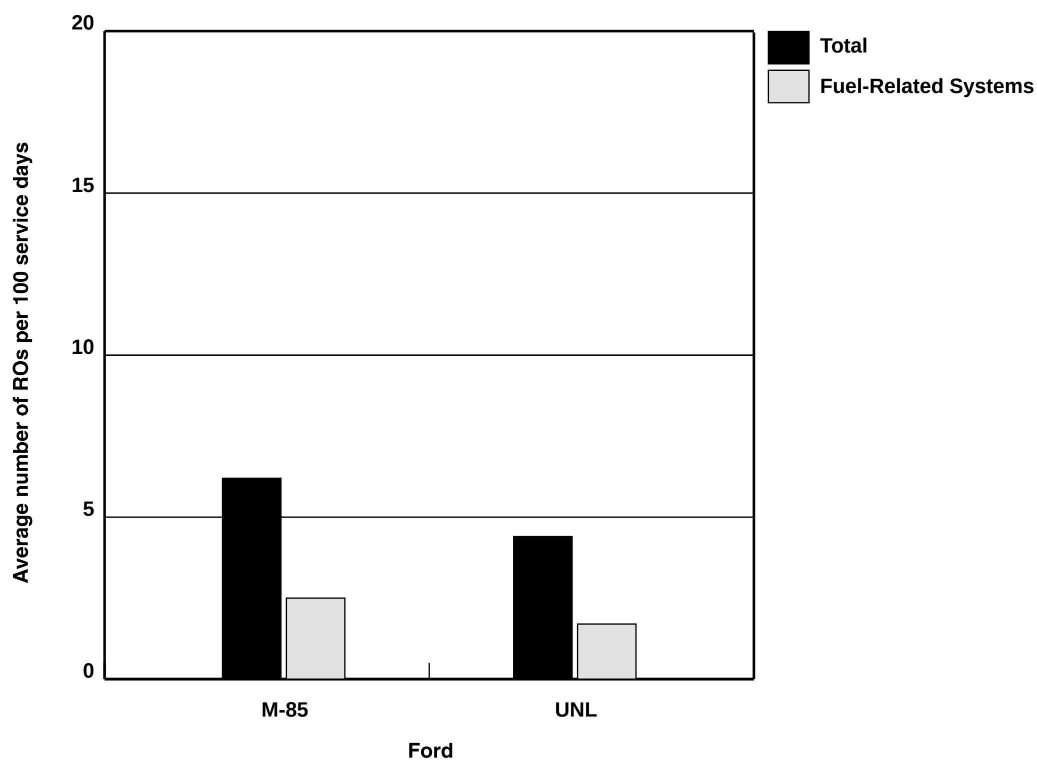


Figure 35. The number of repair orders per 100 days of service for the total van and fuel-related systems is compared for M-85 and control vans.

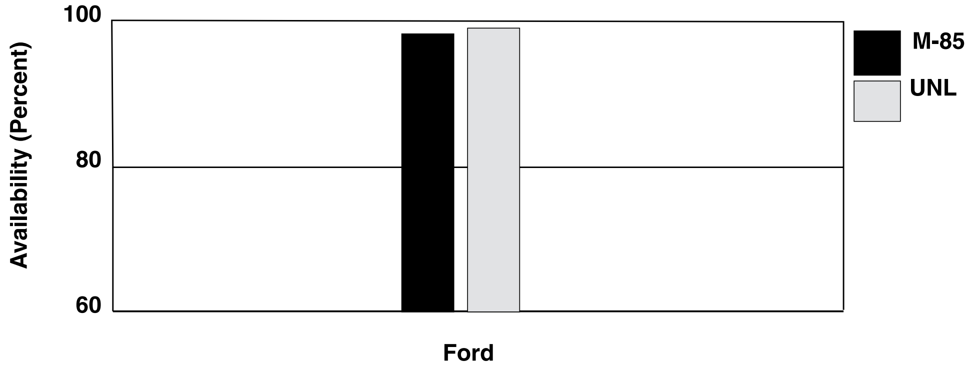


Figure 36. The availability of M-85 and control vans is shown.

Operations Experience

Safety. FedEx experience related to safety in M-85 operations is summarized in two parts: (1) potential exposure of employees to M-85 vapor during fueling and to formaldehyde from vehicle exhaust and (2) incidents such as fuel leaks and vehicle accidents.

Limited measurements were made of methanol vapor concentrations during refueling and near the tailpipes of M-85 vans indoors. Methanol concentrations, when averaged over either the 15-minute or the 8-hour time periods for the limits of the ACGIH and OSHA, were well below the applicable limits.

Formaldehyde is formed in M-85 exhaust, and exposure limits have been established by the ACGIH and OSHA. The CleanFleet M-85 vans were not equipped with catalysts designed to remove formaldehyde during cold start. Concentrations of formaldehyde in excess of the ACGIH guideline were found during morning startup.

During the course of the demonstration, fires occurred in the engine compartments of two M-85 vans. The fires started near the cold-start injector. The cold-start injectors, which were not needed in California, were removed from the vans, and no further problems occurred.

Employee Attitudes. FedEx employees who participated in the demonstration of M-85 vehicles had a positive attitude about using a “clean-burning” fuel to reduce vehicle emissions and improve air quality. They were proud to be driving M-85 vans and reported positive response from FedEx customers who noticed the CleanFleet markings on the vans.

Some 31 percent of the study group reported experiencing health-related problems, citing exposure to fuel vapors and vehicle exhaust resulting in headaches and eye irritation (formaldehyde, a product of combustion, is an eye irritant).

Seventy-five percent of the study group reported no safety-related problems during the demonstration. In spite of two fires in the engine compartments of the M-85 vans, the drivers understood that the problem was solved. The 25 percent who believed they had experienced a safety problem included 19 percent who related to the fires and 6 percent who were concerned about fueling. As the people reflected upon their concerns at the beginning of the demonstration, 44 percent reported a positive change in their attitude about safety and 38 percent reported no change in their attitude.

Concerning vehicle performance, 76 percent of the study group believed that the M-85 vans were about the same as the control vans, and 20 percent believed that the M-85 vans were better than the controls overall.

When questioned about daily operations, some employees noted that the final fuel filter on the M-85 dispenser had to replaced several times during the 24 months as the filters became plugged. Nevertheless, 94 percent of the study group reported that they were able to maintain their regular schedule without interruption.

Nineteen percent of the study group at the M-85 site did not believe that FedEx should convert the entire fleet operation at the site to M-85. Thirty-eight percent favored conversion to M-85; the same percentage had no opinion.

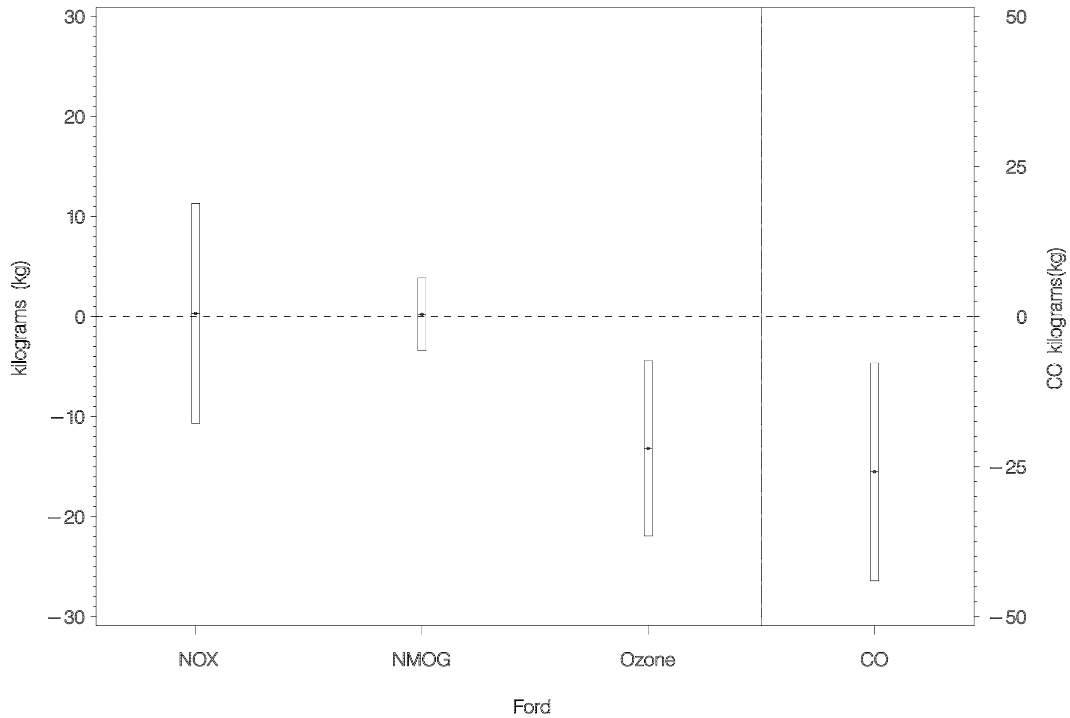
Emissions

As the M-85 vans were used in daily FedEx operations, significant reductions were achieved in the mass of pollutants emitted into the atmosphere for selected compounds. Results are shown in Figure 37 for selected pollutants over the odometer range 5,000 to 25,000 miles. For example, a reduction in emission of CO from the M-85 vans compared to the control vans averaged 26 kg per van. As seen by the confidence interval about the CO mean (the entire interval is below the zero line), there is 95 percent confidence that the mean emission of CO from the M-85 vans was less than from the control vans. The estimate of the reduction in ozone formed in the atmosphere by emissions of NMOG and NO_x is 13 kg. An increase in emission of the four air toxics averaged 0.10 kg (due to the increase in formaldehyde). Carbon dioxide was reduced by 760 kg, while methane emissions fell by 1.3 kg.

Fleet Economics

The estimated cost to a fleet operator to use M-85 in 50 vans in the 1996 time frame is shown in Figure 38. Results are shown before corporate income tax and without tax and other incentives. Three cases are shown for the estimated price of methanol to a fleet in 1996 (f.o.b. California port). During 1994, the price of methanol rose dramatically from historic levels, while in 1995 it began to fall. The price range of 40 to 80 cents per gallon is expected to bracket the price to a fleet in 1996. The total annual cost for the three cases is estimated to be 38.3, 41.5, and 44.7 cents per mile. It was assumed that a fuel storage tank for M-85 would be installed at the site below ground.

Table 28 summarizes the results before and after income taxes, with the effect of incentives included in the after-tax estimates.



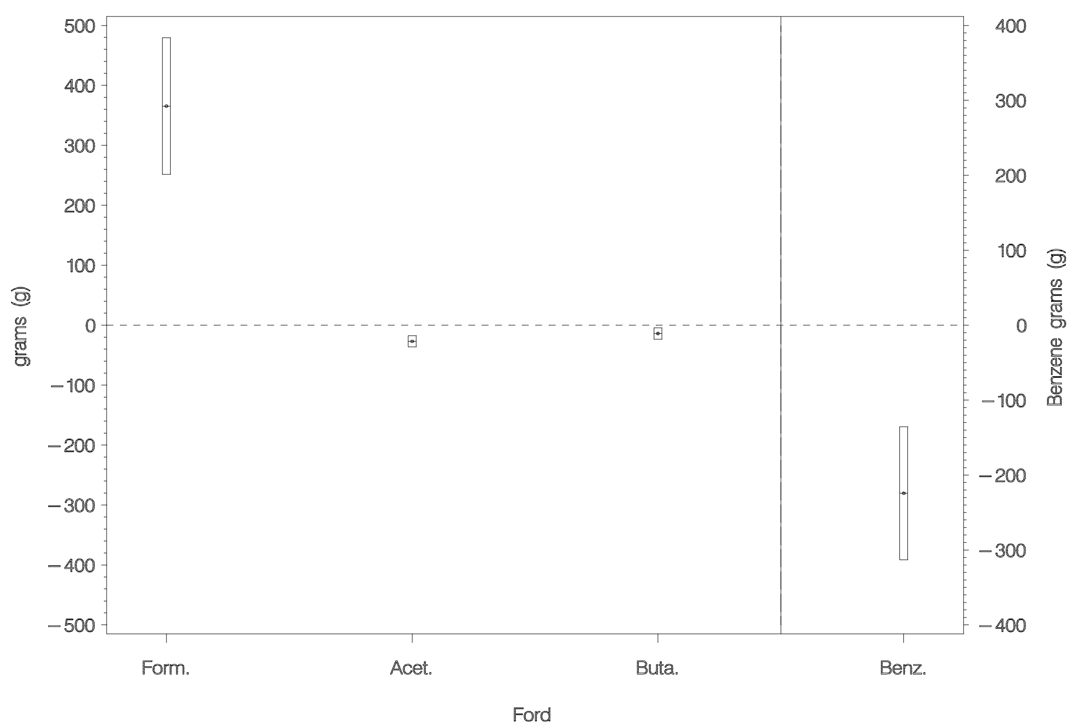


Figure 37. Estimated differences in selected emissions from M-85 vehicles compared with control vehicles are shown over the range 5,000 to 25,000 miles.

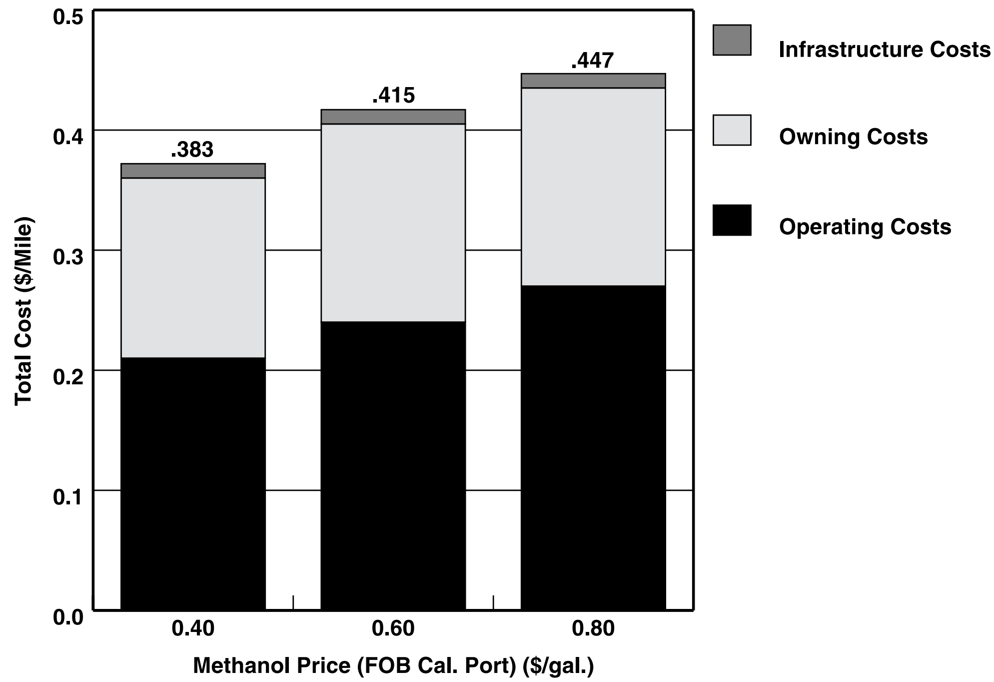


Figure 38. Costs were estimated for an M-85 fleet in a 1996 economic case study.

Table 28. Estimated Total Costs for an M-85 Fleet Before and After Income Tax

Methanol Cost (cents/gallon)	Before Income Tax Without Incentives (cents/mi)	After Income Tax With Incentives (cents/mi)
40	38.3	23.6
60	41.5	25.5
80	44.7	27.3

Electric

Findings from the EV portion of the project are summarized in five parts. The basis for the demonstration and findings is summarized first. Then findings on operations are presented in two sections (data and experience). This is followed by a summary of findings on emissions and fleet economics.

Basis for Demonstration and Findings

The basis for the EV demonstration is summarized in three parts: vehicle technologies, building facility, and vehicle activity.

Vehicle Technologies. The EVs were full-size vans with a General Motors body style (one-ton Vandura) that had been modified for electric propulsion by Conceptor Corporation, a subsidiary of Vehma International, Inc. They had a gross vehicle weight rating (GVWR) of 8,600 pounds. These vans were prototype EVs owned by Southern California Edison and leased to FedEx for the project. Prior to introduction into service at FedEx, they were outfitted with current technology as of 1991.

The two EVs began the demonstration equipped with lead-acid batteries from Chloride. The battery pack contained 36 six-volt, lead-acid monoblocks with a nominal capacity of 205 Ampere-hours (Ah) at a five-hour rate of discharge. The battery pack weighed about 1,140 kg (2,500 pounds), and it had a volume of 14.7 liters. The lead-acid EVs averaged 3,518 kg (7,756 pounds).

A critical component of the EVs was the battery charger. Chargers and batteries are often considered separately; however, for optimum performance these need to be designed and used as a system. Each lead-acid EV was charged using a Chloride charger that provided 35 A of direct current from an input electric service of 200 to 250 volts alternating current (AC) at 50 A nominal. These chargers provided a refreshening current for 10 minutes every four hours. The chargers were hung from the ceiling of the FedEx facility just over the front end of the EVs (see Figure 39).

In January 1993, one lead-acid EV was removed from FedEx service and outfitted with nickel-cadmium (Ni-Cd) batteries. This EV returned to service in November 1993. The Ni-Cd battery pack was composed of 34 SAFT monoblocks. Each monoblock weighed 25 kg (55 pounds) and was rated at a nominal voltage of six volts. The battery pack had a 200 Ah capacity at the C/5 rate (1.2 kWh). The monoblocks were installed in a stainless steel tray. The weight of the batteries themselves was 850 kg (1,870 pounds).

The Ni-Cd battery pack required a charging profile that differed from the lead-acid batteries: an overcharge of 120 to 125 percent. A LaMarche charger with a DC output of 46 A was used. This charger uses single-phase AC power at 208 volts at 155 A.

Building Facility. No special permitting was required for using EVs. An eyewash station was installed close to the battery chargers.

Figure 39. Lead-acid batteries were recharged from ceiling-mounted chargers.

Vehicle Activity. Over the course of the demonstration, the EVs powered by lead-acid batteries, on average, logged 2,606 miles. The EV powered by nickel-cadmium batteries logged 1,406 miles (see Table 29). The delivery and pickup routes consisted of travel from the FedEx facility to high-rise business office buildings nearby.

Table 29. Summary of Vehicle Activity for the EV Fleet

Type of Battery	Average Number of Service Days	Average Total Miles Per Van	Average Miles Per Day
Lead Acid	179	2,606	15
Nickel Cadmium	76	1,406	18

Operations Data

Operations data for the EV portion of the demonstration are summarized for vehicle fuel (energy) economy and vehicle maintenance.

Energy Consumption. The mean energy consumption of the lead-acid EVs was 2.3 kWh/mi. The nickel-cadmium EV averaged 1.9 kWh/mi on daily routes of 10 to 30 miles per day. Using a separate direct current meter mounted on the van, the average energy consumption with the nickel-cadmium batteries was 1.5 kWh/mi. This latter figure does not include the energy consumed by the charging unit. The average driving range of the lead-acid EVs in FedEx operations was about 25 miles. The average driving range for the nickel-cadmium EV was about 50 miles.

The charger hardware and FedEx driving cycle had a dramatic effect on energy consumption and driving range compared to Southern California Edison's experience with other G-Van fleets. Using a charger that did not continue to charge once the lead-acid battery pack was fully charged, and using a more moderate style of driving, Southern California Edison achieved an energy consumption of 1 kWh/mile (alternating current into the charger) and a driving range of 60 miles. This comparison is provided to illustrate that the developmental status of EV charging and EV performance can have a significant impact on an EV fleet.

Vehicle Maintenance. The two EVs in the demonstration were originally equipped with lead-acid batteries. Battery packs or battery monoblocks and watering blocks were replaced several times on these vans. New traction motors also were replaced in both vans because of problems with armatures. As planned, one van was converted to an advanced battery type (i.e., nickel-cadmium) about midway through the demonstration. The nickel-cadmium van required no maintenance from the time it was introduced into the demonstration in November 1993, except for replacing a fuse in the controller.

SUMMARY OF CLEANFLEET FINDINGS

Operations Experience

Safety. FedEx experienced no significant safety problems in using the EVs. Minor issues arose, and they were dealt with. For example, electrolyte from the lead-acid batteries occasionally dripped from the EV while it was being charged. The first occurrences of this etched the concrete floor at FedEx, and an acid-resistant coating was applied to the floor. Subsequently a tray containing an absorbent material was placed beneath the vans to collect the electrolyte. Altering the timing of watering and charging the batteries helped minimize the quantity of electrolyte that overflowed. New technologies such as valve-regulated, sealed, lead-acid batteries have eliminated the requirement for watering batteries, and the use of various pastes has resulted in no acid spills. Other minor issues in dealing with the lead-acid technology were addressed as well.

Employee Attitudes. FedEx employees who participated in the demonstration of EVs had positive attitudes about driving "zero-emission vehicles" or ZEVs. FedEx customers also expressed positive sentiments about the EVs.

Early in the demonstration, concern was raised by FedEx employees about the EVs losing performance and stopping when the energy in the batteries was depleted. Although the lead-acid EVs did run out of energy on a few occasions, the drivers found that this did not constitute a safety issue, and soon they were not concerned about safety when driving the EVs. Also, initial concern about the acidic nature of the electrolyte in the lead-acid batteries was ameliorated when the trays were placed under the vans and people were informed about safe handling procedures.

Limited driving range was the dominant concern expressed by the operations managers at the EV site. These people also perceived that the EVs were somewhat limited because of difficulty in climbing steep ramps or hills.

Emissions

EVs are defined by the ARB as having no vehicle tailpipe and evaporative emissions; thus, they are called "zero-emission vehicles." There are emissions in earlier stages of the fuel cycle (e.g,. electric power plants), but the ARB does not have jurisdiction over these emissions. Consequently, the EVs were not tested for exhaust or evaporative emissions. The small combustion heater aboard the vans was not used during the demonstration.

Fleet Economics

The estimated cost to a fleet operator to use 50 full-size electric vans was estimated for the 1996 and 1998 time frames. It is very difficult to forecast the cost of operating a fleet of EVs because of the current state of technology development and lack of OEM-produced electric vans. The two electric cargo vans used in CleanFleet are not considered representative of EV technology in the 1996 or later time frame. The only EVs expected to be available in 1996 will be conversions of gasoline vehicles or limited production prototypes from OEMs. It is not even clear that electric cargo vans will be available as conversions in 1996. In 1998, when the California ZEV mandate is scheduled to take effect, OEM-produced EVs should be available; but electric versions of full-size cargo vans are not expected to be available at that time.

Despite these limitations, an economic assessment for a fleet of electric cargo vans was developed. The objective was to provide some insight into the key economic issues involved in operating an electric fleet. For the 1998 case, both a low and a high cost estimate were made to bracket the uncertainty. Results are shown in Figure 40 and Table 30. The key cost factors are vehicle price, price of electrical energy consumption, battery life and replacement cost, and vehicle maintenance costs. These issues are described in more detail in Volume 8, Fleet Economics.

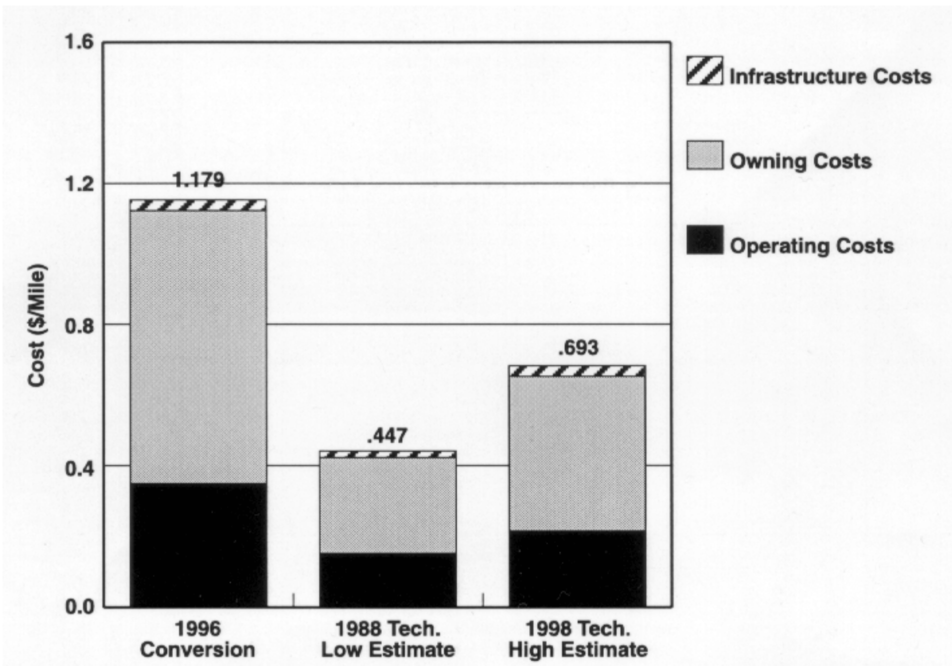


Figure 40. Costs were estimated for an electric van fleet in 1996 and 1998.

Table 30. Estimated Total Costs for an EV Fleet Before and After Income Tax

Case	Before Income Tax Without Incentives	After Income Tax Without Incentives	After Income Tax Incentives Included
1996 Electric Conversion (cents/mi)	118	74.2	69.2
1998 Technology Low Estimate (cents/mi)	44.7	28.1	26.0
1998 Technology High Estimate (cents/mi)	69.3	43.4	40.4

APPENDIX A

List of Publications

APPENDIX A

List of Publications

1. Sverdrup, G. M., King, R. D., Murphy, M., Herridge, J. T., Orban, J. E., and Krenelka, T. C., “Conceptual Design of the South Coast Alternative Fuels Demonstration Project,” 912665, SAE International, Warrendale, PA, 1991.

2. Sverdrup, G. M., Orban, J. E., Murphy, M. J., Herridge, J. T., Latham, H. C., Lloyd, A. C., Leonard, J. H., Sullivan, C., Idell, J. H., and Tweddle, A. S., “The CleanFleet Alternative Fuels Demonstration Project,” 950393, SAE International, Warrendale, PA, 1995.

3. Sverdrup, G. M., Kinateder, J. C., Holdren, M. W., Niemuth, N. A., Kenny, R. J., Mano, H., Howell, W. M., and Maddox, C., Vehicle Emissions Results—CleanFleet Alternative Fuels Project,” 950394, SAE International, Warrendale, PA, 1995.

4. Herridge, J. T., and Lambert, J. E., “Fleet Economics Analysis—CleanFleet Alternative Fuels Project,” 950395, SAE International, Warrendale, PA, 1995.

5. Orban, J. E., Murphy, M. J., and Matthews M. C., “Vehicle Fuel Economy—The CleanFleet Alternative Fuels Project,” 950396, SAE International, Warrendale, PA, 1995.

6. Murphy, M. J., “Safety and Occupational Hygiene Results—CleanFleet Alternative Fuels Project,” 950397, SAE International, Warrendale, PA, 1995.

7. Alexander, G. H., Nelson, S. R., Gaydos, P. A., and Herridge, J. T., “Vehicle Reliability and Maintenance—CleanFleet Alternative Fuels Project,” 950398, SAE International, Warrendale, PA, 1995.