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

Vehicle Component	Ford		Chevrolet		Dodge	
	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

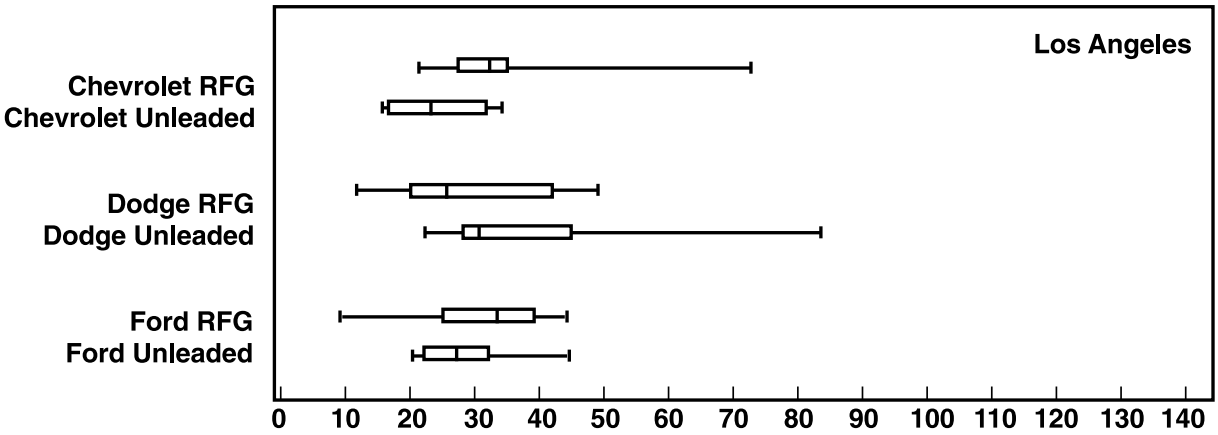

Figure 22. The distribution of the average miles that the RFG and control vehicles traveled each day overlaps, providing comparable routes.

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.

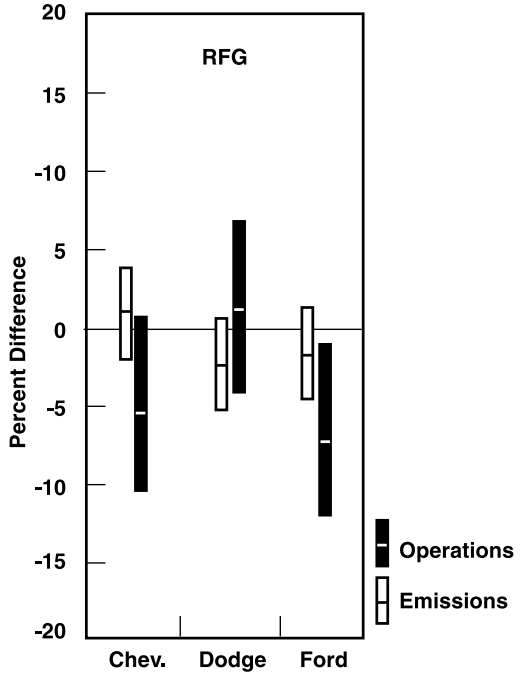

Figure 23. Relative fuel economy (efficiency) for RFG vans was compared to the control vehicles.

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.

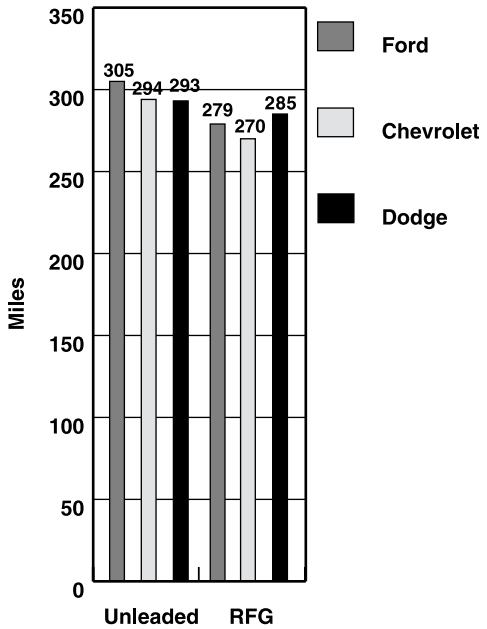

Figure 24. The driving range of RFG and control vans (on a typical FedEx duty cycle at 40 miles per day) was estimated.

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

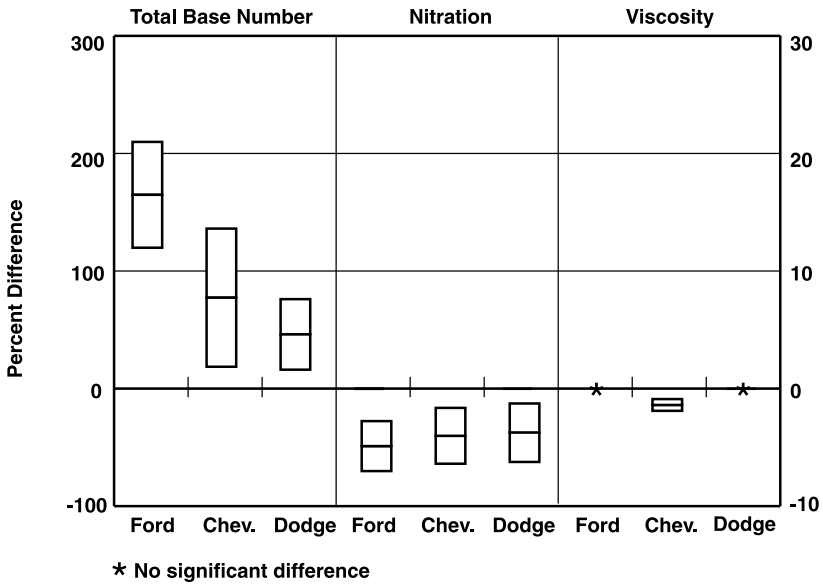

Figure 25. Relative differences in total base number, nitration, and viscosity of used motor oil after 3,000 miles were normalized for RFG and control vans.

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.

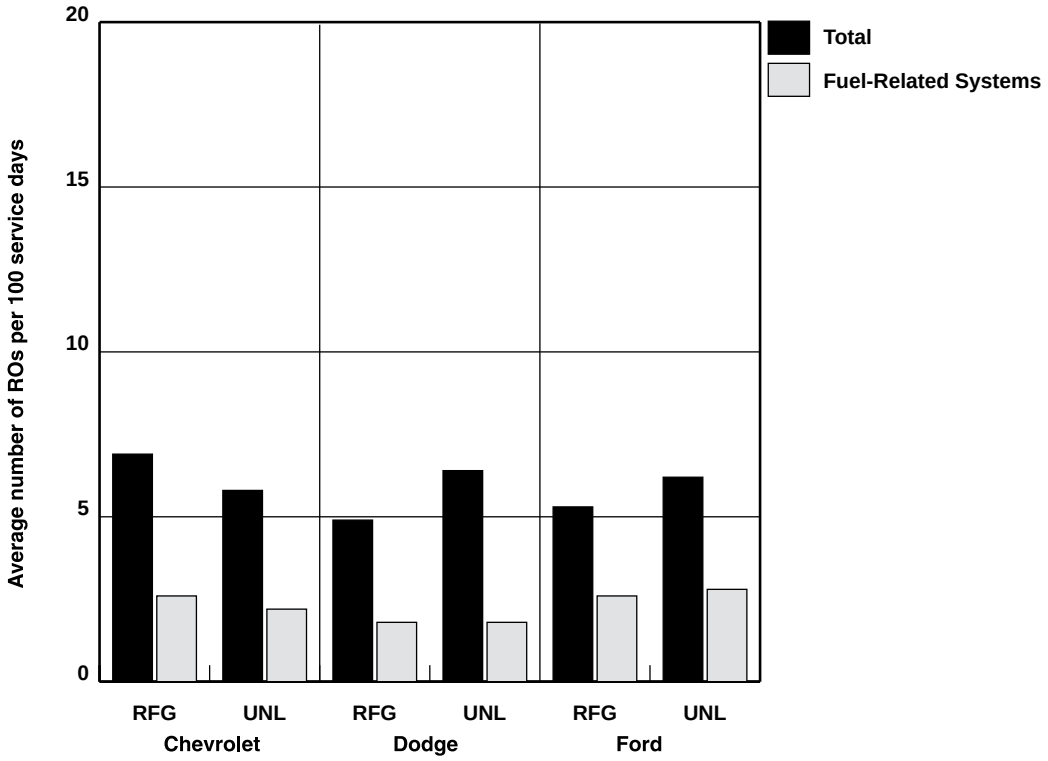

Figure 26. The number of repair orders per 100 days of service for the total van and fuel-related systems is compared for RFG and control vans.

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.

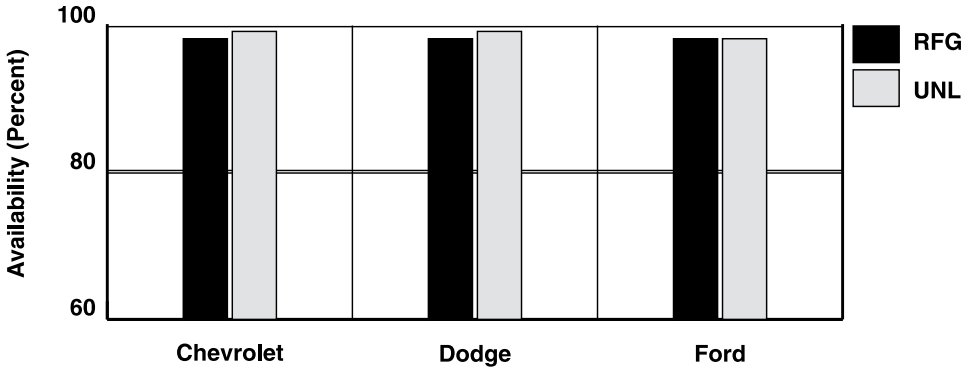

Figure 27. The availability of RFG and control vans is shown.

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

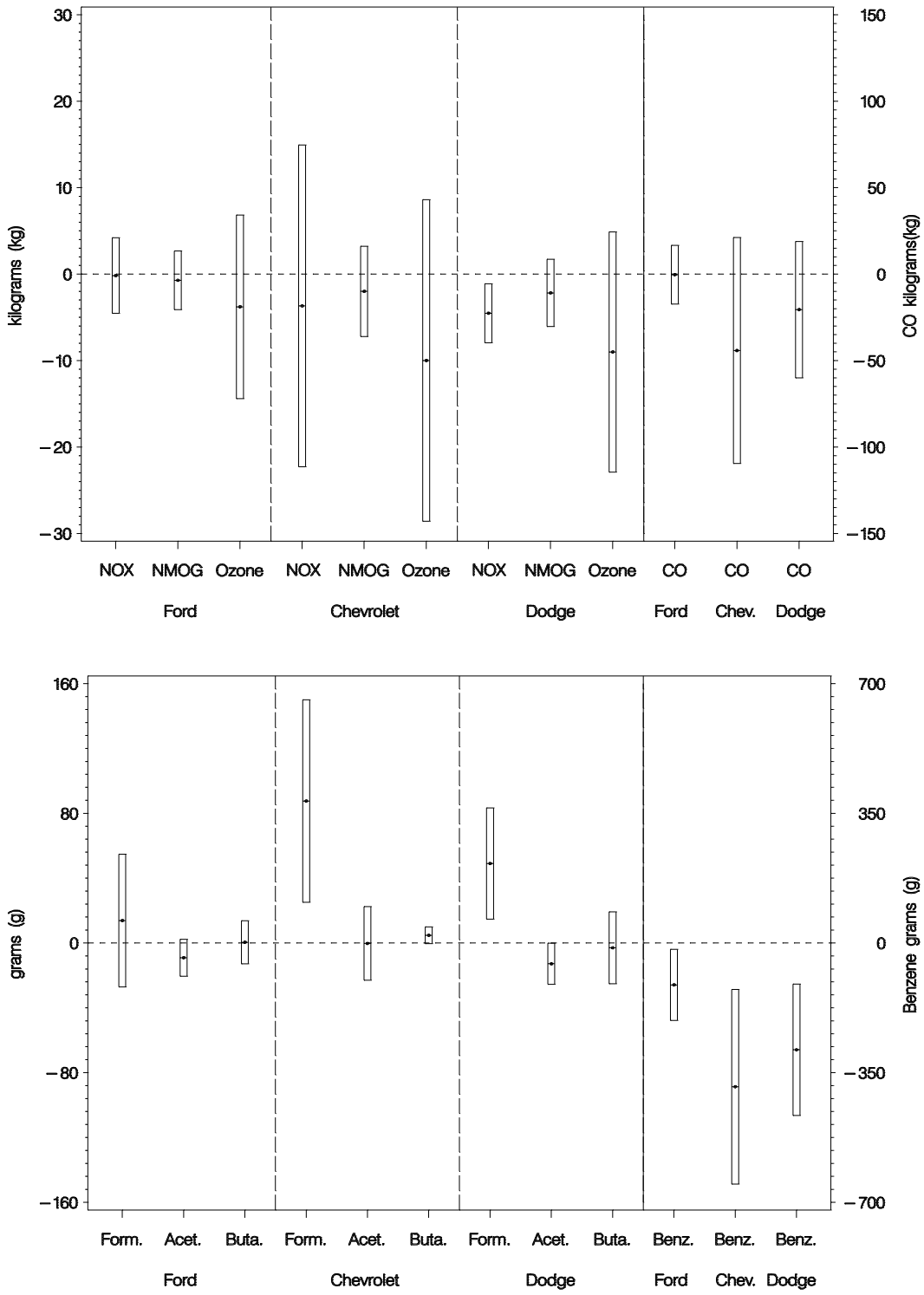

Figure 28. Estimated differences in selected emissions from RFG vehicles compared with control vehicles are shown over the range 5,000 to 25,000 miles.

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.

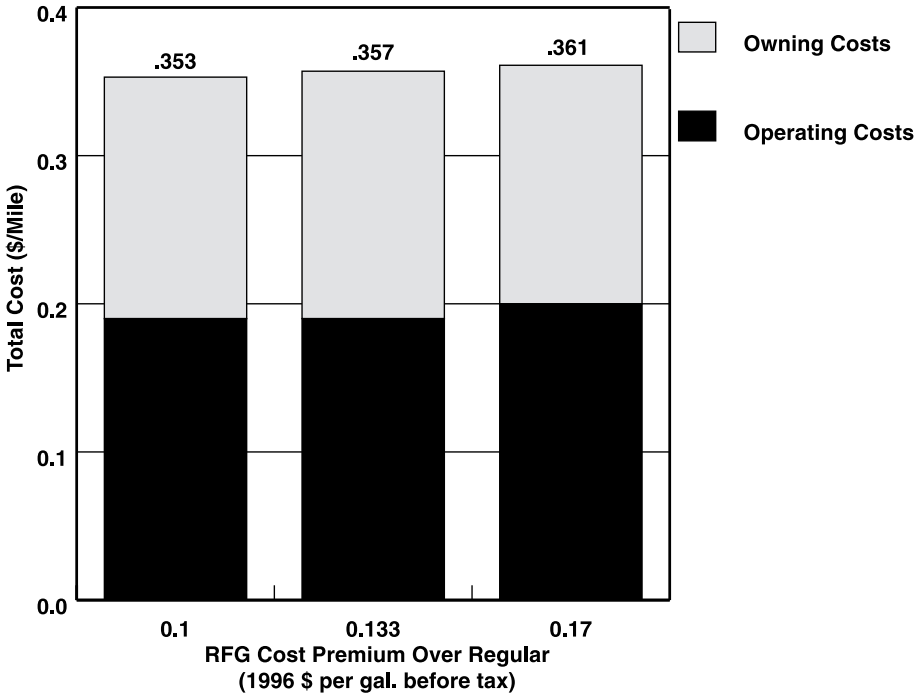

Figure 29. Costs were estimated for an RFG fleet in a 1996 economic case study.

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