CleanFleet

FINAL REPORT

December 1995

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Glossary

ARB	=	California Air Resources Board
CFR	=	Code of Federal Regulations
CNG	=	Compressed natural gas
CO	=	Carbon monoxide
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
EPA	=	U.S. Environmental Protection Agency
FID	=	Flame ionization detector
Fleet	=	A unique combination of vehicle manufacturer and fuel in the CleanFleet project
FTP	=	Federal test procedure
G	=	Grams
GC	=	Gas chromatograph
GVWR	=	Gross vehicle weight rating
HC	=	Hydrocarbons
L	=	Liter
LEV	=	Low emission vehicle (LEV emission standard)
M-85	=	Fuel consisting of 85 percent methanol and 15 percent RFG by volume
Mi	=	Mile
NMHC	=	Nonmethane hydrocarbons
NMOG	=	Nonmethane organic gases
NO_x	=	Nitrogen oxides (sum of nitric oxide and nitrogen dioxide)
OEM	=	Original equipment manufacturer
OMHCE	=	Organic material hydrocarbon equivalent

Glossary
(Continued)

Ozone reactivity	=	Estimate of grams of ozone generated in the atmosphere per mile of vehicle travel in units of g O_3/mi
PRO	=	Propane gas or liquefied petroleum gas
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
RSOR	=	Relative specific ozone reactivity. Specific ozone reactivity for a fleet on an alternative fuel divided by the specific ozone reactivity for the corresponding control fleet on RF-A gasoline reactivity
SHED	=	Sealed housing for evaporative determination
SOR	=	Specific ozone reactivity. Estimate of grams of ozone generated in the atmosphere per gram of NMOG exhaust emissions. Calculated by dividing ozone reactivity (g O_3/mi) by NMOG emissions (g NMOG/mi) to yield g O_3/g NMOG
THC	=	Total hydrocarbons
TLEV	=	Transitional low emission vehicle
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

VEHICLE EMISSIONS

Measurements of exhaust and evaporative emissions from CleanFleet vans running on M-85, compressed natural gas (CNG), California Phase 2 reformulated gasoline (RFG), propane gas, and a control gasoline (RF-A) are presented. Three vans from each combination of vehicle manufacturer and fuel were tested at the California Air Resources Board (ARB) as they accumulated mileage in the demonstration. Data are presented on regulated emissions, ozone precursors, air toxics, and green-house gases. The emissions tests provide information on in-use emissions. That is, the vans were taken directly from daily commercial service and tested at the ARB. The differences in vehicle technology among the three vehicle manufacturers (Ford, Dodge, Chevrolet) and differences in alternative fuel technology provide the basis for a range of technology options. The emissions data reflect these differences, with classes of vehicles/fuels producing either more or less emissions for various compounds relative to the control gasoline.

Introduction

The three principal components of the CleanFleet project were fleet operations, vehicle emissions, and fleet economics. As the demonstration began, knowledge of the emissions from alternative fuel vehicles that were being used daily in commercial fleet operations was sparse and generally not comparable across fuels. Also, comprehensive data sets on regulated emissions, ozone precursors, air toxics, and greenhouse gases were lacking. Consequently, documenting the level of emissions from the CleanFleet vans as they accumulated mileage was a major component of the project.

This volume of the CleanFleet Findings summarizes exhaust and evaporative emissions from vans operating on alternative fuels and a control gasoline. During the 24-month demonstration three vans from each combination of vehicle manufacturer and fuel (termed a fleet) were tested periodically by the California Air Resources Board (ARB) for exhaust emissions. Evaporative emissions were measured once during the demonstration. Emission tests were performed on nine vans operating on compressed natural gas (CNG), six vans operating on propane gas, nine vans operating of California Phase 2 reformulated gasoline (RFG), three vans operating on M-85, and nine vans operating on a baseline gasoline. The electric vans were not tested at the ARB because they are classified as zero emission vehicles.

Vans were brought directly from FedEx operations at the sites shown in Figure 1 to the ARB for testing. Exhaust emissions were measured following requirements of the federal test procedure supple-mented with detailed measurements of organic compounds by the ARB. The resulting data set provides information on the emission levels from model year 1992 vans equipped to operate on the alternative fuels under study. In reviewing the results of the emission tests, it is important to recognize that the various fleets represent different types of technology for fuel handling, combustion, and emission control and also different levels of optimization of vehicle technology for the fuels. The emissions data reflect the range of technologies that were demonstrated.

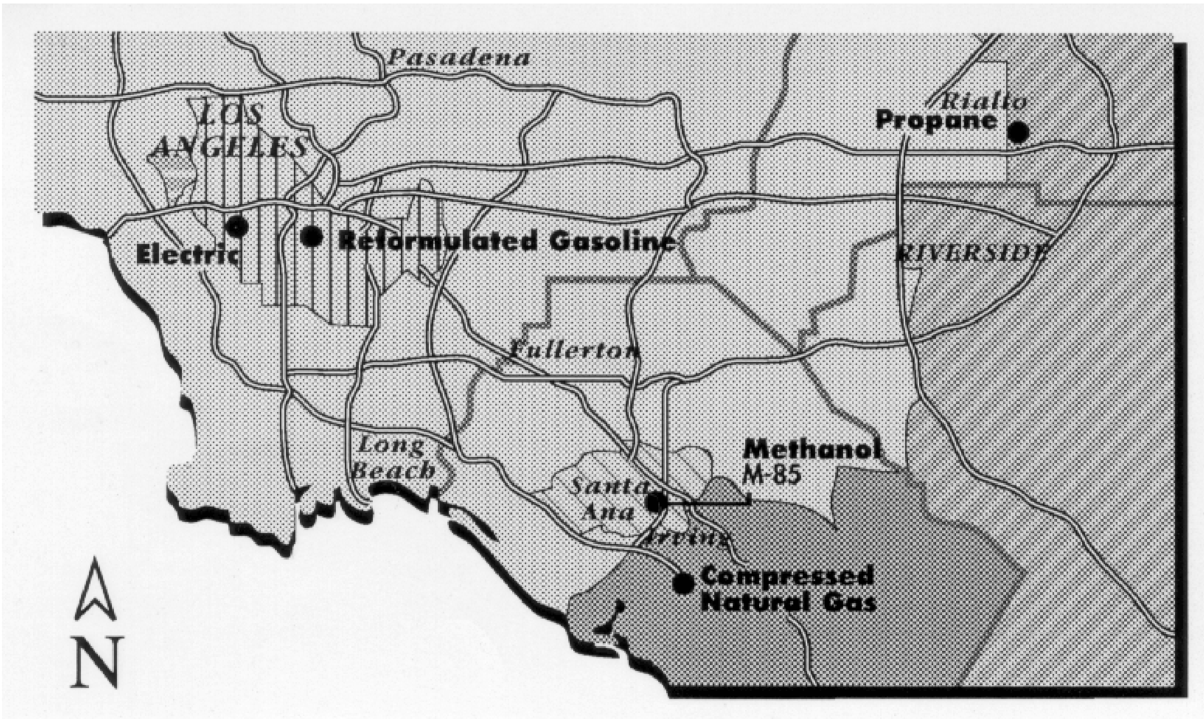

Figure 1. **Service Areas of Vans for Each Fuel Tested (Only a portion of the service area for they propane-fueled vans is shown.)**

Overview of CleanFleet Emissions Tests

The CleanFleet project is a comprehensive evaluation of five alternative motor fuel options. Information was gathered on emissions, fleet operations, and fleet economics. All of these factors will influence policymakers, regulators, vehicle and equipment manufacturers, fuel suppliers, and fleet owners as decisions are made on the use of alternative fuel vehicles in the marketplace. Thus the results presented in this report need to be viewed as one of a number of factors that characterize the attributes of a particular alternative fuel technology.

Objective of the Tests

The CleanFleet emissions tests were conducted to develop data on emissions from in-use CleanFleet vans using the four liquid and gaseous alternative fuels and a control gasoline. Documenting the level of emissions as the vans accumulated mileage in daily commercial operations provides an important data set for understanding the potential magnitude of emissions from alternative fuel vehicles.

The emissions data were gathered to

- Determine average levels of emissions from each fleet (combination of vehicle manufacturer and type of fuel)
- Determine the extent to which these levels conform to existing and future emission standards
- Compare emissions from alternative fuel vehicles to control vehicles (using a regular unleaded gasoline)
- Characterize the variability of emission levels across vehicle technologies
- Measure the effect of vehicle use (in terms of accumulated mileage) on emission levels.

The CleanFleet emissions data help to fill a significant gap in our knowledge of mobile source emissions from alternative fuel vehicles. The CleanFleet tests provide data on (1) a commercial fleet, (2) emissions from in-use vehicles (i.e., the vehicles were not adjusted before the emissions tests), and (3) a class of vehicles in the weight range between automobiles and heavy-duty trucks (i.e., light-duty trucks by federal standards and medium-duty vehicles by California standards). Detailed emissions data on vehicles in these three categories combined have not been available in the past.

Use of the Data

In reviewing the data presented in this report, it is important to keep in mind the differences in vehicle technologies that were tested in order to draw valid, useful conclusions. The conceptual design of the CleanFleet project called for demonstration of a variety of original equipment manufacturer (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 to be demonstrated. The available breadth of technology provides various practical options to fleet operators who plan to use alternative motor fuels. These differences need to be taken into account when comparing emissions data from the various fleets (for CleanFleet, a fleet is defined as a unique combination of an alternative fuel and vehicle manufacturer).

Three principal factors that need to be kept in mind when evaluating the emissions data are their collection from vans that represent:

- Various levels of optimization of combustion and emission control technology across fuels
- Different engine and emission control technologies
- A snapshot of technologies that were available in 1992 during a decade in which technological improvements are being made each year.

Care must be taken in comparing the emissions data on a fuel-by-fuel basis and ascribing relative emissions benefits or drawbacks to the fuels themselves because the emissions result from particular combinations of fuel and vehicle technology being tested. Gasoline engines and emissions control technology have had considerably more research and development than technology for CNG, propane gas, and M-85. To a large extent, the CleanFleet alternative fuel vans were gasoline vans modified to run on propane gas, M-85, or CNG. The Dodge CNG vans were an exception; they were production vans.

In the same manner, care needs to be exercised in comparing emissions data on the basis of vehicle technology (e.g., Ford versus Dodge versus Chevrolet). As will be documented in the next section of this report, CleanFleet vans from the three OEMs have different fuel system, engine, and emission control technologies. For example, engine displacement, compression ratio, fuel delivery, and catalyst systems vary among the OEM vans.

Care must also be exercised in using these data as input to atmospheric models that simulate the impact of these vehicle/fuel technologies on future air quality. Comparative calculations are appropriate; absolute calculations are not. The 1992 CleanFleet technologies do not represent the development of alternative fuel technologies that will be available at the end of the decade. (This includes vehicle technologies for reformulated gasoline which for this project is termed one of the alternative fuels that was demonstrated.) Nevertheless, the CleanFleet vehicle technologies do provide an important benchmark.

Collection and Disposition of Data

The ARB provided emissions measurements on CleanFleet vans at its El Monte, California, facility. The ARB's Mobile Source Division (MSD) and Monitoring and Laboratory Division (MLD) provided the testing and sample analysis, respectively. CleanFleet emissions data (along with data on fleet operations) have been submitted by Battelle to the National Renewable Energy Laboratory's Alternative Fuels Data Center (AFDC).

Vehicle Emission Standards

To improve ambient air quality, significant reductions in emissions from the transportation sector of the U.S. economy must be realized in the next several years. Vehicle emission standards established by both the State of California and the U.S. Environmental Protection Agency (EPA) drive emissions downward. These standards are reviewed in Appendix A.

Both California and federal emission standards for vehicle exhaust are becoming increasingly stringent. Those standards that apply to vehicles in the weight range classification of CleanFleet vans are summarized in Figures 2 and 3 (Appendix A contains tables documenting applicable standards). Standards are shown for nonmethane hydrocarbons (NMHC), nonmethane organic gases (NMOG), carbon monoxide (CO), and nitrogen oxides (NO_x) for selected vehicle model years, California's low emission vehicle (LEV) and ultra-low emission vehicle (ULEV) categories, and the federal category of inherently low emission vehicles (ILEV). In future model years (see Appendix A), fleet owners in California will be required to purchase increasing percentages of LEVs, ULEVs, and zero emission vehicles (ZEVs). Nationwide, purchase of ILEVs is voluntary for fleet owners who desire to gain certain emission credits for state implementation plans or to gain certain exemptions from transportation control measures.

CleanFleet vehicles are of two types with respect to emission standards: certified and experimental. The CleanFleet vans operating on unleaded gasoline and RFG were certified to model year 1992 California emission standards. The Dodge CNG vans were also certified to 1992 California standards. The identical CNG technology in model year 1993 was certified to California's LEV standards. The Chevrolet propane gas vans, Ford and Chevrolet CNG vans, and Ford M-85 vans were operated on experimental permits granted by the ARB. The Ford propane gas vans were operated on permits for ARB-approved modification kits to convert gasoline vans to propane gas vans (because the Chevrolet propane gas and CNG vans had special catalysts, they were granted experimental permits).

For the vans certified to emission standards, two types of certifications are represented by CleanFleet vans. The Chevrolet vans fueled with propane gas and compressed natural gas used 5.7-liter heavy-duty engines. The Chevrolet vans powered by gasoline (RFG and control gasoline) used 4.3-liter heavy-duty engines. Both of these types of engines had been certified to heavy-duty emission standards on engine dynamometers. In contrast, the Dodge and the Ford vans had been certified to California medium-duty emission standards on chassis dynamometers. Consequently, differences in levels of emissions are to be expected between the engines certified to heavy-duty standards and the vans certified to medium-duty standards.

As the OEMs evaluated options for providing vehicles to the CleanFleet project, the sponsors of the project (see the back cover for a list of the sponsors or Working Group) discussed tradeoffs between factors such as vehicle performance, fuel economy, and emission levels. The primary criterion for the vehicles was their ability to be used effectively and reliably by FedEx in its daily operations. With respect to emission levels, the Working Group established a target level of California LEV standards for CleanFleet vehicles operating on CNG, propane gas, and M-85 (see Figure 2 and Table A-3 for applicable LEV standards). The group agreed that vans would not be excluded from the demonstration if they did not meet these emission levels.

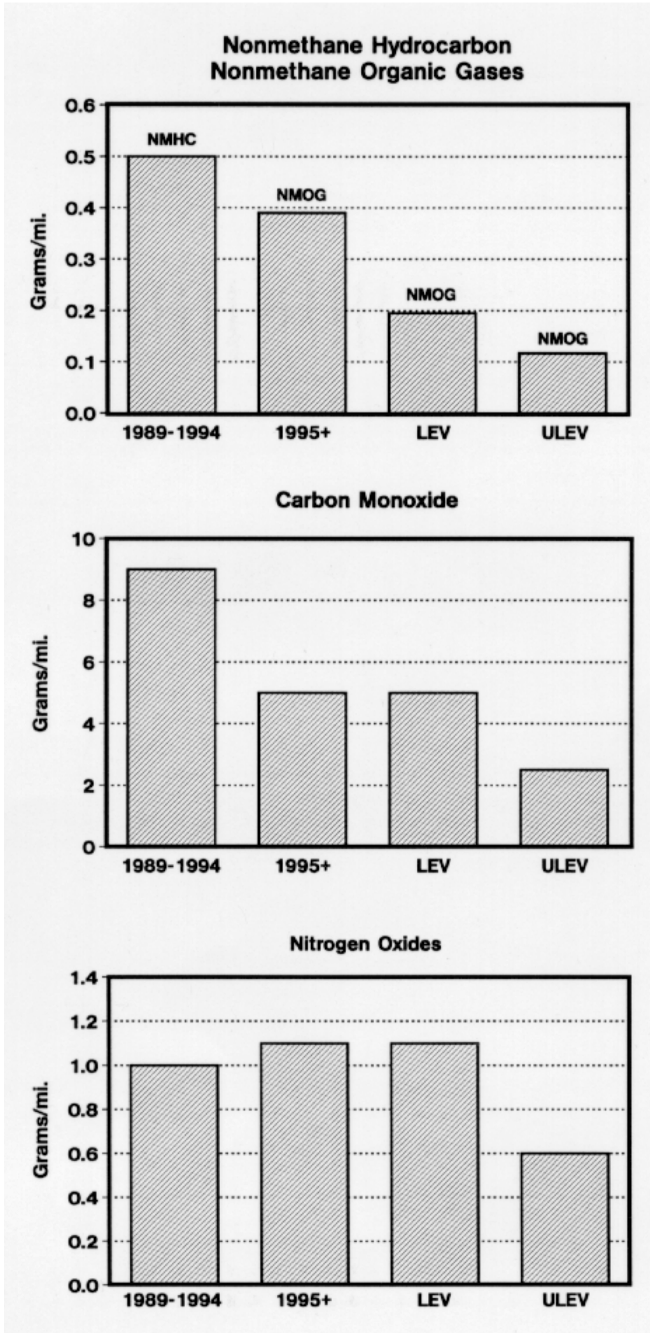

Figure 2. California Exhaust Emission Standards Applicable to Vehicles in the CleanFleet Weight Category

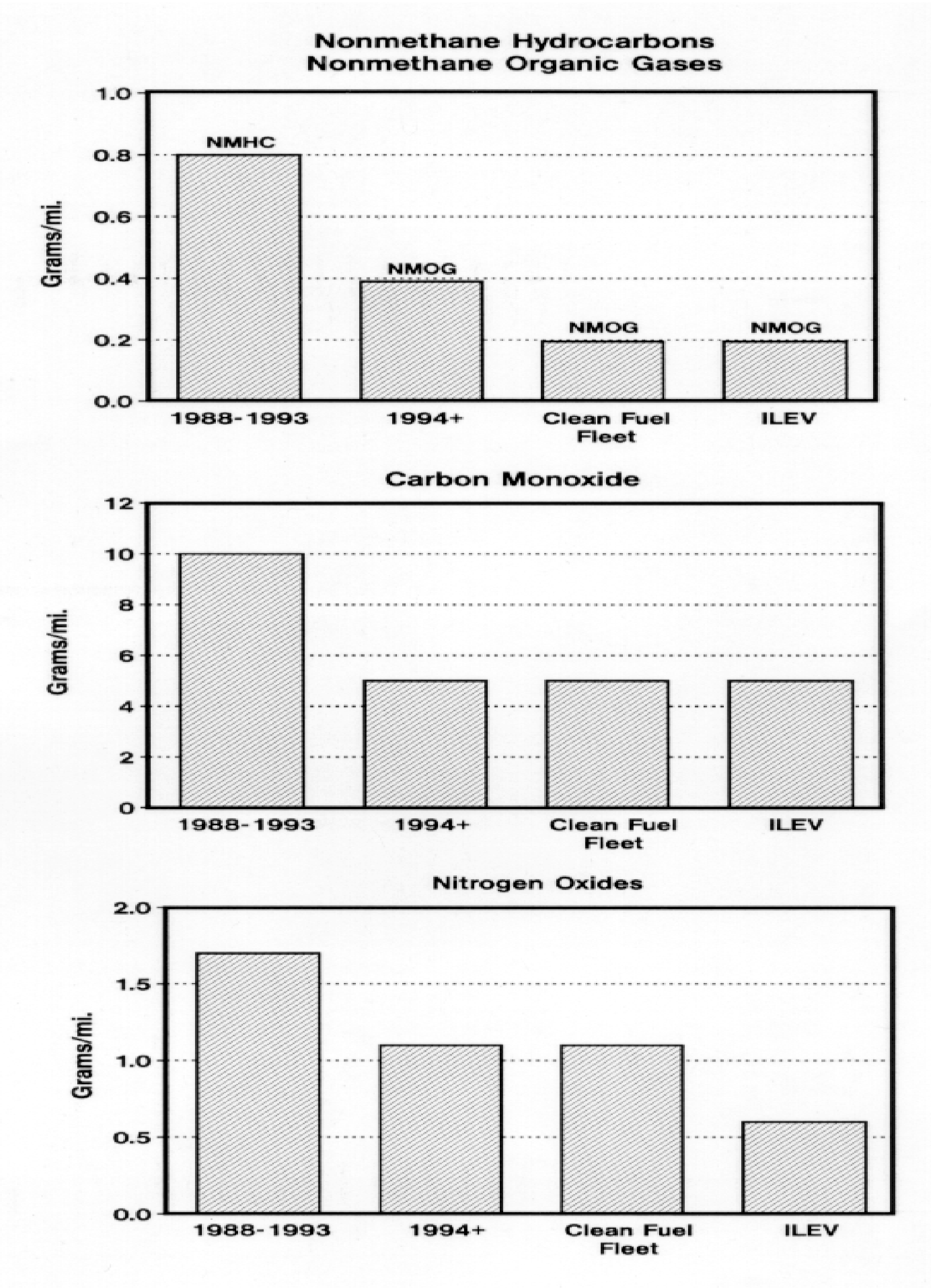

Figure 3. Federal Exhaust Emission Standards Applicable to Vehicles in the CleanFleet Weight Category (Ford, Dodge) with Gross Vehicle Weight Rating Less Than 8,501 Pounds

VEHICLE EMISSIONS

Vehicle Technology Tested

CleanFleet vehicles consisted of electric vehicles, which are defined as "zero emission vehicles" by the ARB, and 109 liquid and gaseous fueled vehicles. These vans represent a range of technologies for use by commercial fleets.

Characteristics of the liquid and gaseous fueled vans that have particular pertinence to emissions are listed in Tables 1 and 2. The project design established as a goal a target level of emissions for vans that were to be tested in CleanFleet. This target was California LEV standards, and it applied to the vans that would be operated on CNG, propane gas, and M-85. It was a target only, and emission level performance was to be balanced with operational performance for FedEx's requirements. The control and RFG vans were certified to model year 1992 California standards.

Table 1. Characteristics of CleanFleet Vehicles

		Engine				
Vehicle Manufacturer	**Fuel**[a]	**Displacement (L)**	**Type**[b]	**Horsepower**[c]	**Compression Ratio**	**Fuel Delivery**
Ford	M-85	4.9	I6	N/A	8.8	SMPI[d]
	Propane gas	4.9	I6	N/A	8.8	TB[e]
	CNG	4.9	I6	N/A	11	SMPI
	RFG/UNL	4.9	I6	150	8.8	MPI
Chevrolet	Propane gas	5.7	V8	N/A	8.6	TB
	CNG	5.7	V8	N/A	8.6	TB
	RFG/UNL	4.3	V6	155 @ 4,000 rpm	8.6	CPI[f]
Dodge	CNG	5.2	V8	200 @ 4,000 rpm	9.08	SMPI
	RFG/UNL	5.2	V8	230	9.08	SMPI

[a] CNG = Compressed natural gas, RFG = Phase 2 reformulated gasoline, UNL = Unleaded gasoline (industry average RF-A gasoline was used for the emissions tests on control vans).
[b] I6 = Inline, 6 cylinder.
[c] N/A = Not available, rpm = engine speed in revolutions per minute.
[d] MPI = Multiport electronic fuel injection, SMPI = sequential MPI.
[e] TB = Throttle body. IMPCO ADP and AFE systems provide fuel to the engine through the throttle body.
[f] CPI = Control port injection.

Table 2. Emission Control Catalysts and Certification Status of CleanFleet Vehicles

Vehicle Manufacturer	Fuel	Catalyst System[a]	Class [b]	Certification Status
Ford	M-85	Gasoline	MD	Exper[c]
	Propane gas	Gasoline	MD	Mod[d]
	CNG	Gasoline	MD	Exper
	RFG/UNL	Gasoline	MD	1992[e]
Chevrolet	Propane gas	Propane gas[f]	HD	Exper
	CNG	Natural gas[f]	HD	Exper
	RFG/UNL	Gasoline	HD	1992
Dodge	CNG	Natural gas	MD	1992L[g]
	RFG/UNL	Gasoline	MD	1992

(a) Three-way catalyst systems optimized for the fuels listed.
(b) MD = vehicles in California medium-duty class. HD = engines in heavy-duty class.
(c) Vehicles were operated under experimental permits from the ARB. Prior to modification to run on the alternative fuel, the vehicles were a model certified to California 1992 standards for gasoline vehicles (MD) or engines (HD).
(d) Gasoline vehicle modified with ARB-approved kit to run on propane gas.
(e) Certified to California 1992 standards.
(f) Engelhard catalysts.
(g) Dodge model year 1992 vans were certified to California 1992 standards. The same technology in model year 1993 was certified to LEV standard.

Ford

The Ford vans all had 4.9-liter (L), inline, 6-cylinder engines and standard production, gasoline three-way catalyst systems. The control vans operating on unleaded gasoline and the vans running on RFG used multiport electronic fuel injection.

The M-85 vans were flexible fuel vehicles (FFV) designed to run on a mixture of methanol and gasoline in the range zero percent methanol by volume/100 percent gasoline (M-0) to 85 percent methanol/15 percent gasoline (M-85). CleanFleet vans were operated on a steady diet of M-85. Nevertheless, they were not dedicated and optimized for methanol. These vans employed a prototype sequential multiport electronic fuel injection system. Although development is progressing on catalyst systems to control formaldehyde emissions from methanol-fueled vehicles, such a system was not supplied by Ford for the CleanFleet demonstration.

The seven Ford CNG vans were vehicles modified to carry and operate on CNG with limited calibration of a sequential multiport electronic fuel injection, and an increased compression ratio compatible with CNG (11:1). These vans were built by Ford specifically for the CleanFleet project.

The 13 Ford propane vans were gasoline vans modified to operate on propane gas by Suburban Petrolane. IMPCO Technology, Inc.'s adaptive digital processor (ADP) fuel system was used in these vans. The ADP is a stand-alone, alternative fuel, electronic, closed-loop feedback controller.

The ADP fuel system consists of the electronic controller with a 16-cell block learn memory designed to provide stoichiometric fuel mixtures when used in conjunction with IMPCO's air/gas valve feedback mixer. The ADP system provides propane gas to the engine through the vehicle throttle body. The ADP controller is not capable of interacting with the OEM's on-board computer.

The ADP controller uses manifold absolute pressure (MAP) and engine speed (revolutions per minute, RPM) to control gas pressure within the alternative fuel system. The ADP system also uses oxygen sensor input to update fuel system data stored in the adaptive memory. By using the stored stoichiometric mixture data, the ADP can instantly adjust the fuel system to meet the required combustion characteristics. This process occurs automatically while the vehicle is being operated. The fuel adjustment function is accomplished by sending a duty cycle signal from the ADP to the fuel control valve that varies the fuel pressure to the IMPCO feedback mixer. This process will continuously readjust the air/fuel ratio over the entire service life of the vehicle. Block learn memory also is used to compensate for engine wear and degradation.

Dodge

The Dodge vans operating on unleaded gasoline, RFG, and CNG were all production vans. The CleanFleet Dodge CNG vans were among the first produced[1). The 21 CleanFleet Dodge vans had 5.2 L, V8 engines. The compression ratio was the standard 9.08:1 used for gasoline vans. Sequential multiport electronic fuel injection was used. A three-way catalyst designed for natural gas exhaust was used on the CNG vans.

Chevrolet

The CleanFleet Chevrolet vans had two types of engines. The control gasoline and RFG vans had V6, 4.3 L engines and used electronic fuel injection through the throttle body. In contrast, the propane gas and CNG vans had V8, 5.7 L engines. Because FedEx would normally use the 4.3 L gasoline engine, not the 5.7 L heavy-duty engine, for gasoline-powered vans, the decision was made to include the 4.3 L engine in the project and not use 5.7 L engines for the two gasolines. This decision by the Working Group reflects the practical nature of this project.

The Chevrolet propane gas and CNG vans were gasoline vans that were modified by IMPCO Technologies, Inc. IMPCO's Advanced Fuel Electronic system (AFE) is a microprocessor-based, engine management system. The AFE system controls spark and exhaust gas recirculation (EGR) functions to provide optimum engine performance. AFE's operational functions interact with the OEM vehicle's on-board computer. The AFE strategy allows the OEM on-board diagnostic routines to remain operational at all times.

The AFE Electronic Computer Module receives engine air flow information from the existing OEM vehicle sensor group that includes MAP, RPM, and intake air temperature (IAT). AFE's gas mass sensor measures and provides data on the volume of gas flow to the engine. By obtaining input from these various sensors, the air and gas flow rates are calculated. With these data, AFE is able to calculate and provide the engine with an accurate amount of air and fuel. This is accomplished by delivering the fuel mixture at positive pressure to the air inlet above the throttle body. The motor-controlled flow valve inside the gas mass sensor then corrects the fuel mixture based on the engine demand requirements.

As combustion occurs, the oxygen sensor monitors the exhaust gases and transmits these data to the on-board computers (OEM and IMPCO's AFE). The computers use this input to control air/fuel ratio and tailpipe emissions. The ideal stoichiometric mixture data are then stored in the AFE block learn memory (16 cell). The block learn memory is programmed to be adaptive. This allows the block learn strategy to be updated continuously for the life of the vehicle.

The Chevrolet propane gas and CNG vans utilized Engelhard three-way catalyst systems. The catalysts were optimized by Engelhard for exhaust products from propane gas and natural gas, respectively.

Experimental Design

CleanFleet emissions tests were designed to produce a high quality database on emissions from in-use vans as the vans accumulated mileage. The matrix of tests, compounds measured, treatment of vehicles, supply of fuels, test procedures, and data analysis model are summarized below.

Matrix of Tests

The emission testing program called for a series of three sets of tests as the vehicles accumulated mileage: early in the demonstration, midway through the demonstration, and at its conclusion. These tests were planned to be conducted at approximately 4,000, 14,000, and end-of-test mileage on each van. However, because of time constraints in testing, it was not possible to test each van at exactly these prescribed mileages. Because the data were evaluated over mileage during the demonstration, the exact mileage at the time of testing was not as important as it would have been if the principal evaluations were comparisons across types of fuel or OEM technologies.

Exhaust emission tests were performed in each of the three rounds of emissions tests. Evaporative emissions were measured once. Duplicate tests were performed on each van when only exhaust emissions were measured. One-third of the vans were tested in duplicate when both exhaust and evaporative emissions were measured.

To accommodate the constraints of the ARB, three vans from each fleet (i.e., a combination of OEM and fuel) were tested for emissions. A total of 36 vans were tested. The matrix of tests is shown in Table 3. Several vans received more than two tests during one or more of the three rounds of tests (see Appendix C).

Compounds Measured

The compounds measured in the exhaust and evaporative emissions can be categorized as shown in Table 4: regulated compounds, ozone precursors, air toxics, and greenhouse gases.

Regulated Compounds. Six compounds or aggregates of compounds are classified as regulated emissions in Table 4. Two of these are common to both California and federal standards and are common to all fuels and all vehicle model years: carbon monoxide and nitrogen oxides (the sum of nitric oxide and nitrogen dioxide).

Total hydrocarbon (THC) values were obtained by measuring all hydrocarbons, including methane, using a flame ionization detector (FID). Total hydrocarbons have been regulated in the past for some classes of vehicles. They are not regulated for light- or medium-duty vehicles, but they were measured (results are in Appendix F), along with the regulated compounds, for comparison to the values for NMHC.

NMHC are regulated for model year 1992 vehicles by both California (see Table A-3) and federal standards (see Table A-10). Regulating NMHC emissions is more appropriate for ozone control than regulating THC because methane is much less reactive in the atmosphere than other hydrocarbons.

VEHICLE EMISSIONS

Table 3. Number of Emission Tests Scheduled on CleanFleet Vehicles[a]

Testing Round	Fuel	Vehicle Manufacturer	Exhaust Tests	Evaporative Tests	Total Tests
1 & 3	RFG	Ford Chevrolet Dodge	3(3)	0	6
	Propane gas	Ford Chevrolet	3(3)	0	6
	M-85	Ford	3(3)	0	6
	CNG	Ford Chevrolet Dodge	3(3) 3(3) 3(3)	0 0 0	6 6 6
	RF-A (Control)	Ford Chevrolet Dodge	3(3) 3(3) 3(3)	0 0 0	6 6 6
					72[b]
2	RFG	Ford Chevrolet Dodge	3(1) 3(1) 3(1)	3(1) 3(1) 3(1)	8 8 8
	Propane gas	Ford Chevrolet	3(1) 3(1)	3(1) 3(1)	8 8
	M-85	Ford	3(1)	3(1)	8
	CNG	Ford Chevrolet Dodge	3(1) 3(1) 3(1)	3(1) 3(1) 3(1)	8 8 8
	RF-A (Control)	Ford Chevrolet Dodge	3(1) 3(1) 3(1)	3(1) 3(1) 3(1)	8 8 8
					96
TOTAL					240

[a] The number of duplicate tests is shown in parentheses.
[b] Each of rounds 1 and 3 has 72 tests.

Table 4. List of Classes of Compounds Measured in the Emission Tests

Regulated Emissions	**Air Toxics**
Total hydrocarbons	Benzene
Nonmethane hydrocarbons	1,3-Butadiene
Nonmethane organic gases	Formaldehyde
Carbon monoxide	Acetaldehyde
Nitrogen oxides	
Formaldehyde	
Ozone Precursors	**Greenhouse Gases**
C_2-C_{12} hydrocarbons	Carbon dioxide
• Alkanes	Methane
• Alkenes	Nitrous oxide
• Alkynes	
• Aromatics	
Oxygenated organic compounds	
• Aldehydes	
• Ethers	
• Ketones	
• Methanol	
• Ethanol	
Methyl nitrite	
Nitrous acid	
Nitrogen oxides	

Its role in urban ozone formation is negligible compared to NMHC. NMHC measures the mass of hydrocarbons alone, excluding the mass of oxygenated compounds such as aldehydes and alcohols. Because exhaust from gasoline is overwhelmingly composed of hydrocarbons, regulating NMHC was adequate until the advent of oxygenated fuels such as methanol. Exhaust emissions from alcohol-fueled vehicles, for example, contain significant amounts of oxygenated compounds. Some of these compounds (e.g., formaldehyde) can be highly reactive in forming ozone in the atmosphere. Therefore, California regulations control emission of these compounds as well as hydrocarbons.

The U.S. EPA developed emission standards for methanol-fueled vehicles based upon the organic material hydrocarbon equivalent (OMHCE) parameter. The OMHCE approach assumes that the ozone reactivity of exhaust is governed by the amount of carbon, and it limits the mass of carbon emitted into the air. OMHCE essentially discounts the oxygen content of oxygenated compounds in emissions and allows the mass of emissions from methanol-fueled vehicles to be compared directly to mass emissions from gasoline-fueled vehicles on a carbon basis. OMHCE converts emissions of hydrocarbons, methanol, and formaldehyde to emissions of carbon, plus associated hydrogen, assuming a carbon-to-hydrogen ratio typical of gasoline. The emission standards for alcohol-fueled vehicles in terms of OMHCE are numerically equal to standards for NMHC for gasoline-fueled vehicles. One drawback of the OMHCE approach is that it does not account for the relative reactivity of the oxygenated compounds in exhaust, some of which can be highly reactive in the atmosphere. In this report (Appendices F and G), the emissions data for the M-85 vans are reported as OMHCE for comparison with the NMHC data from the other fuels.

To better control emissions of ozone-forming compounds, the ARB adopted emission standards based upon the full weight of oxygenated compounds. The standards move from NMHC to nonmethane organic gases (NMOG). NMOG is the full, unadjusted mass of all measurable hydrocarbons (except methane) containing 12 or fewer carbon atoms, and all ketones, aldehydes, alcohols, and ethers containing five or fewer carbon atoms. The ARB reports the six-carbon aldehyde, hexanal, as well.

Values of NMOG can be calculated by more than one procedure. One method estimates the value of NMOG as the sum of NMHC from a FID, plus the concentrations of alcohols (principally methanol for CleanFleet) and carbonyls (e.g., formaldehyde and acetaldehyde) determined by other methods. A second method estimates NMOG as the sum of all concentrations represented by peaks in gas chromatograms. For the CleanFleet measurements, NMOG is calculated as the sum of over 150 species determined by gas chromatography.

Interest in alternative motor fuels stems in large measure from data that suggest that emissions from vehicles burning these fuels are less reactive in the atmosphere in terms of their ozone-forming potential. Thus they have been termed “clean fuels.” The ARB has adopted procedures to account for the less reactive nature of these exhaust compounds. Termed the maximum incremental reactivity (MIR) scale, each compound in NMOG exhaust is assigned a factor that represents its propensity to contribute to ozone formation in the atmosphere. The ozone-forming potential of exhaust is then calculated by multiplying the concentration of each compound by its reactivity factor and summing the results. The sum is expressed in grams of ozone potentially formed per mile of vehicle travel. Ozone potentials for the exhaust from CleanFleet vans are also summarized in this report.

The ARB has established, through testing, an average factor to be applied to exhaust from various fuels. These reactivity adjustment factors (RAF) are to be applied to the NMOG mass results to adjust the NMOG mass data downward to credit these “cleaner” emissions for their low ozone reactivity. Values of RAFs for passenger cars operating on alternative fuels and for medium-duty vehicles (which the Ford and Dodge CleanFleet vans are) operating on alternative fuels are being developed by the ARB (see Appendix A). RAF values are not used in this report.

The ARB’s purpose in creating RAFs was to ensure a “level playing field” for all fuels with respect to emission of NMOG. With the ARB’s RAF approach, different vehicles certified to a particular LEV standard would have the same impact on air quality (ambient ozone) because the basis for certification is the ozone-forming potential of exhaust gases, not simply the mass of NMOG emissions. Thus different fuel/vehicle combinations, gasoline or alternative fuel, that were certified to a particular LEV standard would be classified as having the same impact on air quality.

Ozone Precursors. Ozone precursors are those organic compounds that react in the atmosphere in the presence of nitrogen oxides to form ozone. Classes of hydrocarbons and individual compounds are listed in Table 4. A detailed listing of the organic compounds measured by the ARB is provided in Appendix B.

Air Toxics. The Clean Air Act Amendments (CAAA) of 1990 define five substances emitted from vehicles as air toxics. These are benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and polycyclic organic matter (POM). The CAAA require that, beginning in 1995, the sum of these substances be reduced by 15 percent when using reformulated gasoline compared to a baseline gasoline. A reduction of 25 percent in mass emissions of air toxics is required beginning in 2000. For CleanFleet, a decision was made not to measure POM because (1) it is expected to be present at very low levels in exhaust, (2) CleanFleet emissions concerns focus more on ozone issues than carcinogenicity issues (some POM are carcinogens), and (3) the procedures for effectively measuring POM in exhaust need further development.

Other compounds classified as air toxics in atmospheric chemistry are also reported in Appendix F. These are xylenes, styrene, toluene, and acrolein.

Concern over emission of air toxics as a group relates primarily to the direct influence of these compounds on public health, not ozone formation and its effects on public health. It is important to recognize that mobile source emissions are but one source of the these compounds; they are emitted by a variety of other sources including industrial operations and consumer products themselves. In addition to these direct sources of air toxics, some compounds, such as formaldehyde, are also formed in the atmosphere and contribute to human exposure.

Greenhouse Gases. Three greenhouse gases were measured: carbon dioxide, methane, and nitrous oxide. Carbon dioxide and methane are routinely measured by the ARB. Nitrous oxide was added to the standard list of measurements for these tests (see Appendix B).

Treatment of Vehicles

CleanFleet vehicles were serviced by FedEx according to standard practices. When maintenance was required on special alternative fuel components, either OEM-backed dealerships or the organizations that modified the vans worked on them. Information on vehicle maintenance was entered into FedEx's information management system, and the data were transmitted to Battelle.

A summary of maintenance activities on those CleanFleet vans in the emissions testing program is provided in Appendix C. Only work performed on systems that might influence emissions is shown. This work covers the following vehicle systems:

- Ignition
- Engine Group (filters)
- Air Intake
- Exhaust
- Fuel
- Power Plant.

Vehicles were taken to the ARB for testing directly from their daily operations. No special preparation or maintenance was performed on the vans before they were tested. Vans running on propane gas, unleaded gasoline, M-85, and RFG were driven to the ARB. The CNG vans were transported on flatbed trucks to ensure that sufficient fuel was in the vehicle fuel tanks for the tests.

VEHICLE EMISSIONS

Fuel Supply

The alternative fuels used in the emissions tests were in keeping with the project's design, i.e., to gather information on practical aspects of alternative fuels in everyday commercial operations. In this case, the focus was on emissions from in-use vehicles. The alternative fuels used in daily operations were the fuels used for the emissions tests.

The fuel used in the control vans for daily operations was regular, unleaded gasoline purchased by standard FedEx practice. The composition of the unleaded gasoline varied across the demonstration sites and seasonally. Because a consistent baseline was needed for the emissions tests on the control vans, the industry average unleaded gasoline (RF-A) was chosen to fuel the control vans for the emissions tests. The ARB supplied the RF-A gasoline.

Supplies of M-85 and RFG were taken from the fuel storage tanks at the demonstration sites and brought to the ARB by Battelle in sealed drums. The RFG used from the inception of the demonstration through September 1993 (including all first round emissions tests) was a single batch blended in April 1992. A tank load was brought to the demonstration site in Los Angeles every four weeks and stored onsite in a 5,000-gallon underground storage tank. A second batch of RFG was used from September 1993 through the end of the demonstration. This fuel was used for the second and third rounds of emissions tests. The M-85 was generated every three weeks by loading methanol into a tank truck in San Pedro, driving to the RFG demonstration site and splash blending the proper quantity of RFG into the methanol, and then driving down to the M-85 site in Santa Ana. The composition of the M-85 and RFG varied slightly from month to month.

Propane gas was brought to the 1,000-gallon onsite storage tank about weekly. The composition of propane gas can vary from delivery to delivery. For the emissions tests, the vans were filled with propane gas at the Rialto site and driven the 35 miles to the ARB in El Monte. Sufficient fuel remained in the tanks for the duplicate exhaust tests and the return to home base.

Natural gas was taken from the pipeline, compressed onsite in Irvine, and dispensed into the vans to a maximum pressure of about 3,000 psi. The composition of pipeline gas can vary throughout a day, let alone a month. The monthly composition data for CNG indicate a stable composition for the natural gas used in CleanFleet vans. The CNG vans were taken to and from the ARB on flatbed trucks to ensure that sufficient supply of fuel was in the vehicle fuel tanks for emissions testing.

Each month a sample of RFG, propane gas, CNG, and M-85 was analyzed for selected constituents and properties. To characterize the fuels, the ARB provided a detailed analysis of one sample of each fuel during each round of tests. The results are included in Appendix D. A detailed list of components measured in the two gasolines (RFG and RF-A) is available from Battelle.

The RFG was produced in two batches for the project. Fuel from the first batch was used for the first round of emissions tests; fuel from the second batch was used for the last two rounds of emissions tests.

Test Procedures

The tests were performed by the ARB according to the Federal Test Procedure (FTP) specified in the Code of Federal Regulations, CFR 40 Part 86 (see Appendix B). The RFG and control vans were tested on the dynamometer set according to the tabulated curb weight and GVWR (see Table A-1). The CNG, propane gas, and M-85 vans were weighed by the ARB, and the dynamometer was set accordingly.

The procedures used to identify and quantify hydrocarbons (i.e., the so-called speciated data) were changed by the ARB midway through the first round of tests. A summary of the changes, including lists of species reported by the two analytical procedures, is provided in Appendix B. The revised procedure provides somewhat better resolution of co-eluting peaks in the gas chromatography. This resulted in identification of several species previously labelled as "unidentified." The reported data for NMOG and ozone potential from the two procedures are essentially the same.

As exhaust emission levels decrease with each model year, two factors become increasingly important in emission measurements: pollutants in background air and the detection limit of the measurement process. The ARB uses ambient air to dilute raw vehicle exhaust prior to measurement. On polluted days in the South Coast Air Basin, background levels of pollutants can be comparable to concentrations of some trace species in the diluted exhaust of clean burning vehicles. One effect of this is that the variability in results for these trace species increases as a result of calculating the difference between two small numbers that are nearly equal in magnitude (e.g., subtracting a background level of a compound that is close to the concentration of the compound in the diluted exhaust).

A second factor is the detection limit of the measurement process for individual organic compounds. The ARB has defined its detection limit as 20 parts per billion carbon (ppbC) to reduce spurious noise in reported values for trace organic compounds. To the extent that reactive compounds in very clean diluted exhaust exist at concentrations less than 20 ppbC, the reactivity of the exhaust will be underestimated using the ARB's procedure. The issue of detection limits is common to all emission laboratories.

The test program was to include a complete two-hour evaporative emissions test on each vehicle. Because it was not possible to equip the CNG and propane gas fuel tanks with an internal temperature sensor, a compromise "isothermal" test was substituted for the 40 CFR 86 prescribed diurnal portion of the test. The emissions were then to be measured as if the vehicle had experienced a diurnal test.

The configuration of the fill pipe on the fuel tank of the liquid fuel vehicles dictated an additional modification to standard procedure. Because it was not possible to insert a temperature probe into a significant number of vans, a decision was made to eliminate the diurnal portion of the evaporative test and complete the project with the hot soak tests only.

Two different SHED (sealed housing for evaporative determination) facilities were used: a 48 m^3 flexible roof unit built in 1973 and a 51 m^3 variable volume SHED which replaced it in 1994. Both SHEDs meet applicable federal test standards.

VEHICLE EMISSIONS

Statistical Modeling Approach

A principal goal of the emissions testing program in the CleanFleet project was to determine the average emission levels of pollutants from each fleet as the vehicles accumulated mileage. Emissions tests were performed on each of three vehicles from each fleet. The statistical analysis was performed using a mixed model (random and systematic effects) analysis of variance (ANOVA) procedure.[2] The model produces optimal (least uncertainty) estimates of average emissions as a function of vehicle miles travelled.

Factors. For each pollutant, the ANOVA model considered the following factors: vehicle technology, mileage, and measurement/testing error. Each fleet (distinct combination of fuel type and manufacturer) was considered to have a different average level of emissions at the beginning of the demonstration, and each was assumed to be affected by vehicle mileage accumulation to a different degree. Additional factors were included in the model to account for random vehicle-to-vehicle differences in both average emissions and mileage effects.

Form. The statistical model chosen to describe the data is a log-linear model. For each species, emissions were modeled versus mileage, m_{ij}, as

$$\log\ (E_{ij}) = \alpha + \beta \log m_{ij} + v_i + \delta_i \log m_{ij} + \epsilon_{ij}.$$

where E_{ij} is the measured emissions in (g/mi) from the *j*th test on the *i*th vehicle. The terms α (intercept) and β (slope) represent the systematic fleet-specific effects. The terms v_i and δ_i represent vehicle-specific deviations from the fleet-specific effects. The final term ϵ_{ij} represents testing variability that may include variations in test procedures and chemical analyses.

Preliminary analysis indicated that, for many species, the variability in emissions tended to increase with the mean. To account for this, emissions were log-transformed during analysis, and back-transformed for presentation of results. In most cases, the log transformation was sufficient to stabilize the variance and allow one estimate of variability to be used over mileage and across fleets for each species. In other cases, separate subpools of fuel types were defined. For example, vehicle and test variances of NO_x and benzene were estimated for RFG and RF-A separately from those for CNG, propane gas, and M-85 fueled vehicles.

Model Justification. It is important to recognize the different sources of variation. Twelve fleets were under consideration. Within each fleet three vehicles were selected for emissions testing. As illustrated in the plots of individual test results versus mileage, there were differences in emissions results from individual vehicles. The most obvious example of this was seen in the Ford CNG fleet.

The impact of this vehicle effect is accounted for in the mixed model ANOVA by giving appropriate weight to each test result in estimating the systematic effects. For species where vehicle-to-vehicle variability was large relative to the within-vehicle (replicate test) variability, each vehicle was given nearly equal weight in determining means and mileage effects. When vehicle-to-vehicle variability was small relative to test variability, each test was given nearly equal weight. This methodology results in the smallest uncertainty of the estimated systematic effects[2].

Adequacy. The selected models were validated by comparing observed results with predicted results. Standardized residuals (observed values minus predicted values) and estimated random effects (vehicle deviations from fleet averages and mileage effects) were plotted and compared to control limits to identify suspect results. Questionable results were checked by the ARB for analytical validity, and some were removed. This process was iterative, resulting in model adjustments until the models were judged to be adequate.

Results

The emphasis of this report is on (1) the relative emission levels of pollutants from CleanFleet alternative fuel vehicles compared to gasoline-powered vehicles and (2) changes in emission levels over vehicle mileage.

Exhaust emission results are presented in this section of the report for individual regulated compounds (e.g., CO) and classes of compounds (e.g., NO_x, NMOG, NMHC). To report a metric for ozone precursors in vehicle exhaust (i.e., the hundreds of constituents comprising NMOG and the NO_x), the parameter "ozone reactivity" (also called ozone forming potential) is presented. This is a composite indicator of emissions leading to formation of ozone in the atmosphere. The ozone reactivity was calculated by the ARB using the maximum incremental reactivity approach(3). Measured levels of nitrous acid and methyl nitrate are not reported. Their concentrations were below the detection limit of the Fourier-Transform Infra-Red (FTIR) spectroscopy system. Because the nitrous oxide data for the control vans are sparse, the statistical model was not applied to these data. Only measured results are presented for N_2O.

Measurements of 1,3-butadiene, when detected, show more scatter than other parameters. This reflects the low levels of 1,3-butadiene in exhaust coupled to its chemical instability in the dilute exhaust collected in bags for measurement. To overcome the problem of decay in concentration, measurements of 1,3-butadiene were generally made within one hour of collecting the sample.

For each fleet of vehicles, exhaust emission results are presented in the format illustrated by Figure 4 (pages 29-32). Each figure has four panels labelled a, b, c, and d. For each fleet, panel "a" contains data for nitrogen oxides, nonmethane organic gases, and ozone reactivity. These plots are grouped together because ozone is formed in the atmosphere from complex reactions involving NO_x and individual NMOG. Panel "b" contains data for carbon monoxide, formaldehyde, and acetaldehyde. Panel "c" contains data for the air toxics 1,3-butadiene and benzene. Together, panels "b" and "c" provide information on CO and the four air toxics addressed by the CAAA. Finally panel "d" contains data on the greenhouse gases methane, carbon dioxide, and nitrous oxide.

In each panel two plots are presented for each parameter. On the left is shown the measured data along with an estimate of the mean emission level from the statistical modeling. In each of these plots, the open symbols represent data for the three alternative fuel vans that were tested from the fleet. The dashed line is the model estimate of the mean emission level of that parameter as a function of mileage. The solid symbols and model line represent the control fleet. The circles, squares, and triangles, as groups, represent one of the three vehicles that was tested from the fleet (In Appendix C, these three symbols are identified with specific vehicles). The level of California exhaust emissions standards are shown on those plots to which the standards would apply. These are medium-duty standards for model year 1992, 1995 and beyond, LEV, and ULEV. These standards are shown solely to provide a point of reference in viewing the data; the relative level of measured emissions compared to the standards does not imply lack of or adherence to the standards. The medium-duty standards are not shown on the plots for the Chevrolet vans because the engines in these vans were heavy-duty engines.

The plots on the right in each panel present a comparison of the mean emission levels of the alternative fuel vans compared to the control vans over mileage. The mean difference in emission levels is plotted as the solid line in percent difference. If the mean emission level of a compound from the alternative fuel vans were the same as from the control vans, the percent difference would be zero, and the solid line would fall on the "zero percent difference" horizontal line shown in the plot. For example in Figure 4a for nitrogen oxides, at 15,000 miles the emission level of NO_x from the Ford CNG vans is estimated to have been about 63 percent greater than NO_x from the control vans. The 95-percent confidence bounds are shown as dashed lines below and above the mean difference. At a prescribed mileage level, if both the dashed lines are below or above the "zero percent difference" solid line, there is 95 percent confidence that the relative percent difference is different from zero. In other words for NO_x, while the mean NO_x emissions at 15,000 miles are estimated to have been 63 percent greater from the CNG vans than from the controls, the scatter in the data resulted in a relatively large uncertainty in the model estimate, and it cannot be said with 95 percent confidence that the emission levels of NO_x from the CNG and control vans were in fact different from one another. In contrast, for NMOG and ozone reactivity over the entire mileage range, the 95-percent confidence band is entirely below the "zero percent difference" line, and the NMOG and ozone reactivity of the exhaust from the CNG vans is estimated with 95 percent confidence to be less than for the control vans. The spread in the confidence interval at low and high mileage compared to the confidence interval at the intermediate mileage is a general trend signifying that the comparison between alternative fuel and control vehicles is more precise near the middle of the range of the independent variable (i.e., odometer reading) than at the extremes.

Model estimates of the mean emission levels of parameters are presented in numeric form in Appendix G. These estimates correspond to the lines plotted in the left plots in Figures 4-12.

Compressed Natural Gas

Exhaust emission data for the Ford CNG vans are shown in Figure 4. The NO_x emissions from the control Ford vans show relatively little scatter about the estimated mean and a very gradual deterioration with increasing mileage of the in-use vans. In contrast, the NO_x emissions from the CNG vans show higher deterioration rates and more variability. These trends stem from the differences in mean emission levels for the three Ford vans that were tested. The mean emission level of NO_x at 5,000 miles was modeled as 0.12, 1.33, and 1.87 g/mile. The deterioration of vehicle emissions of NO_x was consistent; each of the three vans tested had increases in NO_x of between 0.2 and 0.4 g/mi between 10,000 and 20,000 miles. This range of mean emission levels from the three vans produced considerable uncertainty in the estimated mean value for the three vans, and this uncertainty is reflected in the large 95-percent confidence band for the relative difference in emissions shown in the plot on the right. It cannot be said with 95 percent confidence that the mean emission level of NO_x from the CNG vans was different from the control vans because of scatter in the data.

The NMOG emission levels from the CNG vans exhibit the same qualitative progression as for the NO_x levels (triangles highest, circles lowest). The NMOG emissions from the control vans had a higher deterioration rate than the NMOG emissions from the CNG vans. This is illustrated in the plot on the right that shows the mean relative difference sloping downward from a value of 70 percent less than the controls at 5,000 miles to 74 percent less at 25,000 miles. These values are also reflected in the ozone forming potential or ozone reactivity. Mean ozone reactivity of CNG exhaust was about 91 percent less than for gasoline exhaust over mileage from 5,000 to 25,000 miles.

Referring to Figure 4b, mean emission levels of CO from the CNG fleet were 70 percent less than from the control vans over the range 5,000 miles to 25,000 miles. Formaldehyde emissions averaged about 8 percent less at 5,000 miles to 11 percent less at 25,000 miles, but the uncertainty in this estimate is relatively high; and, statistically, the mean emission levels of formaldehyde from the Ford CNG and control vans cannot be said to be different at the 95 percent confidence level. The three CNG vans had greater spread in formaldehyde levels than did the control vans. Levels of the other three air toxics (acetaldehyde, benzene, and 1,3-butadiene) from the CNG vans were significantly less than from the control vans. Note that in Figure 4c the reported measurements of 1,3-butadiene were zero, i.e., below the detection limit of the ARB (see also Table F-6). The data points are shown in the left plot as zero g/mi. In the "percent difference" plot to the right, the relative difference is reported as "no emissions detected." This procedure is used for other fleets as well.

Methane emissions ranged from 16 to 28 times those from RF-A gasoline over mileage. This is not unexpected given that methane is the principal constituent of natural gas and is absent from gasoline. Note that the spread in emission levels of methane is similar to that for NO_x. The spread in emission levels may reflect the limited build of these vans (seven in number) and the resources that could be applied to their optimization. Emission levels of carbon dioxide averaged about 23 percent less than from gasoline control vans; emissions of nitrous oxide were about the same as from gasoline, but only two measurements of N_2O are available for the Ford control vans.

Results for the Chevrolet CNG vans are shown in Figure 5. It is important to note that the Chevrolet vans were equipped with heavy-duty engines that had been certified as an engine family to heavy-duty gasoline emission standards. The Chevrolet CNG engines were 5.7 liter engines, and the control van engines were 4.3 liter engines. Because of continued operational problems involving the AFE alternative fuel system (e.g., stalling), all AFE components were replaced in the vehicles in September 1993 at odometer levels of about 10,000 to 14,000 miles (see Table C-1). The AFE computer was reprogrammed. This work occurred shortly before the second round of emission tests on the three Chevrolet CNG vans. In spite of these changes in fuel system components, no step change in emission levels was measured. In contrast, the control vans received normal preventive maintenance only during the 24-month demonstration.

Of the regulated emissions, CO, NO_x, NMOG, and NMHC, significant deterioration compared to gasoline was seen only for CO. Ozone reactivity averaged 95 to 93 percent less than for gasoline exhaust across mileage. Levels of air toxics and greenhouse gases were consistent with the results from the Ford vans relative to gasoline controls. Methane emissions were more elevated compared to the controls than for the Ford CNG vans, about 40 times higher than from the control vans at 25,000 miles. Nitrous oxide emissions were much less than for the controls, reflecting elevated levels of nitrous oxide in the exhaust of the control vans.

The Dodge CNG vans (Figure 6) had the lowest exhaust emission levels, reflective of their status as production vehicles. The mean relative difference of 47 to 40 percent for NO_x across mileage reflects the low emission levels of NO_x from both the Dodge CNG and control vans. The mean ozone reactivity was about 99 percent less than for gasoline exhaust at 5,000 miles and 93 percent less at 25,000 miles. Levels of air toxics were consistent with the other OEM CNG vans compared to the control vans. The "percent difference" plot for formaldehyde shows a substantial deterioration in emissions relative to the gasoline control vans, but the uncertainty in this comparison is high due to variability in the data. A striking increase in emission of acetaldehyde can be seen for one control van (solid circles) at 43,000 miles compared to 28,000 miles. This increase was the result of higher emission of acetaldehyde in the cold start transient phase (bag 1) of the FTP cycle. The emission levels were measured as 9.43 mg/mi at 28,000 miles and 17.1 and 18.7 mg/mi at the two 43,000 mile tests. Methane emissions from the Dodge vans were lower compared to their controls than for the other two OEM vans.

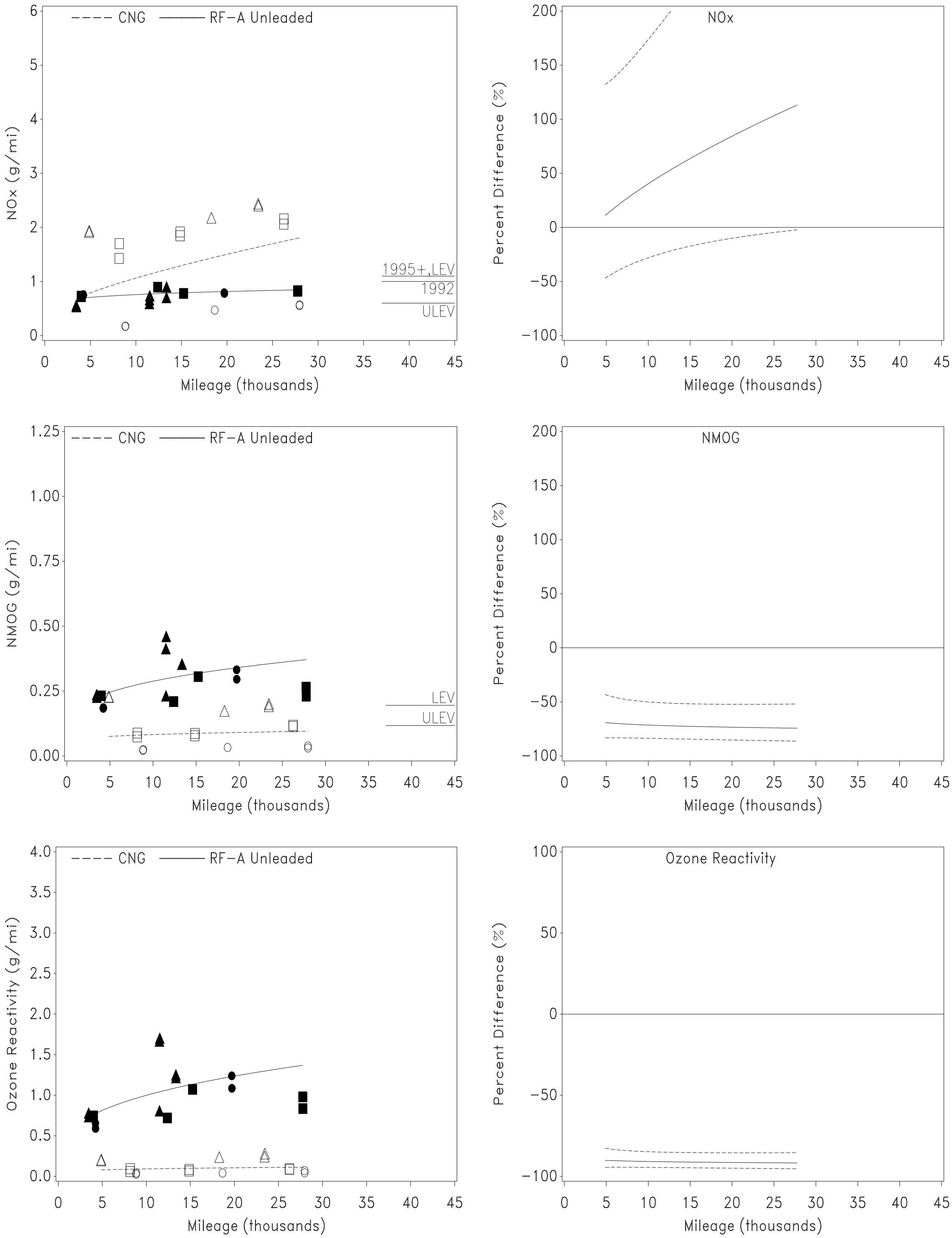

Figure 4a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Ford CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

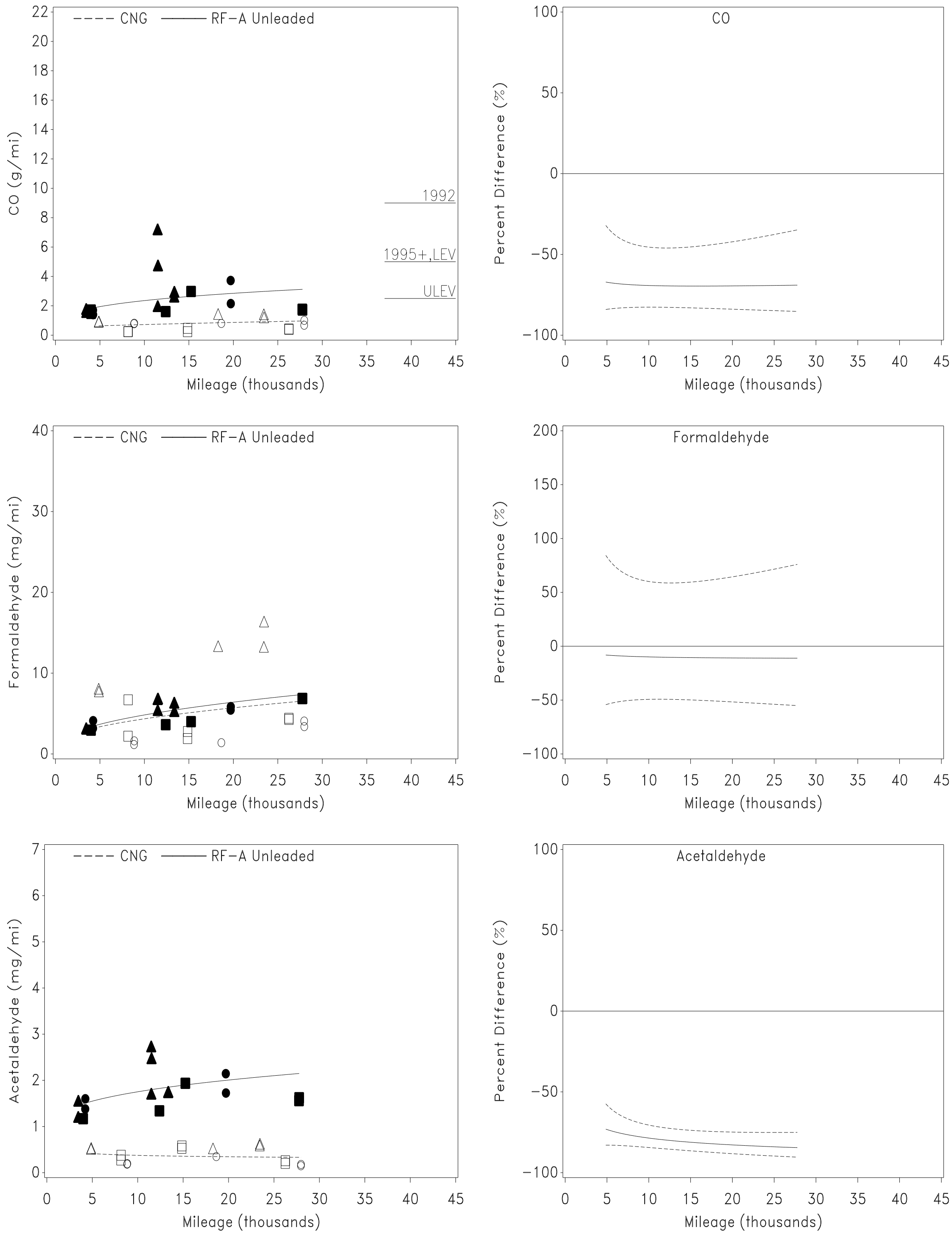

Figure 4b. **Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Ford CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds**

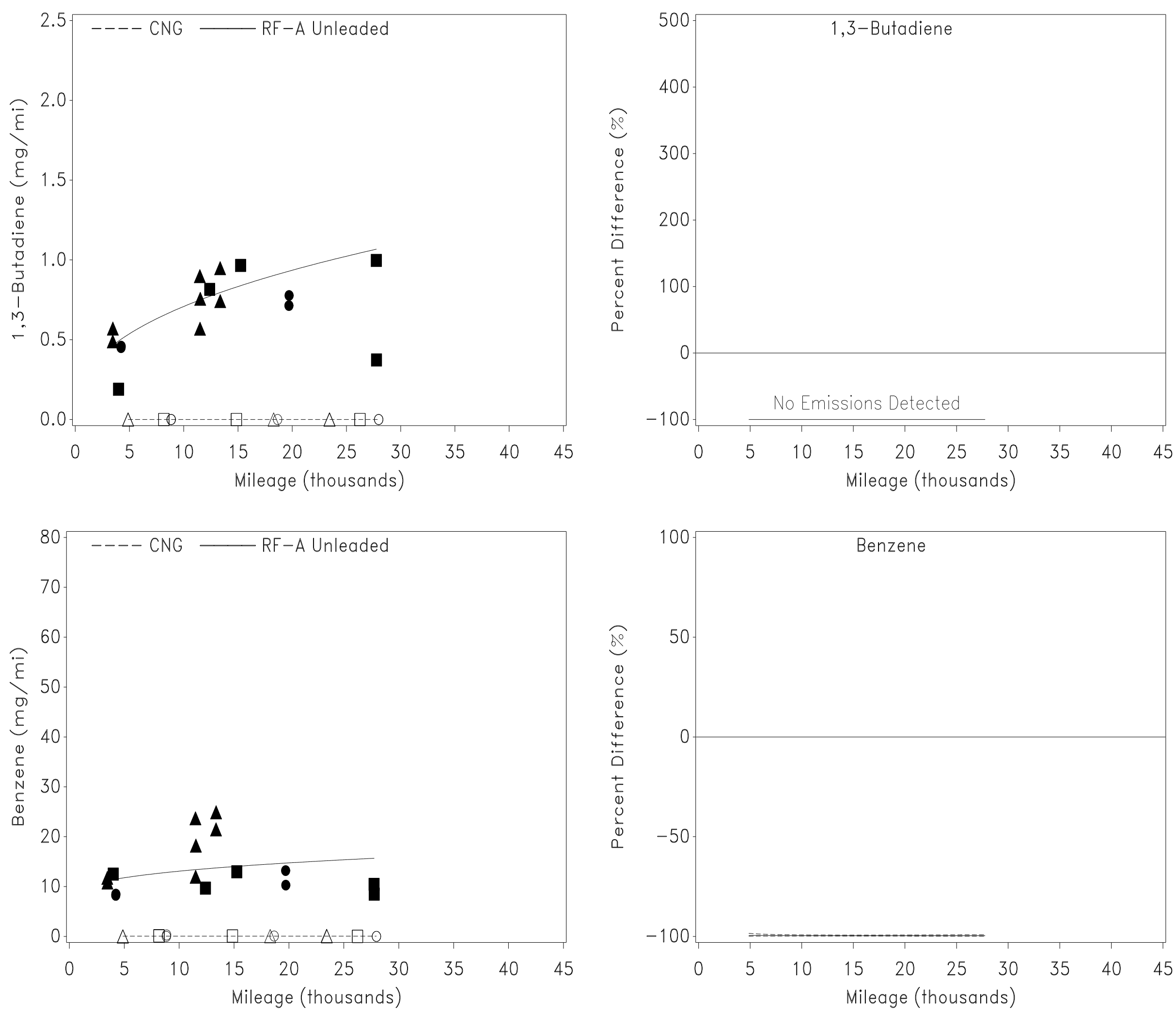

Figure 4c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Ford CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

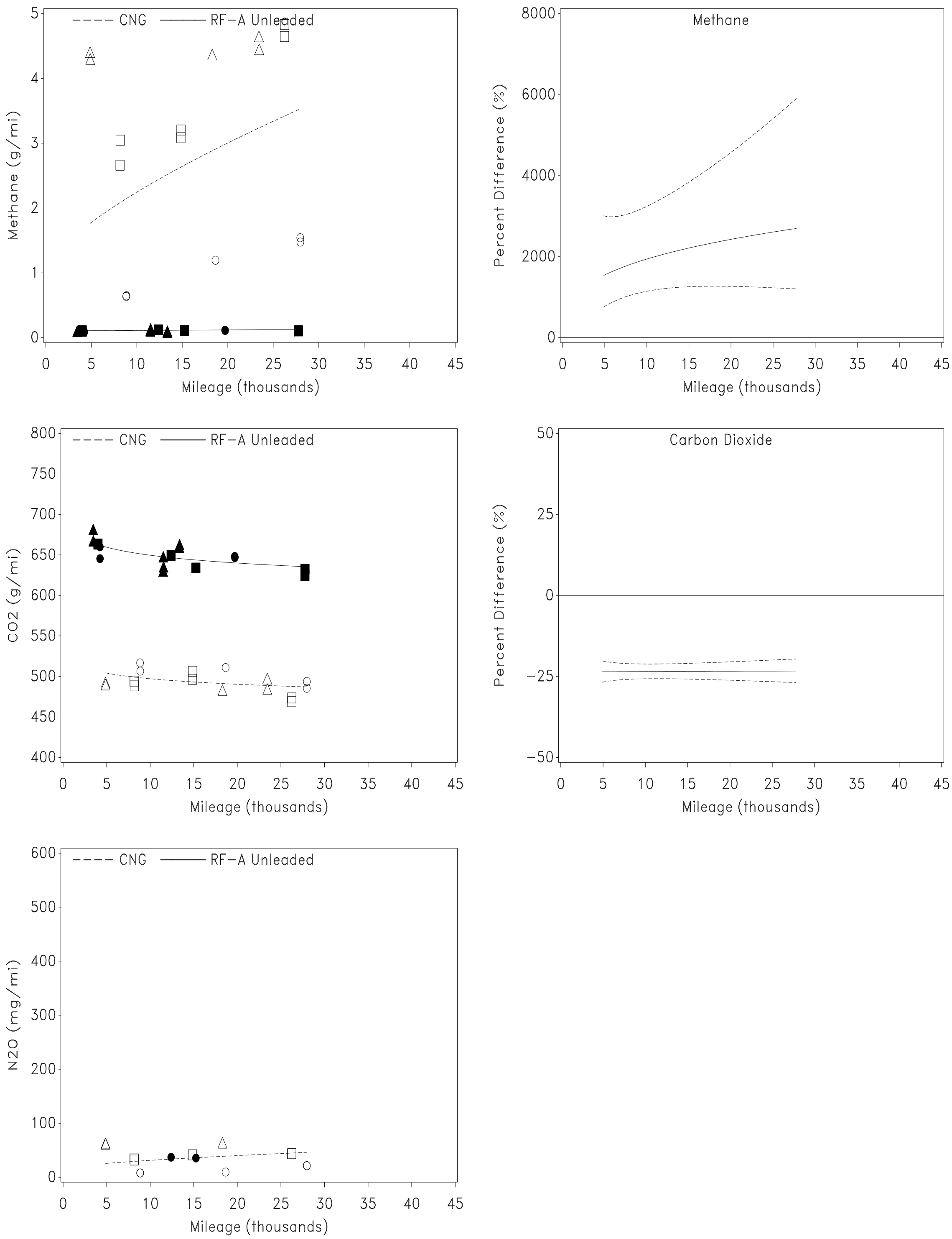

Figure 4d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Ford CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

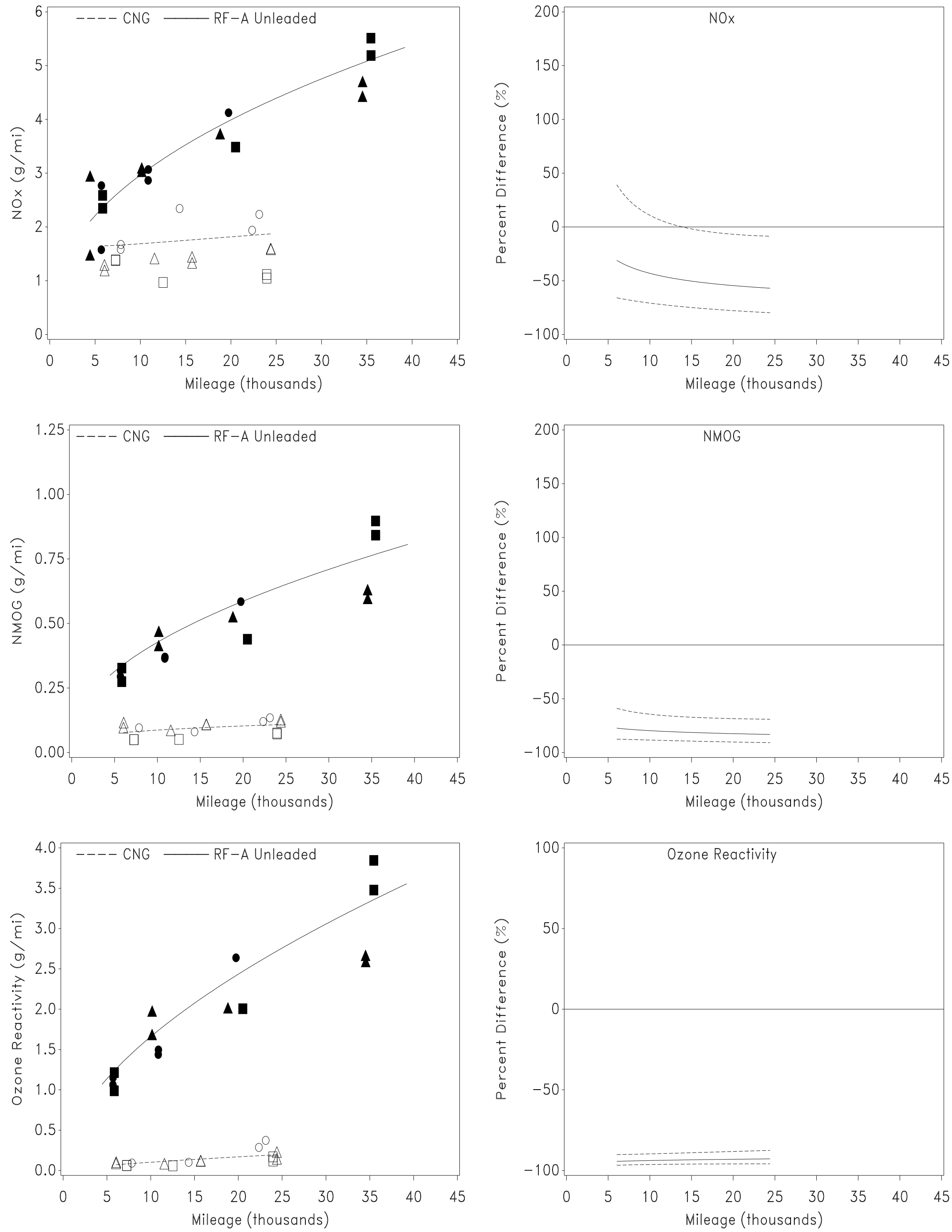

Figure 5a. **Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Chevrolet CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds**

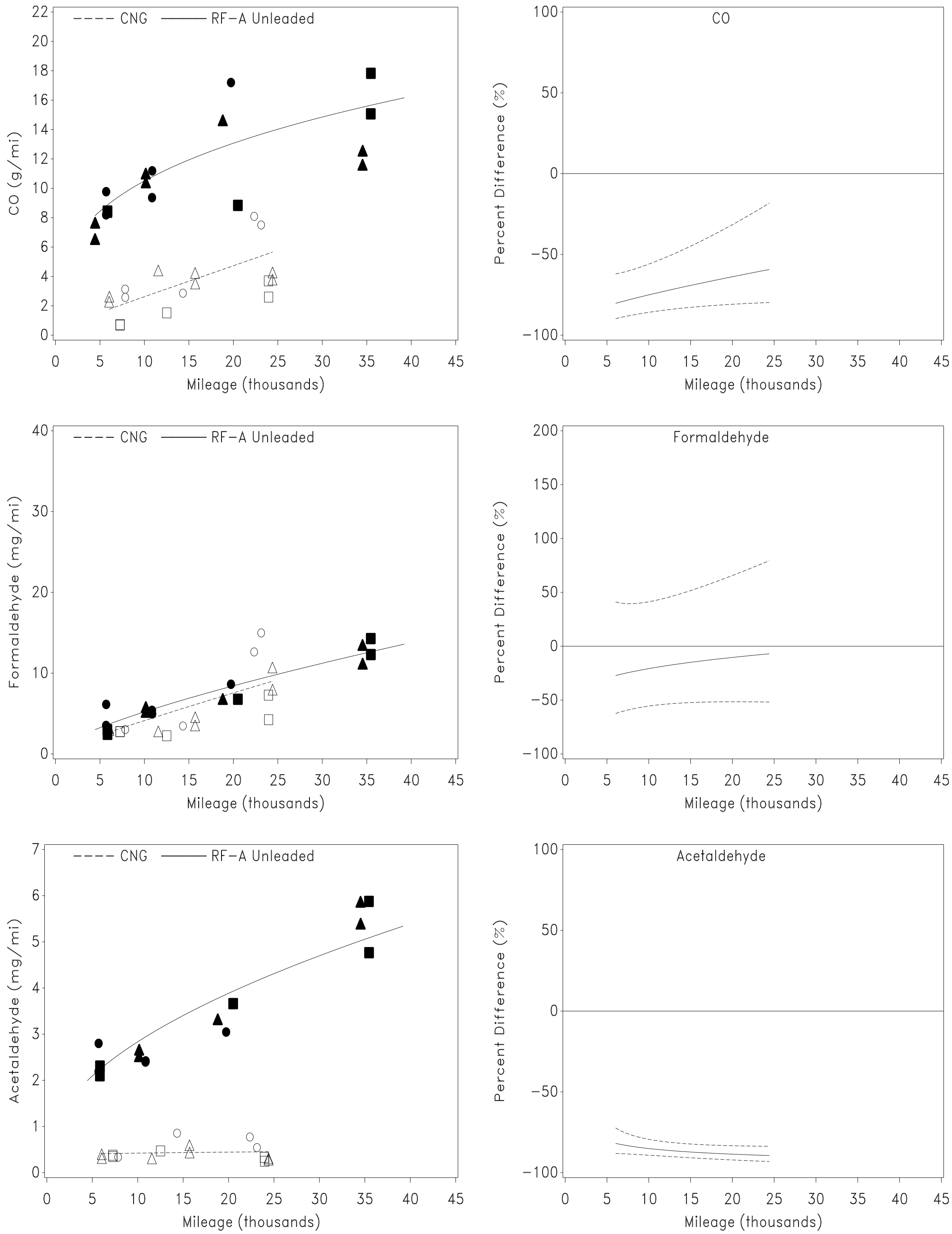

Figure 5b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Chevrolet CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

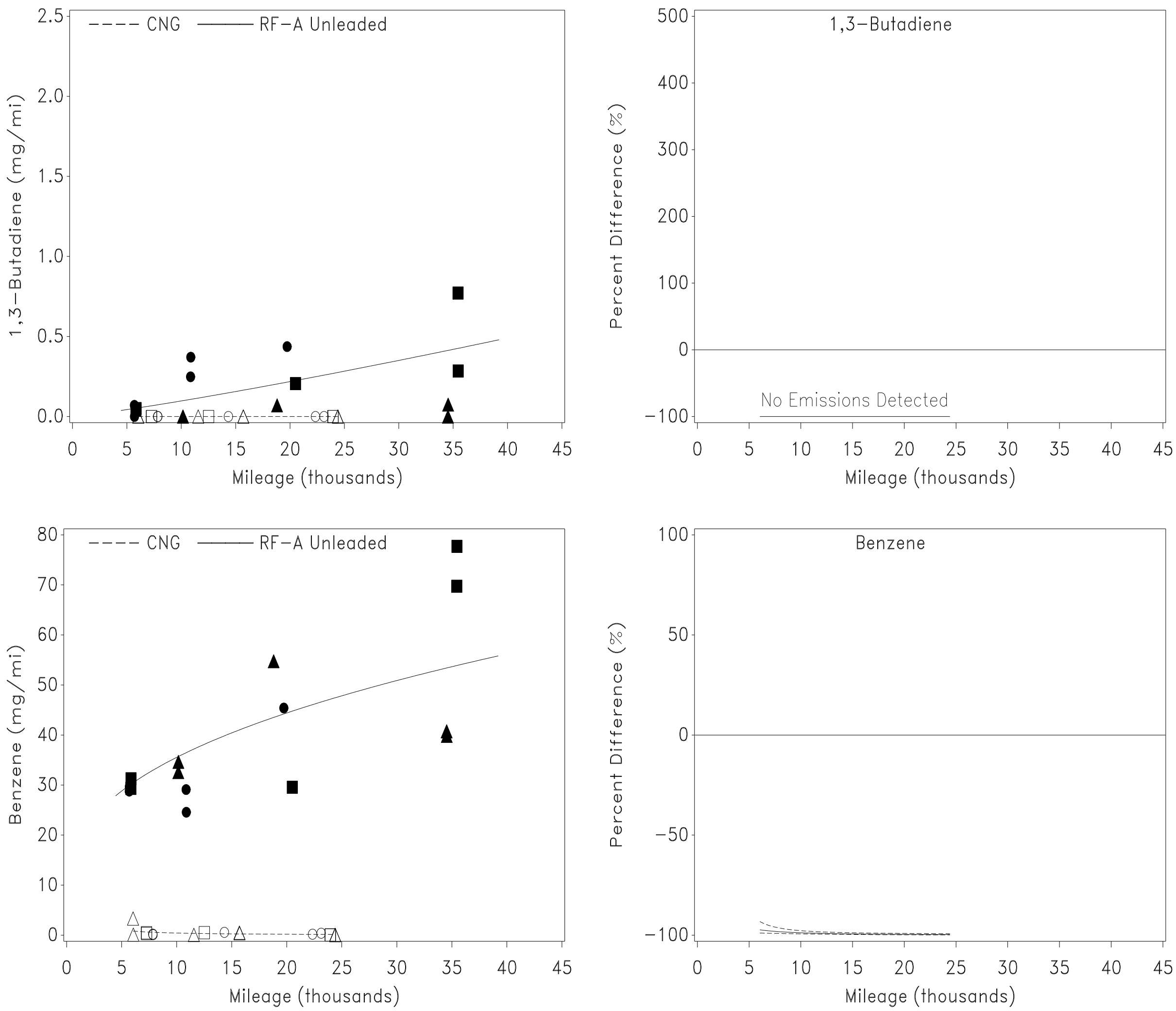

Figure 5c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Chevrolet CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

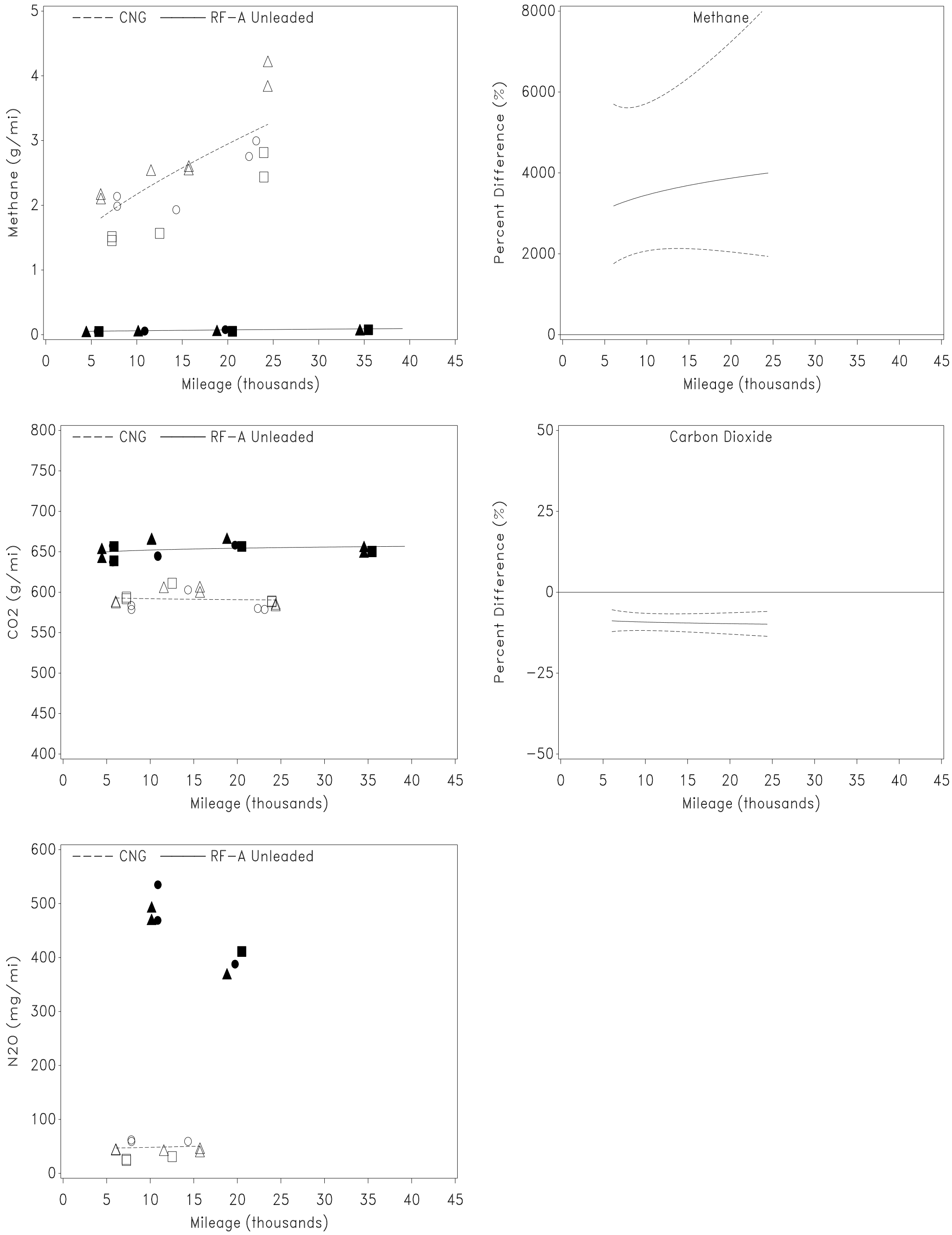

Figure 5d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Chevrolet CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

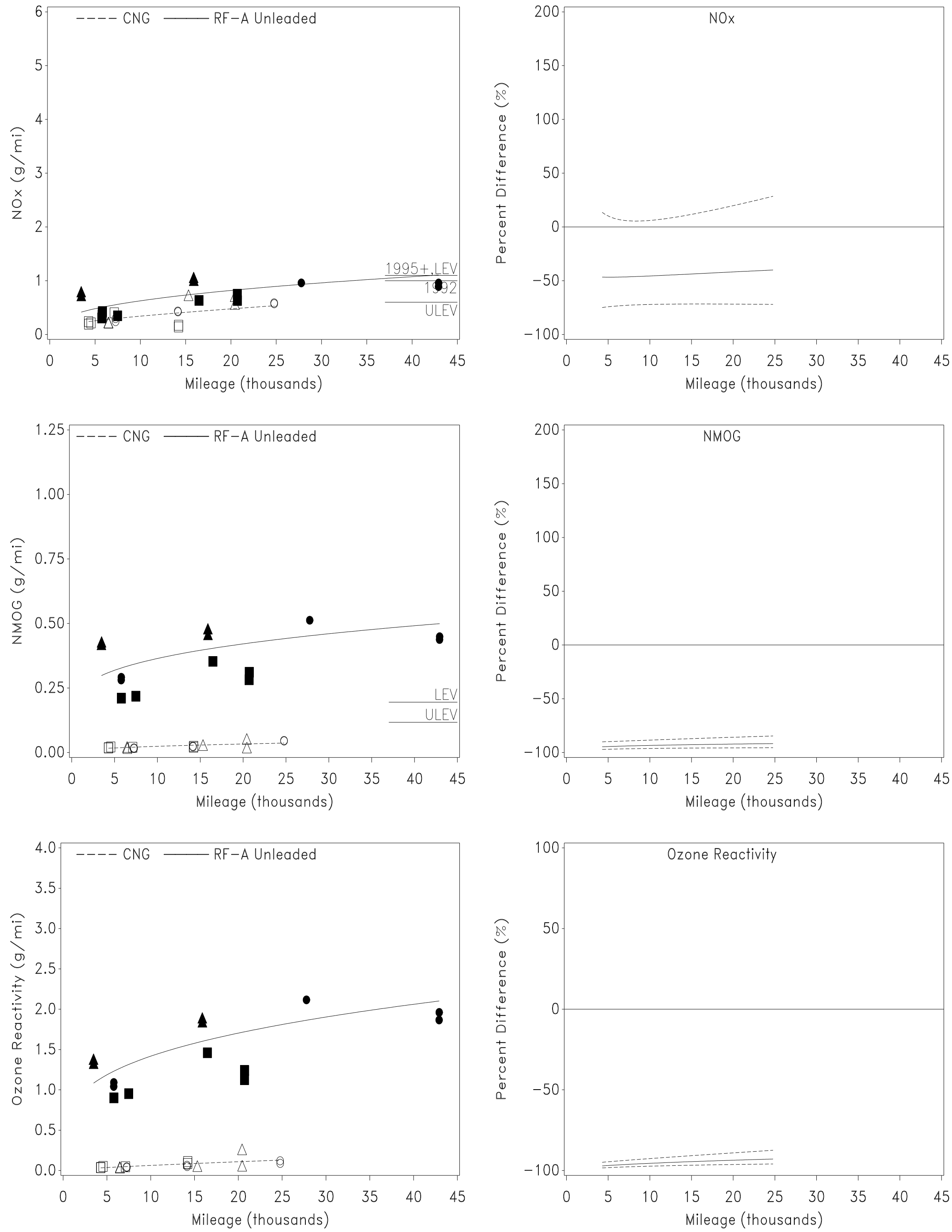

Figure 6a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Dodge CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

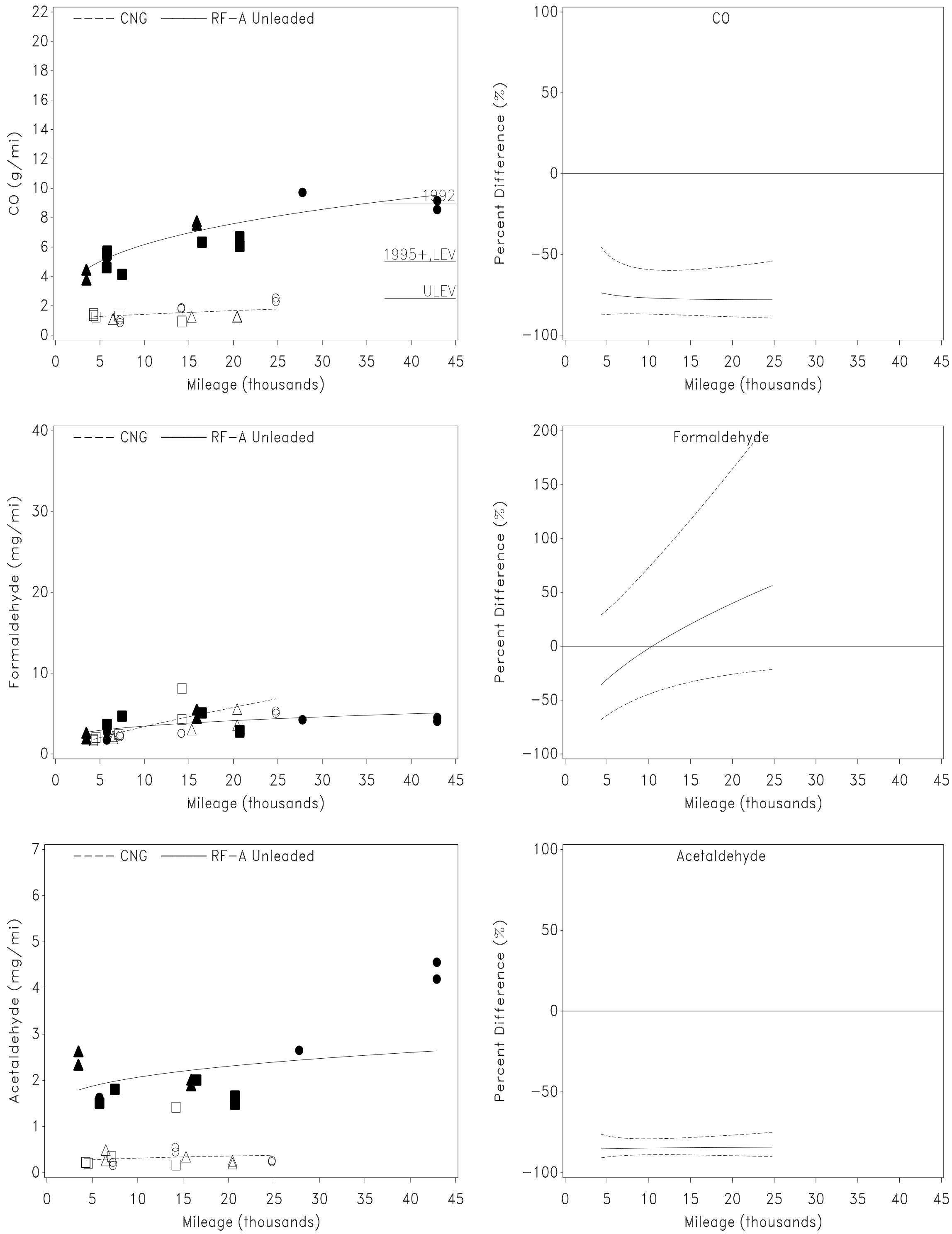

Figure 6b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Dodge CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

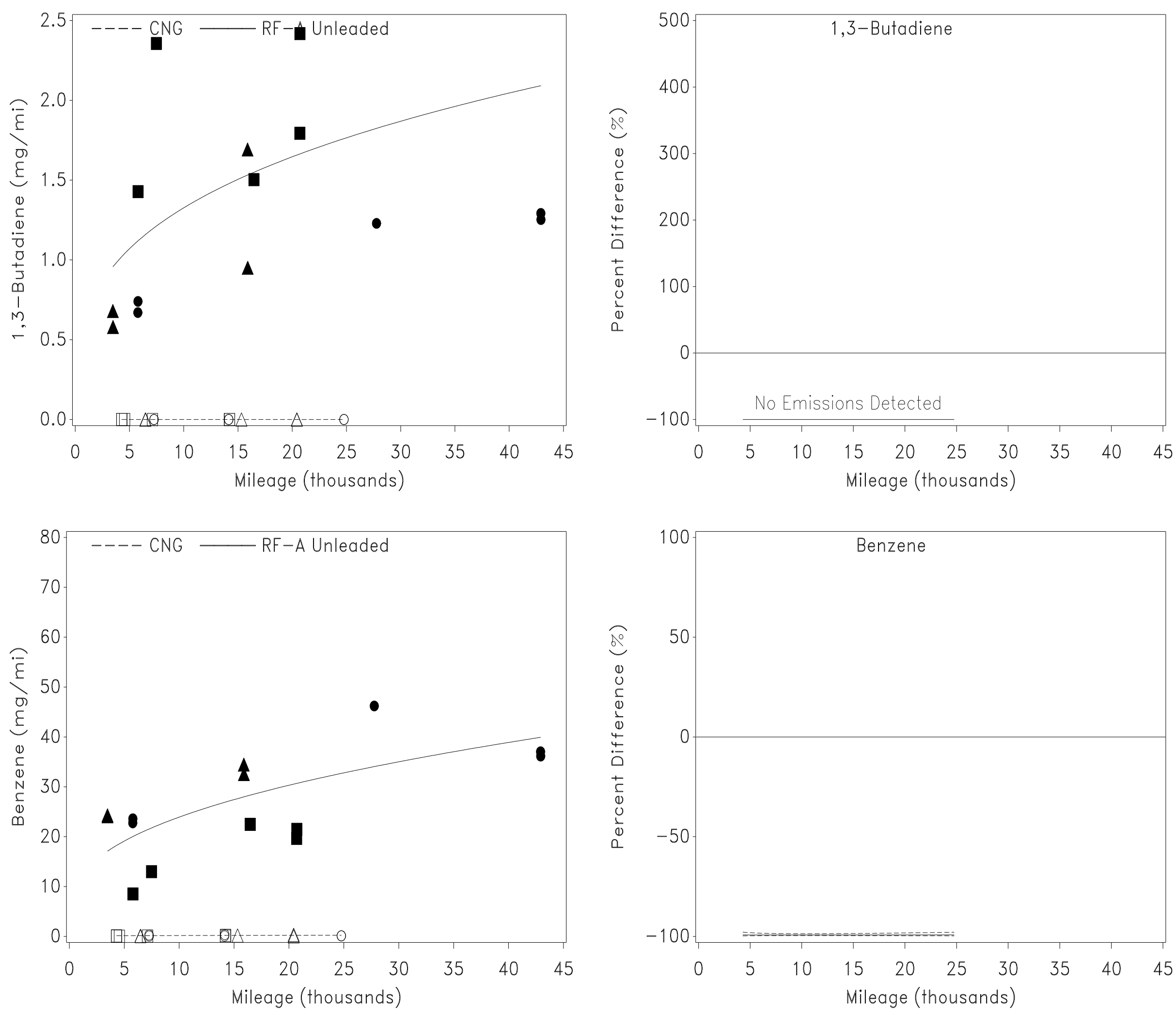

Figure 6c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Dodge CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

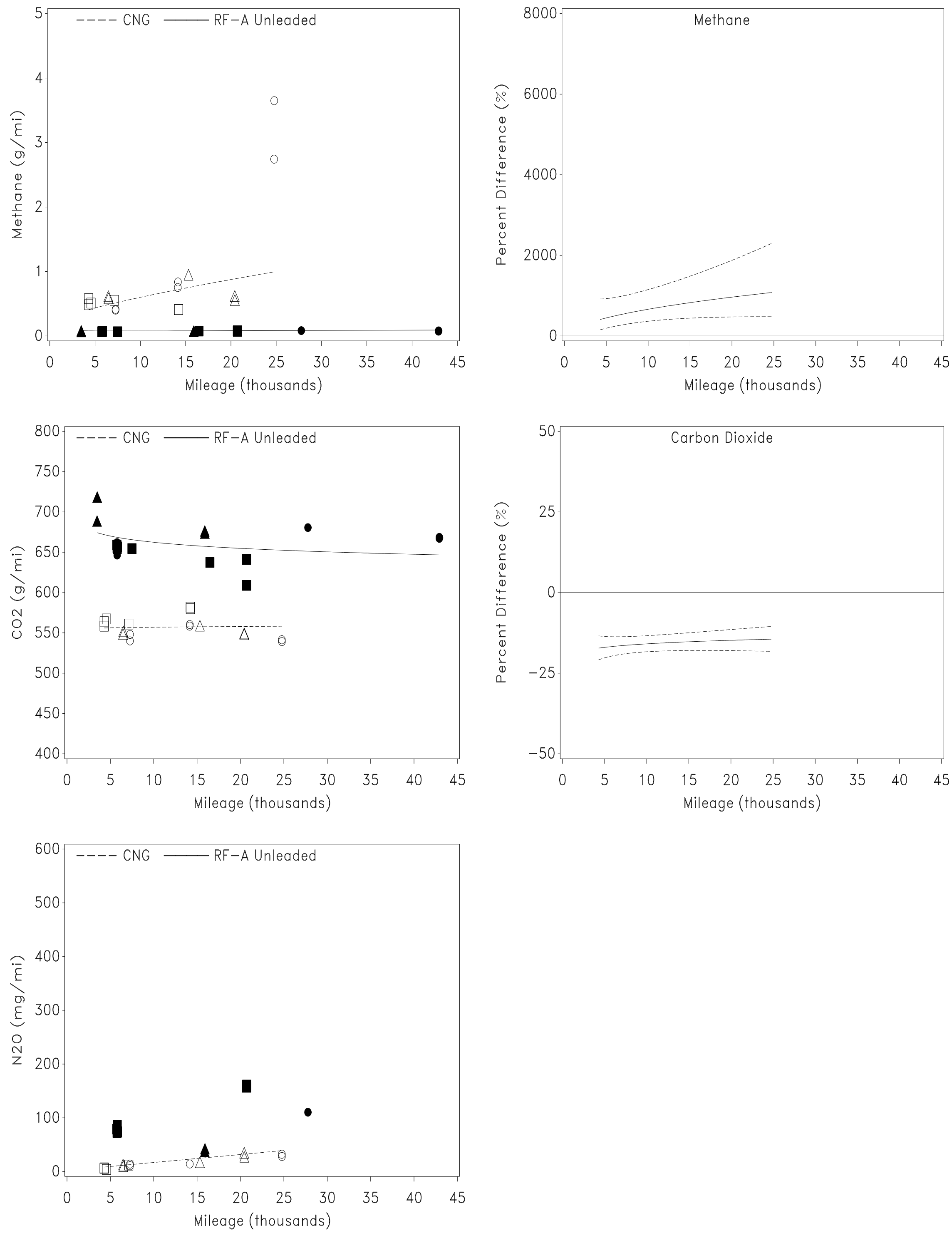

Figure 6d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Dodge CNG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

VEHICLE EMISSIONS

Propane Gas

Results for propane gas are presented in Figures 7 and 8. In Figure 7a, the mean ozone reactivity of propane gas exhaust from the Ford propane gas vans varied from 62 percent less than for RF-A exhaust at 5,000 miles to 71 percent less at 25,000 miles. Note that, even though the NMOG emissions were higher for propane gas vehicles than for their controls on a mass basis (the plot of NMOG), the calculated ozone reactivity was less. This is because the mass emissions of NMOG from propane gas had a significant fraction of unburned fuel as propane in the exhaust. NMOG mass emissions were comprised of 86 percent propane at 5,000 miles dropping to 83 percent propane at 25,000 miles. Propane is relatively unreactive photochemically in the atmosphere, and therefore the NMOG emissions had a lower ozone reactivity than the emissions from the control vans on RF-A gasoline.

The measured emissions of NO_x, NMOG, and CO in Figures 7a and 7b all show a relatively constant level with mileage. Note one extremely high value for CO emissions at about 20,000 miles. This test was performed within days of work on the ADP fuel system to correct problems the system was experiencing in receiving a signal from the engine. It is not known if this maintenance work contributed to the high CO emissions.

The mean relative emissions of CO, NO_x, and NMOG in Figure 7 all show a downward trend with mileage. That is, the emission levels for propane gas vans became increasingly smaller than from the control vans. This trend reflects near constancy of emission levels for propane gas over mileage, while the control vans on gasoline exhibited degradation of emissions as mileage increased. The extent of variability in the data is evident from the width of the 95-percent confidence intervals.

Relative emission levels of air toxics and greenhouse gases did not show much variation with mileage compared to the exhaust from the control vans. Levels of acetaldehyde, benzene, and 1,3-butadiene were significantly less in exhaust from propane gas than in exhaust from the control vans. The level of formaldehyde in propane gas exhaust varied from about 55 percent less at 5,000 miles to 45 percent less at 25,000 miles compared to RF-A gasoline exhaust, but variability in the data precludes establishing a difference in mean emissions with 95 percent statistical confidence. Note that the scale for the plot of percent difference for methane extends from -100 to 300 percent, a change from the scale for CNG vehicles of -100 to 8,000 percent in Figures 4d, 5d, and 6d. The scale to 300 percent is used for propane gas, RFG, and M-85. Nitrous oxide emissions were measured over a small mileage interval and were highly variable.

Results for the Chevrolet propane gas vans are presented in Figure 8. NMOG mass emissions were higher than for gasoline. Propane comprised about 83 percent of the NMOG mass. Note the large spread in measured emissions of NMOG at about 25,000 miles from one propane gas van. Although the NMOG emissions from propane gas were higher than from gasoline, the ozone reactivity was less, averaging about 58 percent less at 5,000 miles and 76 percent less at 25,000 miles.

Carbon monoxide levels ranged from 49 to 58 percent less than for gasoline over mileage. Note the high exhaust level of CO at about 13,000 miles for one propane gas van.

Emission levels of the air toxics from propane gas vans were about constant over mileage or exhibited decreasing trends. In contrast to the constancy of the emission levels plotted in units of g/mi, the relative difference in emissions of the air toxics formaldehyde and acetaldehyde shows a downward trend with increasing mileage. This trend is the result of increasing emission levels of these two compounds in the exhaust of the control vans. A similar result exists for 1,3-butadiene and benzene, but it is not apparent in the plots due to the low levels of these compounds in propane gas exhaust and the scale of the plots.

Emission levels of the two greenhouse gases methane and carbon dioxide were constant over mileage. The large uncertainty band for relative methane emissions and the tight uncertainty band for relative emissions of carbon dioxide reflect two factors: the small differences in emission levels for each of these compounds compared to their controls, combined with low levels for methane and high levels for carbon dioxide with respect to measurement capabilities. Relative differences in emission levels of nitrous oxide are not plotted because of the limited data set for the control vans.

It is important to remember that the Chevrolet vans were equipped with heavy-duty engines that had been certified originally to heavy-duty exhaust emission standards. As for the Chevrolet CNG vans, the AFE fuel system components were replaced in September 1993 in an attempt to correct operational problems. The AFE components were replaced at 14,000 to 16,000 miles (see Table C-3). No significant change in emissions was found as a result.

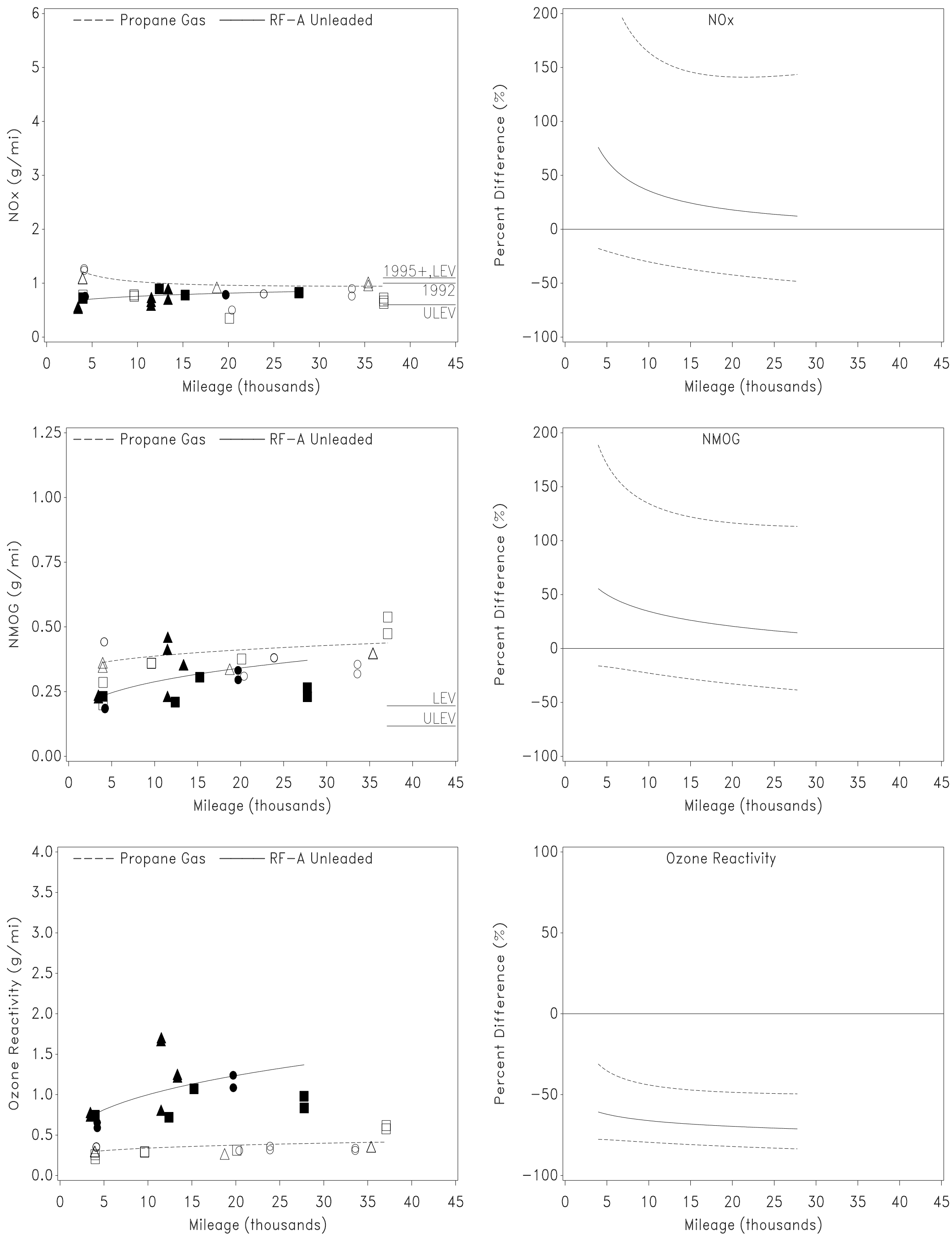

Figure 7a. **Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Ford Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds**

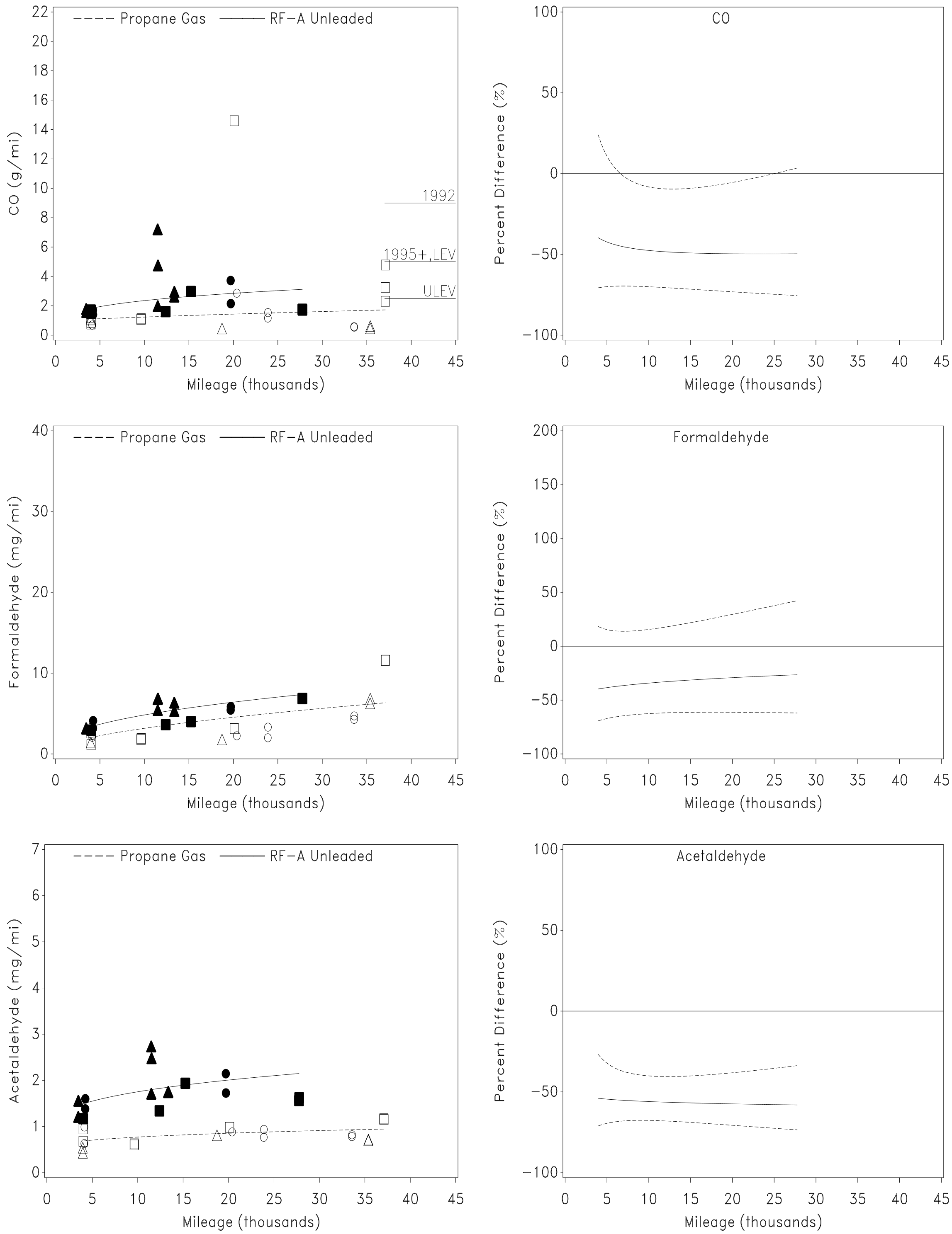

Figure 7b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Ford Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

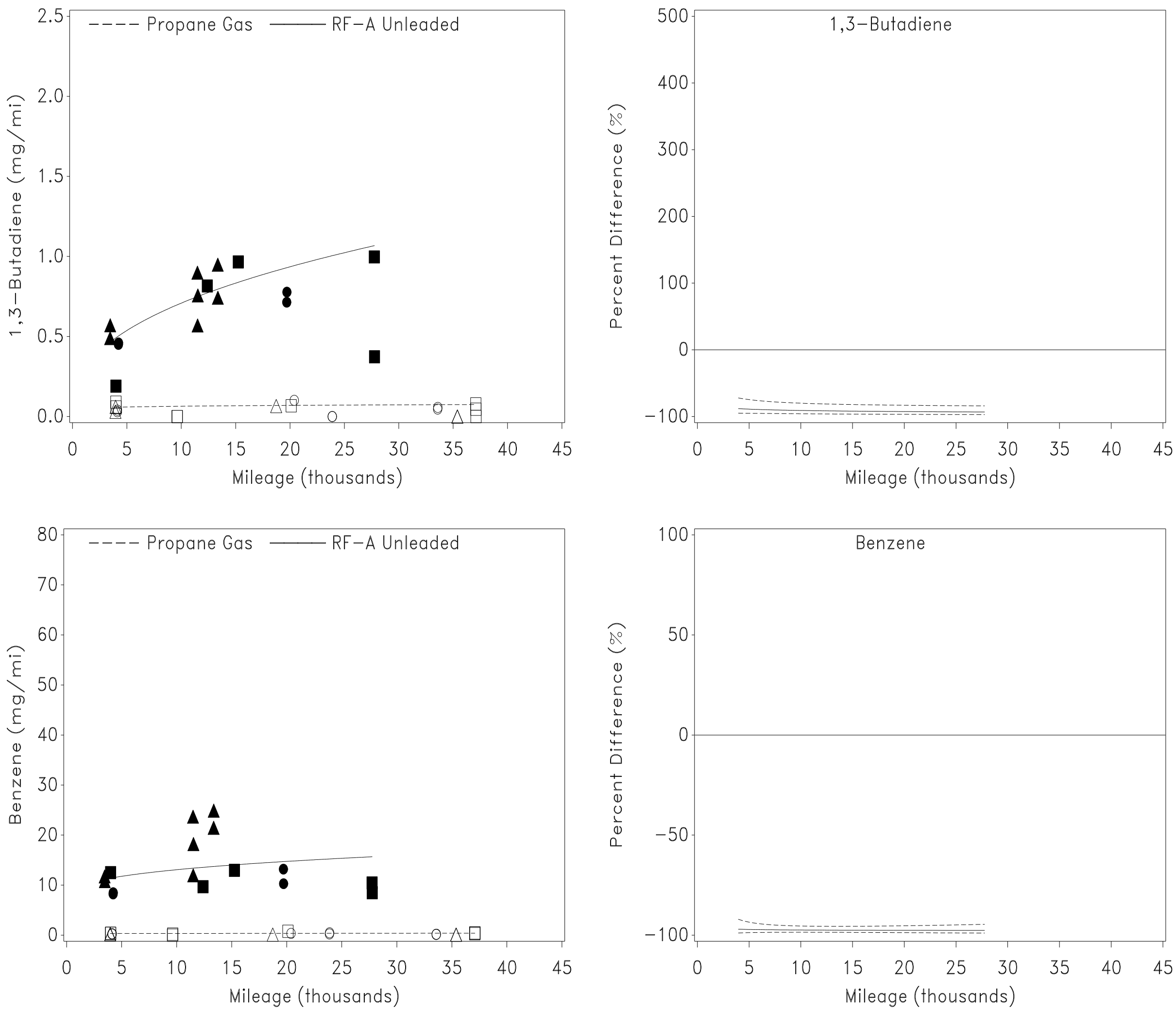

Figure 7c. **Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Ford Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds**

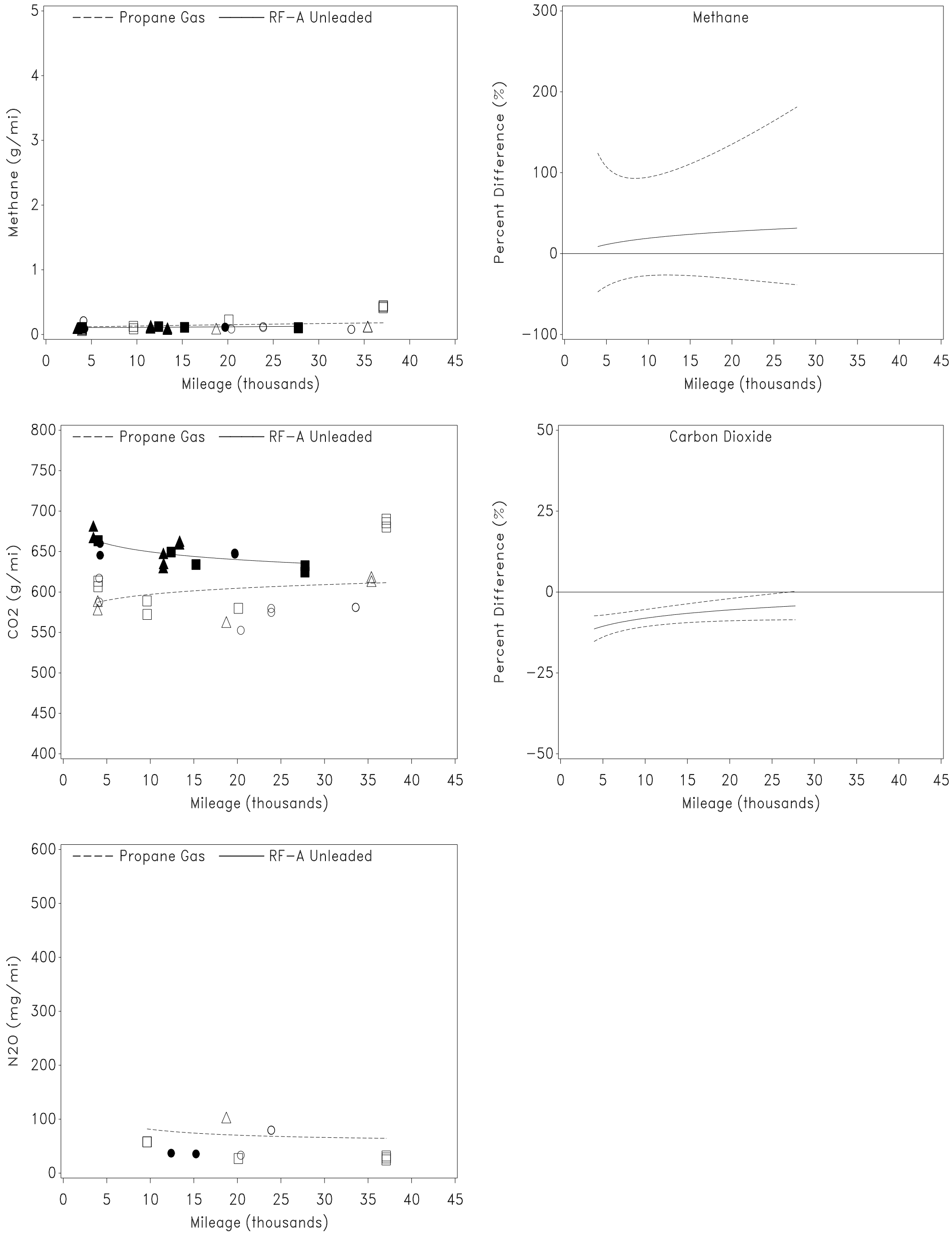

Figure 7d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Ford Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

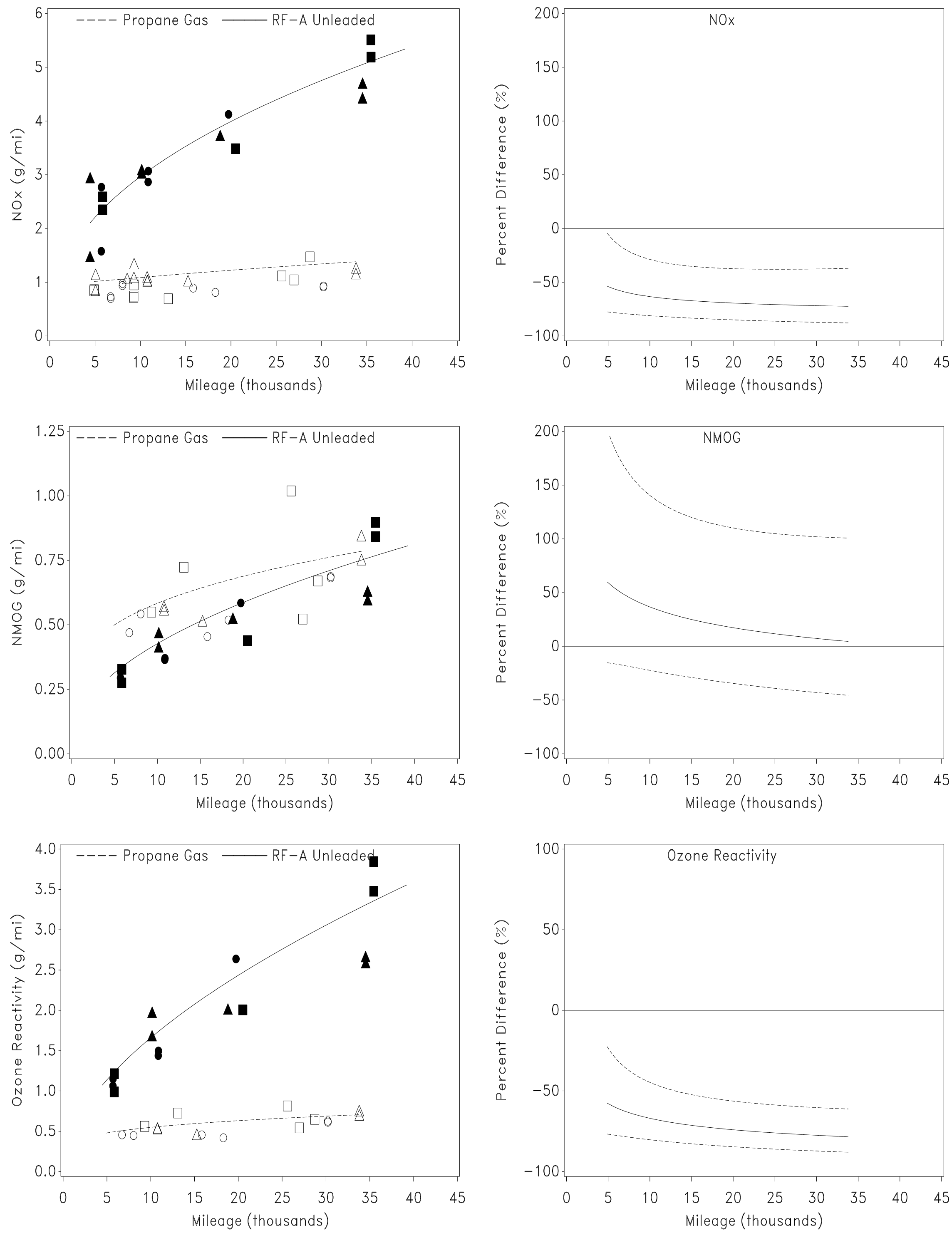

Figure 8a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Chevrolet Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

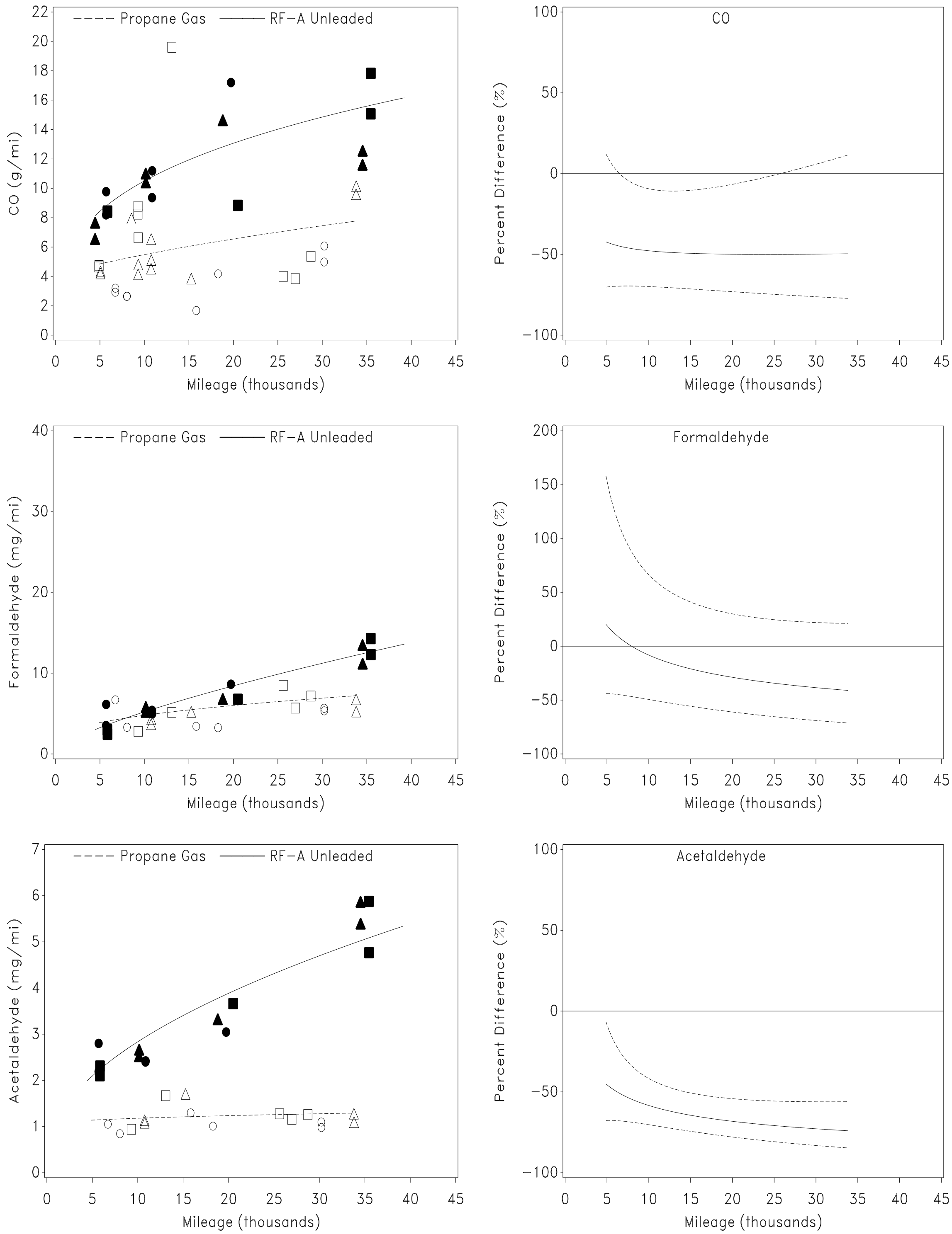

Figure 8b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Chevrolet Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

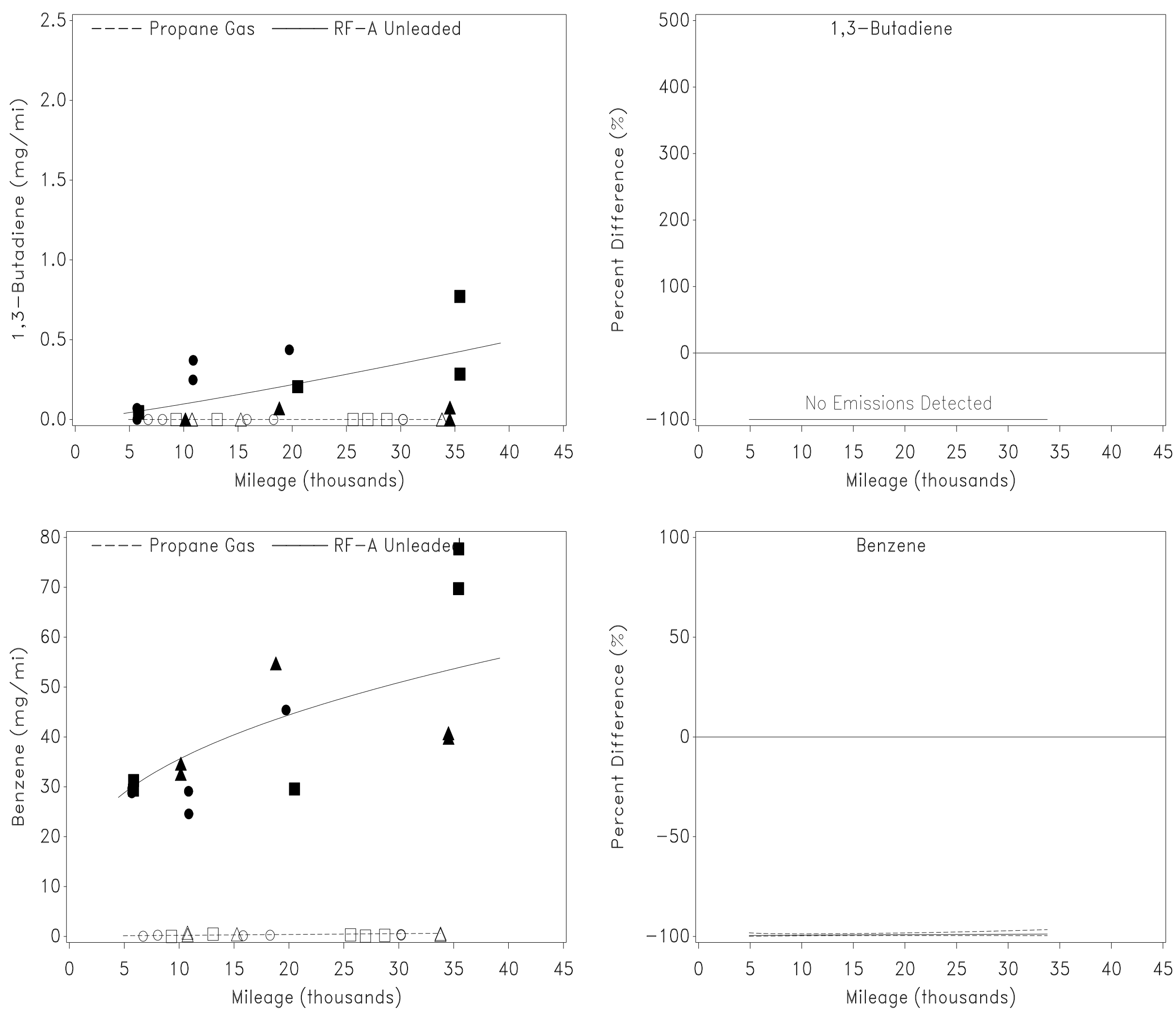

Figure 8c. **Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Chevrolet Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds**

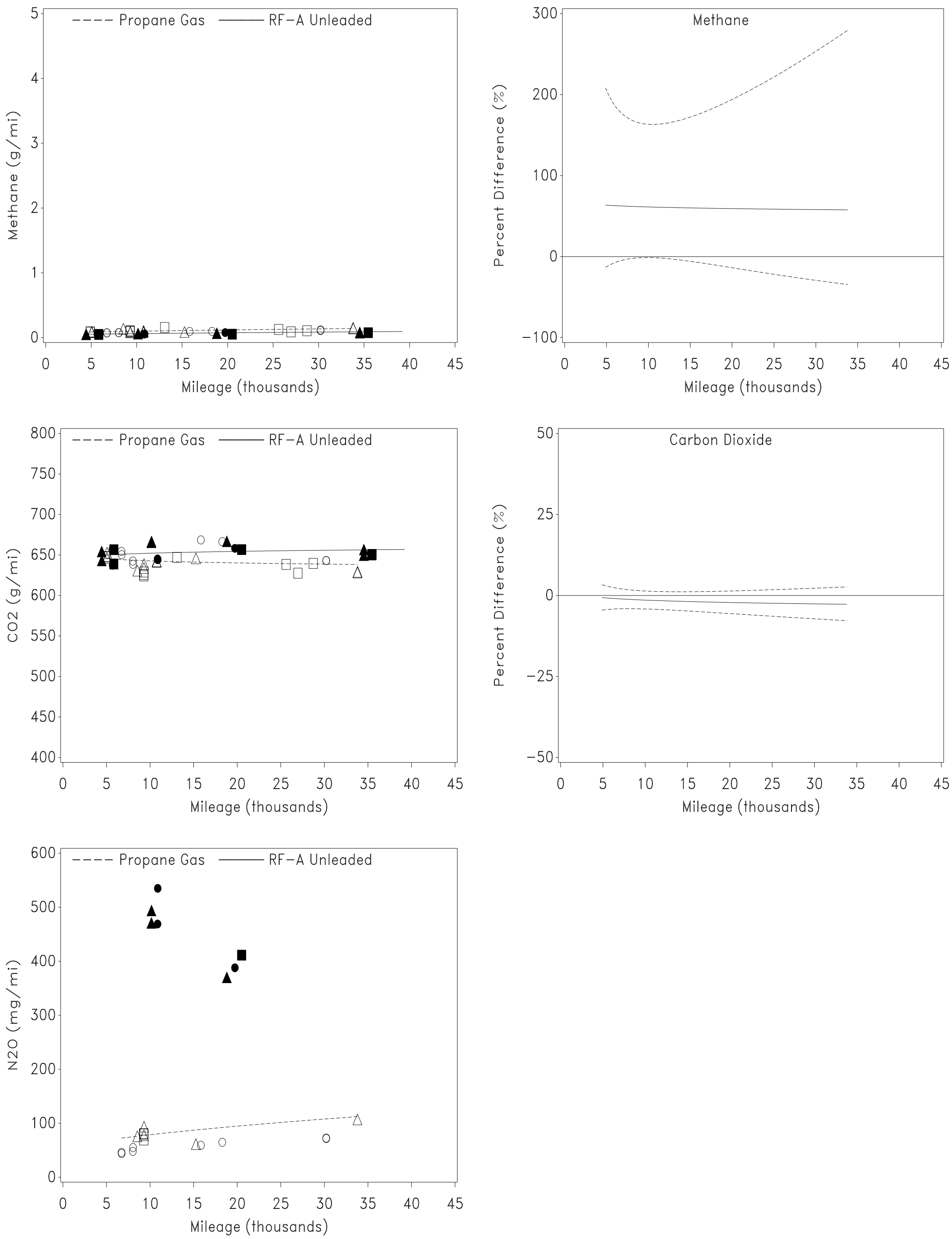

Figure 8d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Chevrolet Propane Gas and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

VEHICLE EMISSIONS

Phase 2 RFG

Results for RFG are presented in Figures 9 through 11. The confidence bounds shown in these plot are generally larger than for CNG and propane gas. This reflects the combined variability of both the RFG and RF-A control gasoline exhaust results. Uncertainty in the mean value was generally higher for the gasoline vans than for the CNG or propane gas vans. Modest reductions in emissions of ozone precursors (NO_x and NMOG) were measured.

The average ozone reactivity of the Ford RFG exhaust was about 13 percent less than that of the control gasoline at 5,000 miles and about 19 percent less at 25,000 miles. Measured emissions of CO deteriorated, rising from about 15 percent less than for control gasoline at 5,000 miles to about 7 percent more at about 25,000 miles; however, because of variability in the data it cannot be stated with 95-percent confidence that the mean emission levels of CO from the RFG vans were different than from the control vans. This uncertainty applies to all emissions in Figure 9a. Formaldehyde emission levels were about the same for the RFG and control vans. Benzene emission levels from the Ford RFG vans ranged from 44 to 39 percent less than from their controls from 5,000 to 25,000 miles. Levels of greenhouse gas emissions were about the same as from control gasoline.

Exhaust from Chevrolet RFG vans (Figure 10) and control vans reflects the two fuels and the heavy-duty engines. Note that the CO emission levels were higher than from the medium-duty Ford and Dodge vans (Figures 9b and 11b). Formaldehyde emission levels were higher than for the control vans; benzene levels were lower than for the control gasoline (Figure 10c). Emissions of 1,3-butadiene were higher but with considerable variability in results. Acetaldehyde levels were generally less in RFG exhaust than in RF-A exhaust. The relative emission levels of these air toxics deteriorated with mileage compared to levels for control vans.

Exhaust levels of methane and carbon dioxide were about the same as for the control gasoline vans. The emission levels of nitrous oxide from the heavy-duty Chevrolet engines running on RFG and RF-A were substantially higher than from the medium-duty Ford and Dodge vans (Figures 9d and 11d).

The Dodge RFG emissions were measured over a larger mileage range than the Ford and Chevrolet RFG emissions. Mean emission levels of CO and NMOG from the RFG vans were less than from the control vans, although mean emission levels from the RFG vans appeared to be deteriorating somewhat faster with mileage. The limited range of mileage over which the Dodge RFG emissions were tested did not permit a comparison of emission levels with control vans at higher mileage. Carbon monoxide was 34 percent lower at 5,000 miles and essentially equivalent at 25,000 miles. Ozone reactivity was 45 percent less than for the exhaust from RF-A gasoline at 5,000 miles and 19 percent less at 25,000 miles. Formaldehyde levels were higher than for the control vans and increased with mileage. Levels of acetaldehyde and benzene were lower than for control gasoline. Levels of methane and carbon dioxide were about the same as for the control gasoline.

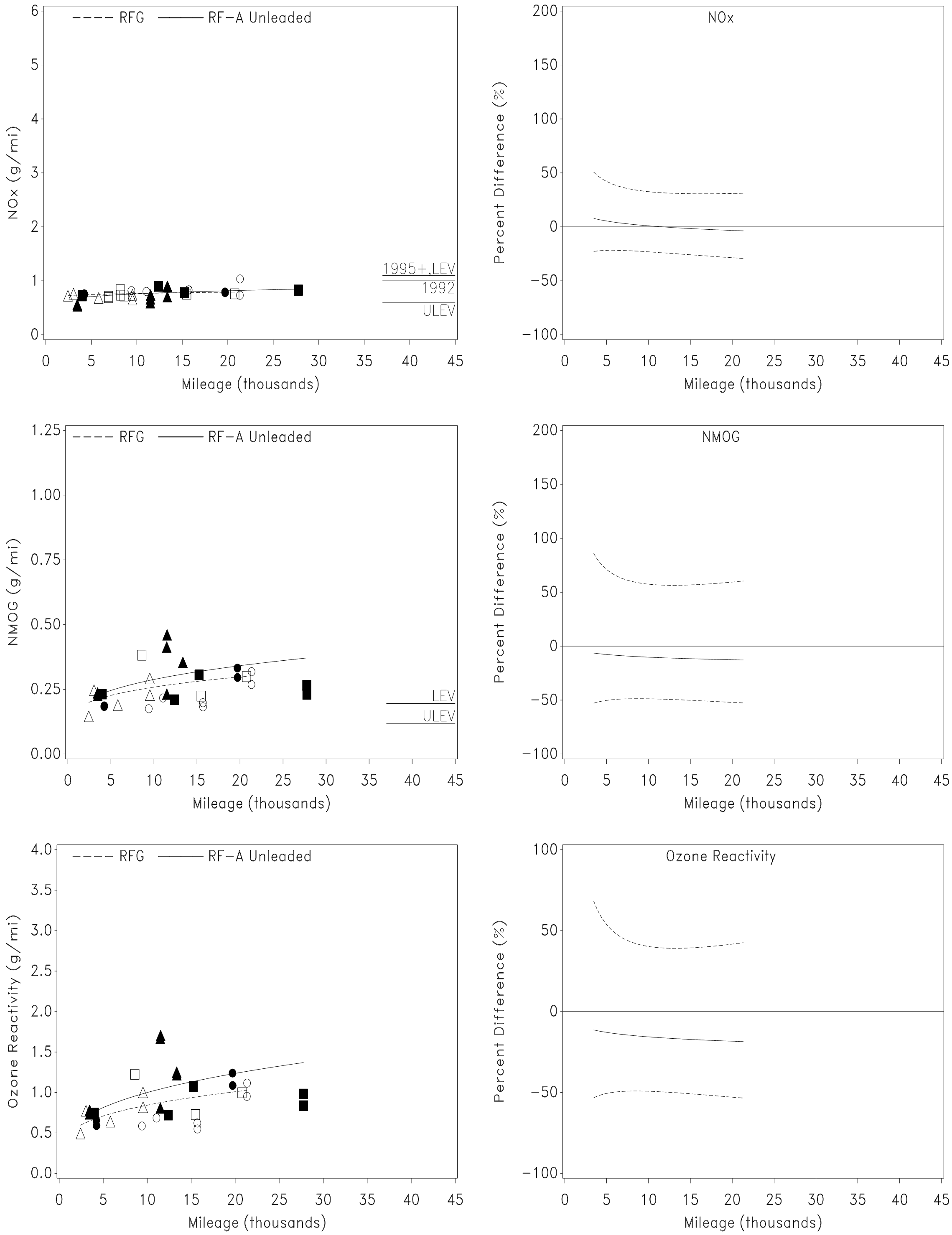

Figure 9a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Ford RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

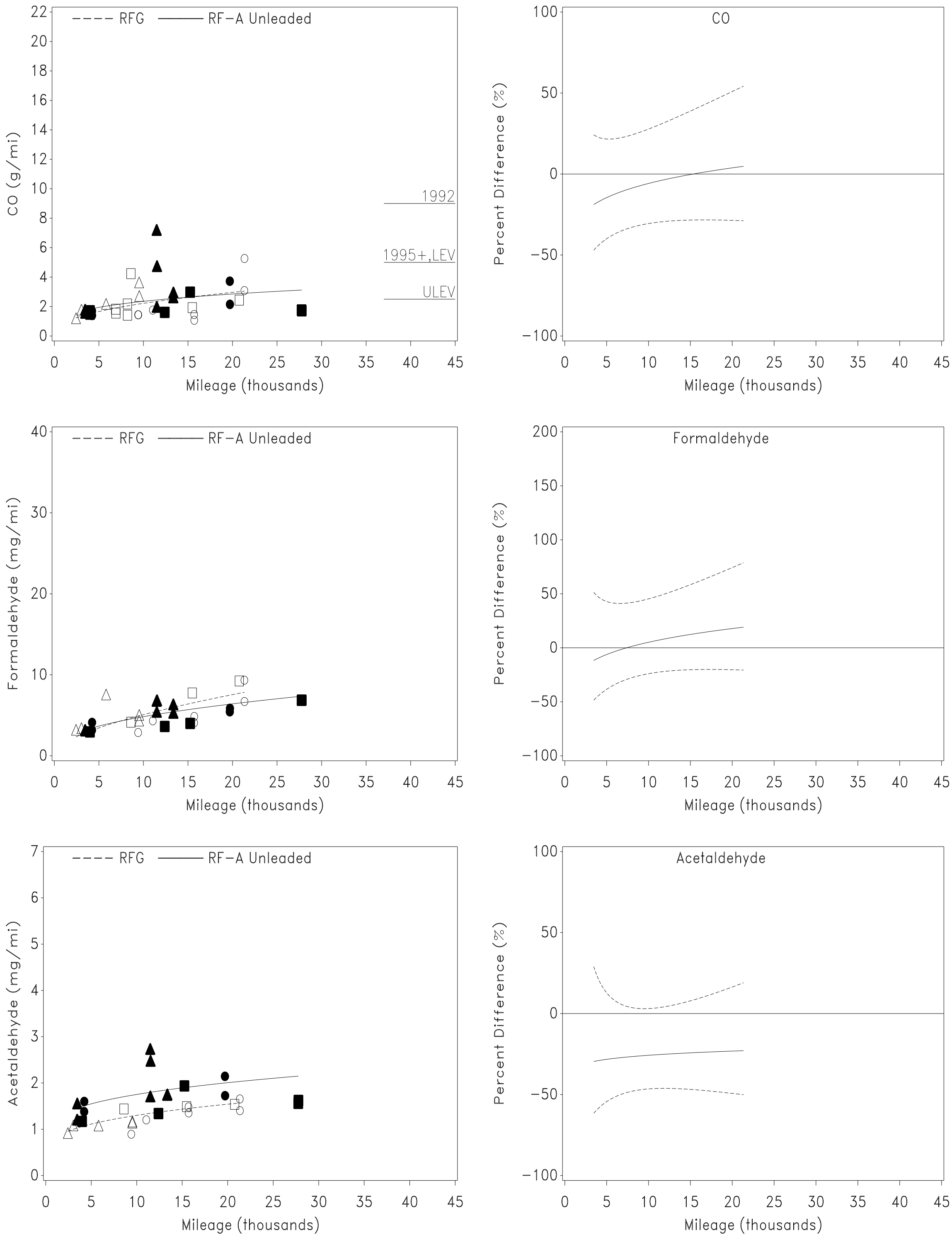

Figure 9b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Ford RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

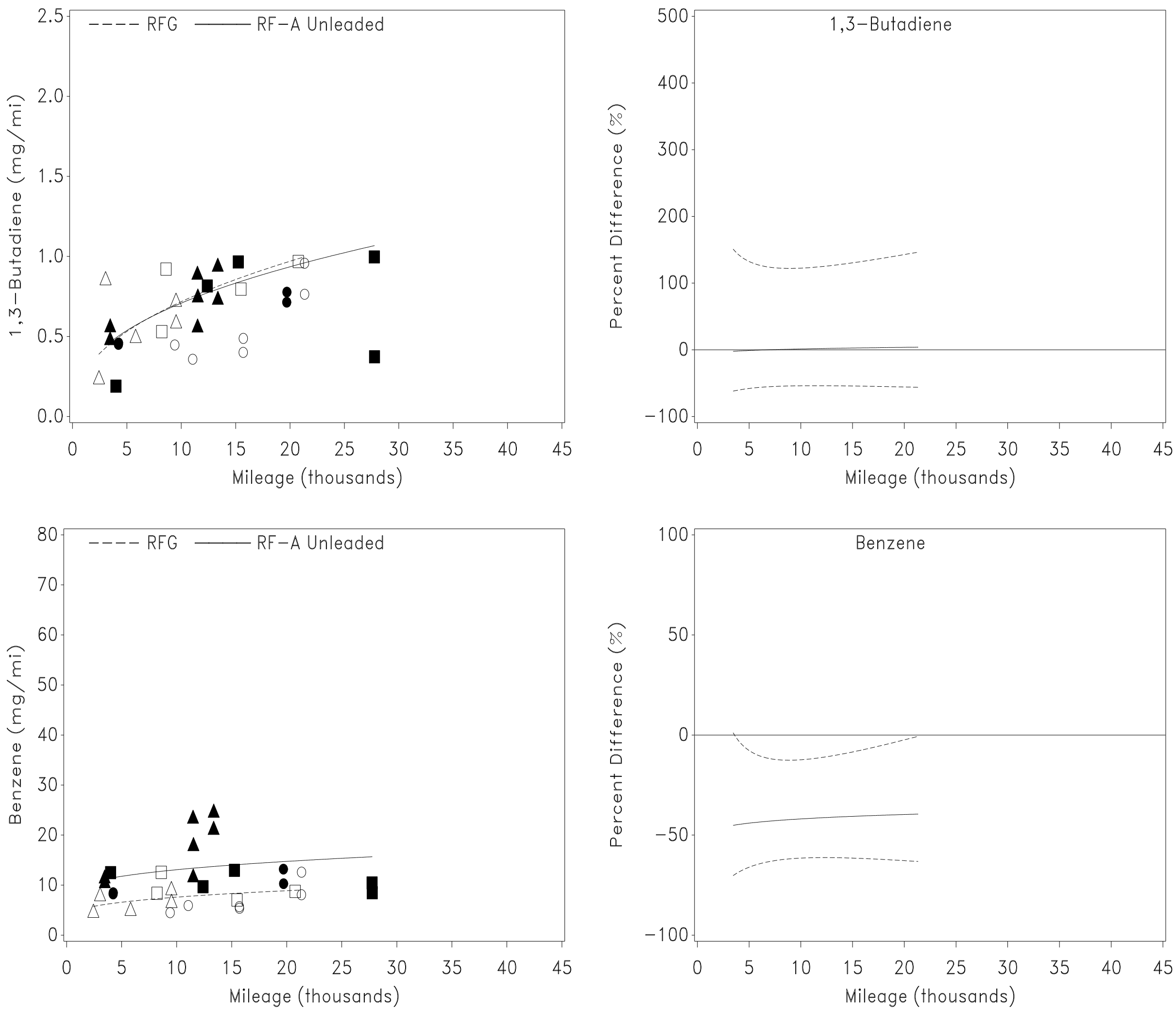

Figure 9c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Ford RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

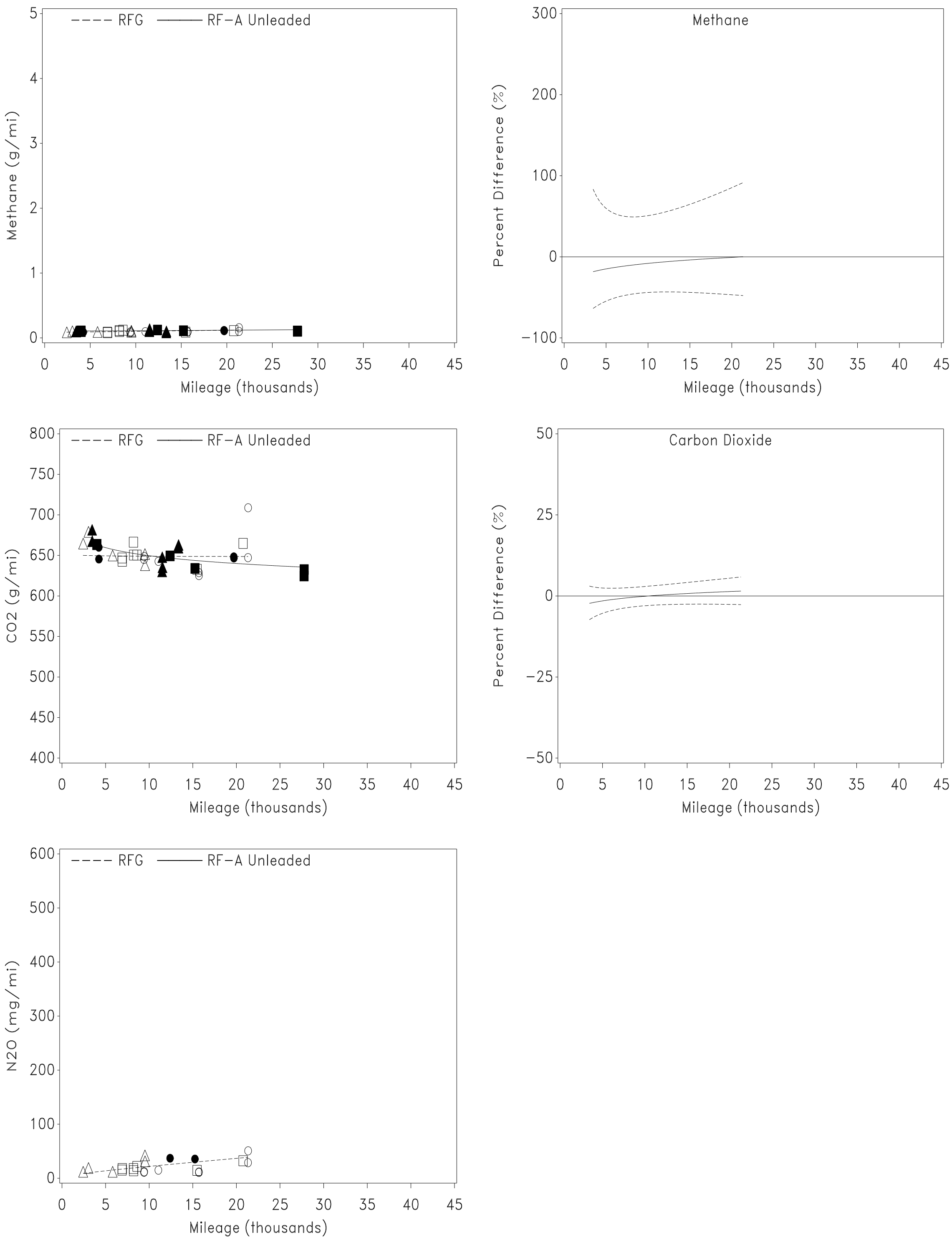

Figure 9d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Ford RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

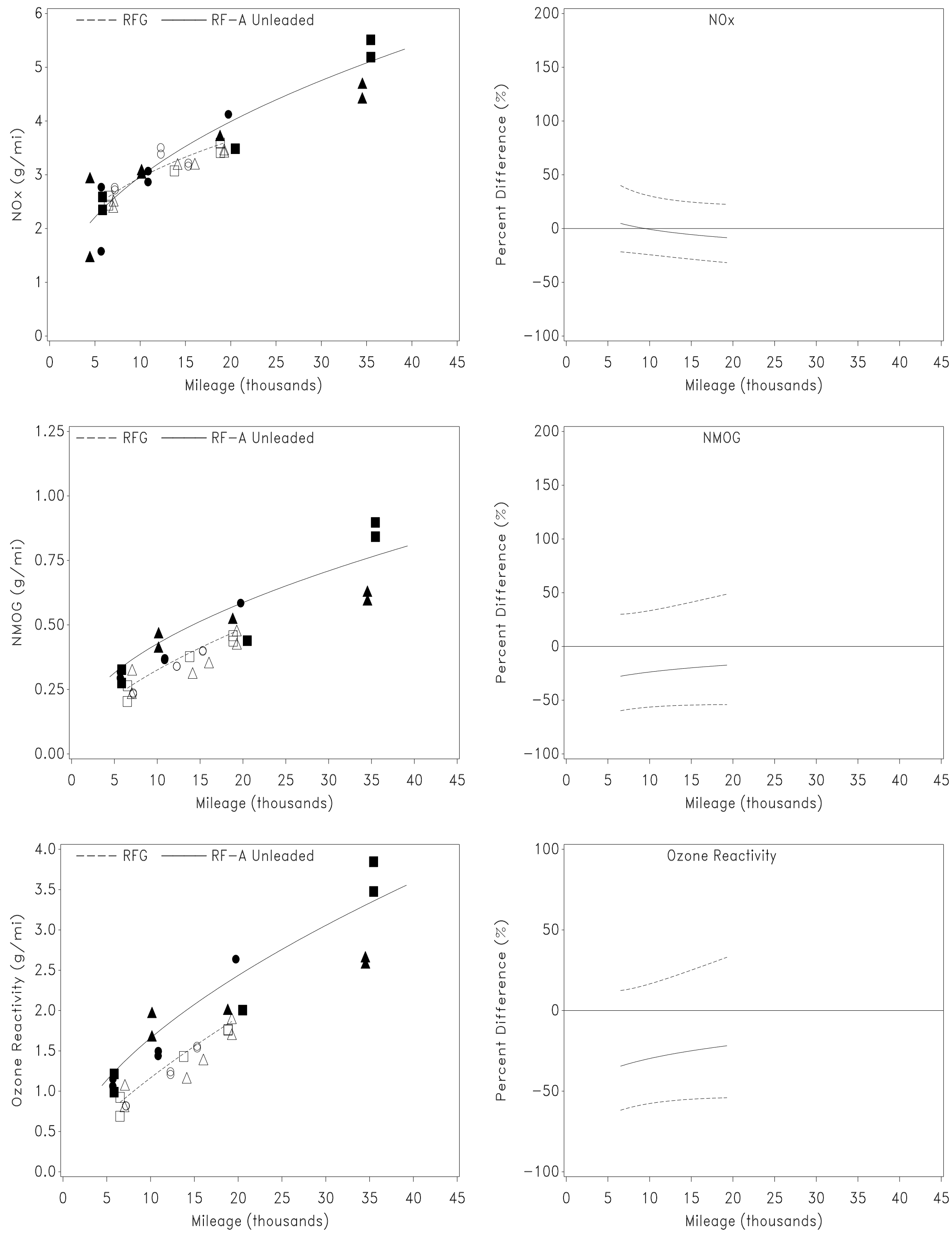

Figure 10a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Chevrolet RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 96 Percent Confidence Bounds

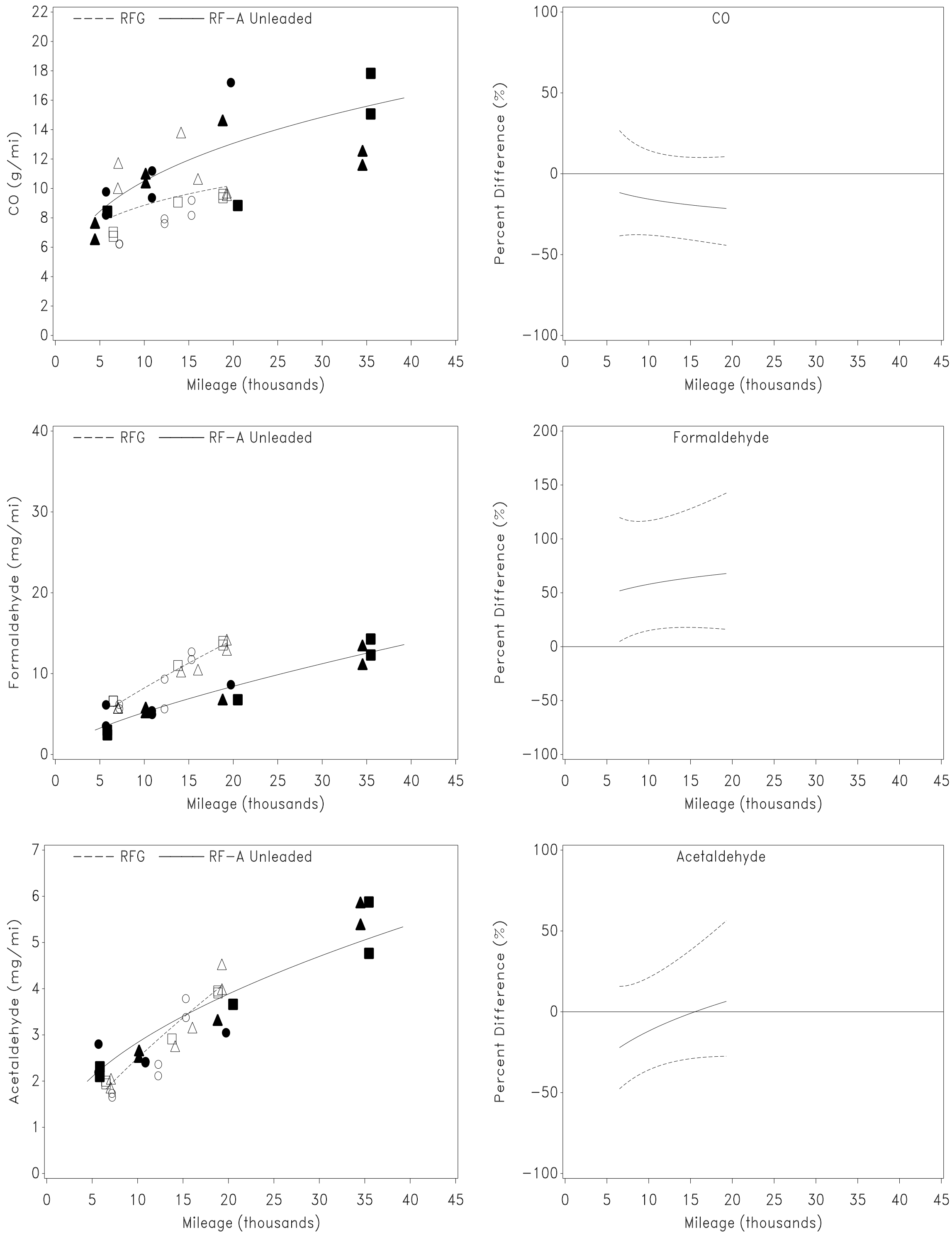

Figure 10b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Chevrolet RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

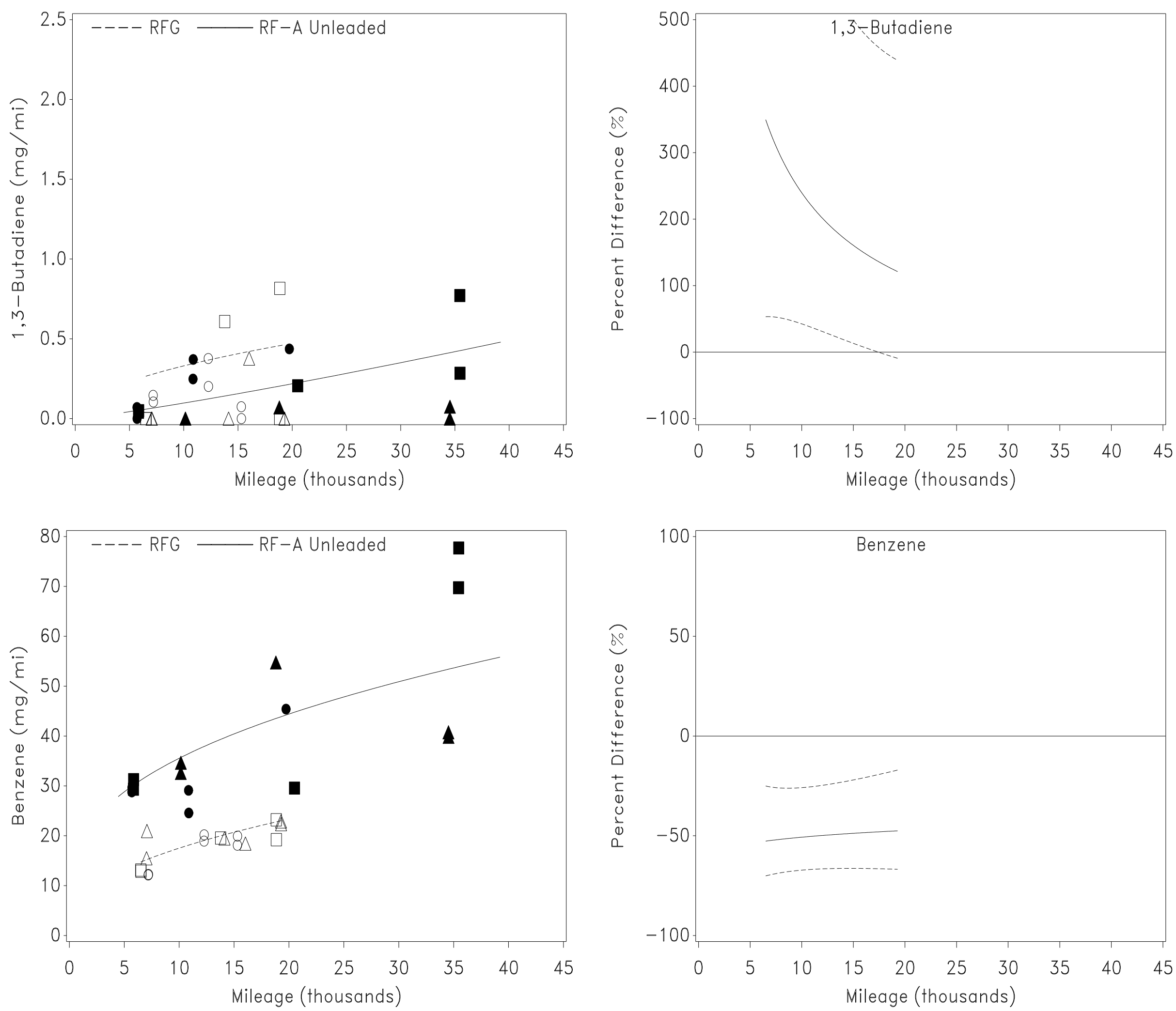

Figure 10c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Chevrolet RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

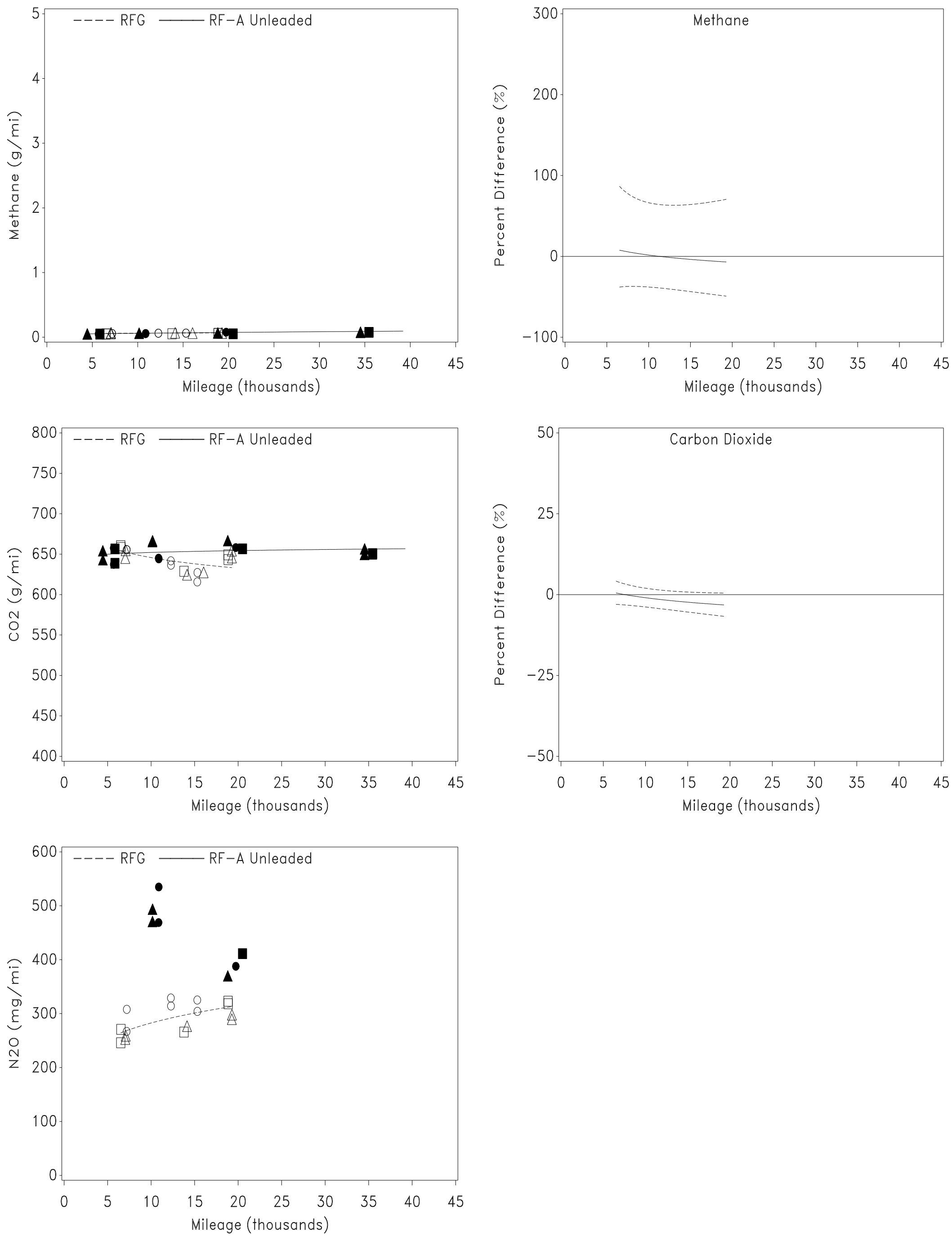

Figure 10d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Chevrolet RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

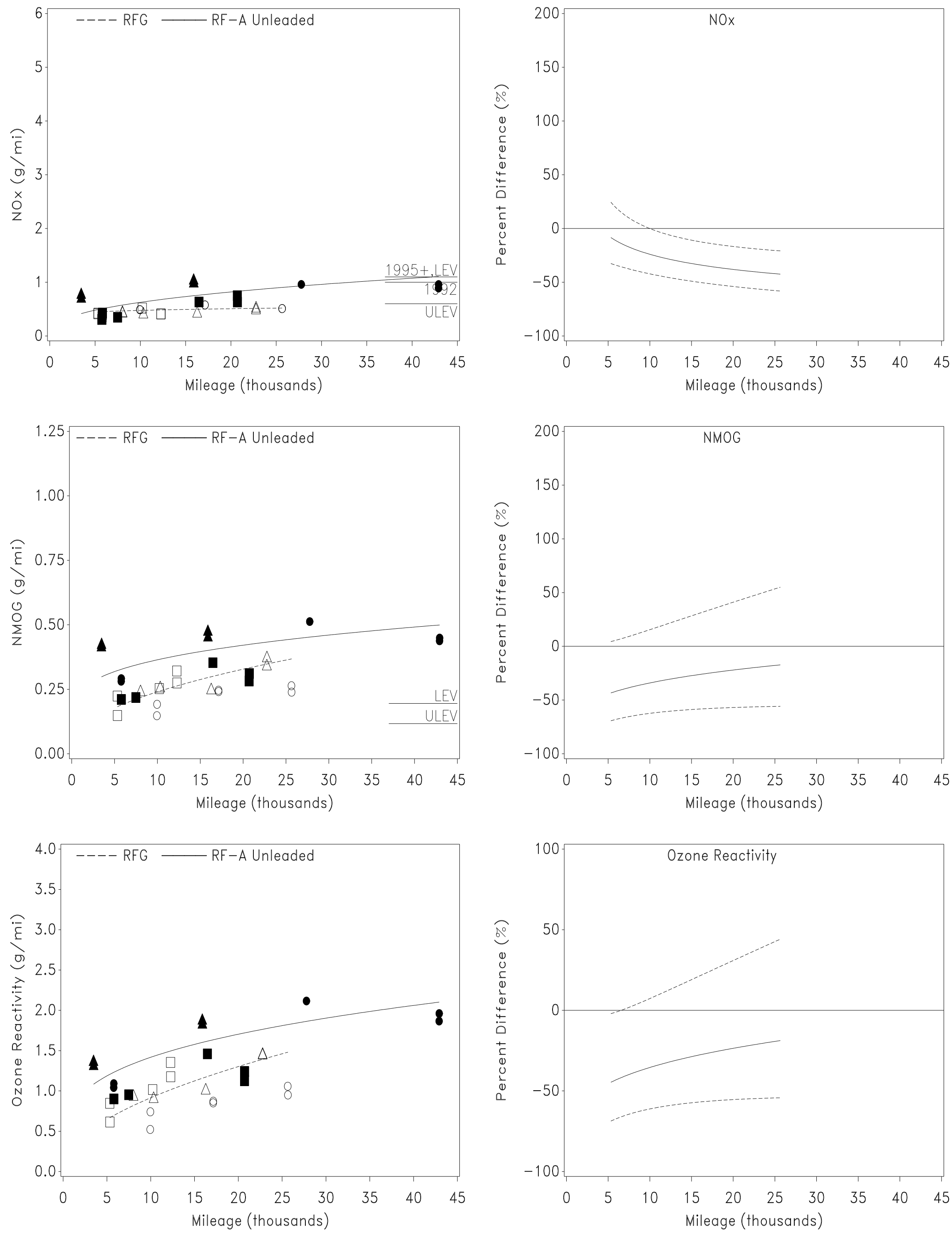

Figure 11a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Dodge RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

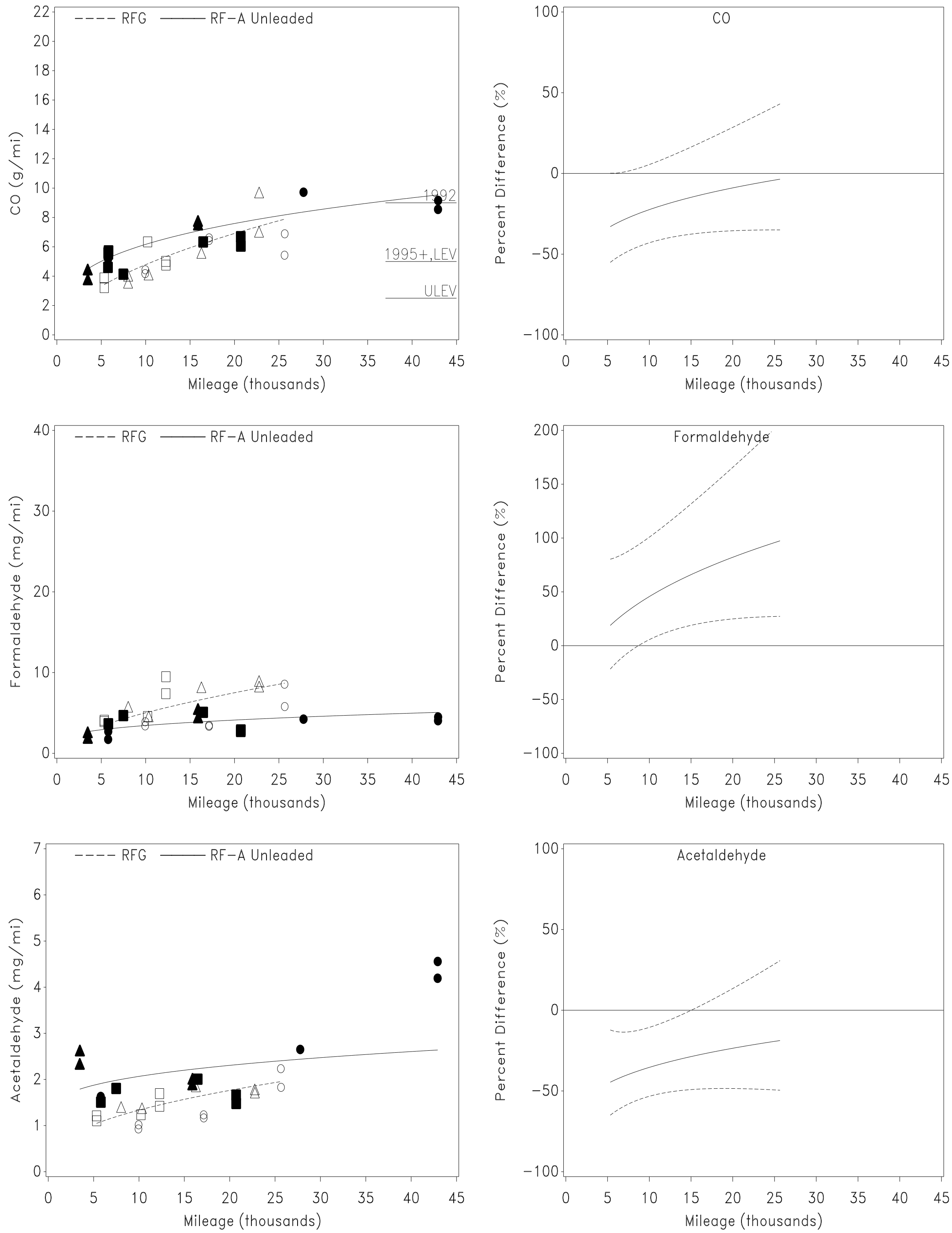

Figure 11b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Dodge RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

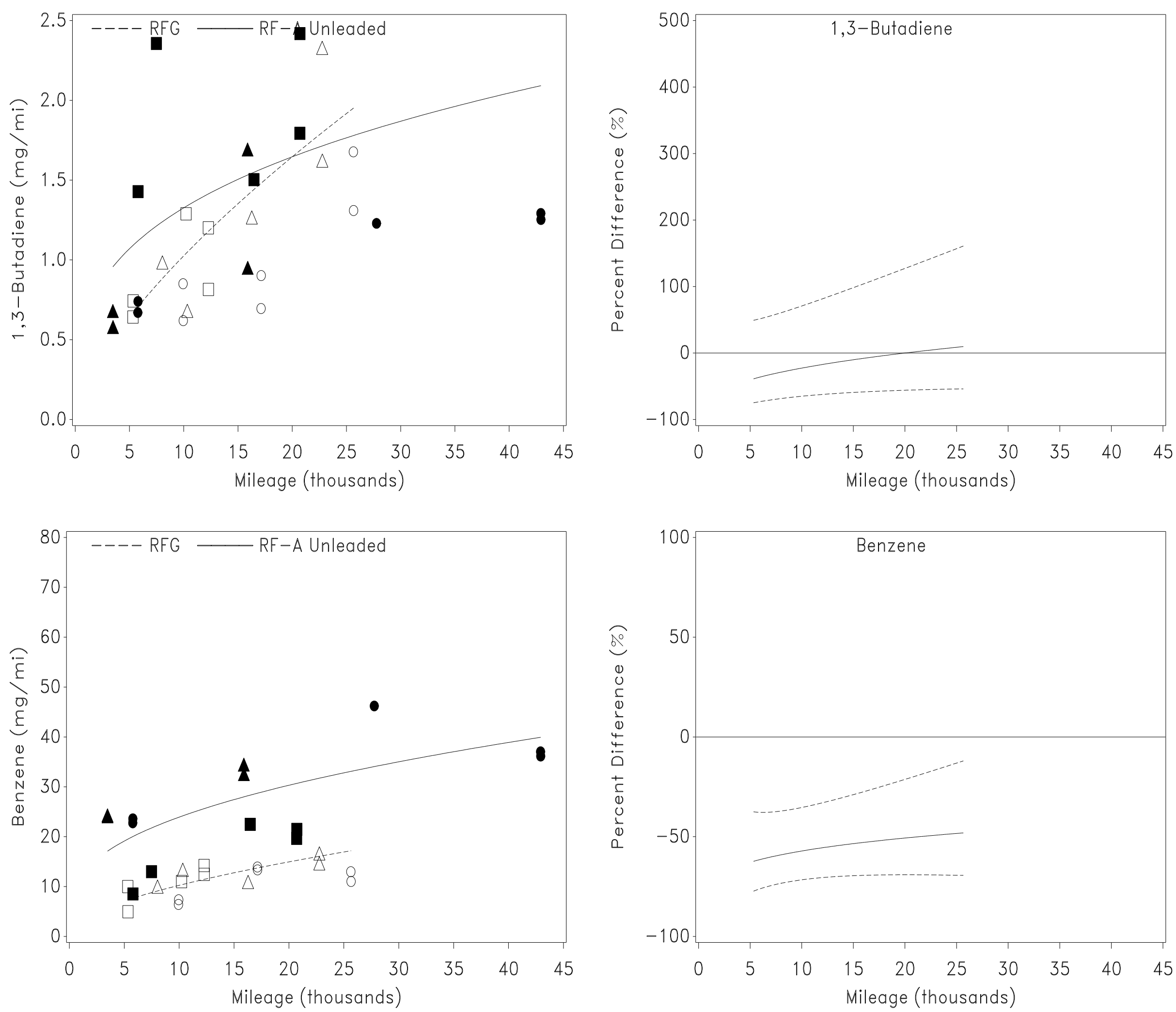

Figure 11c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Dodge RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

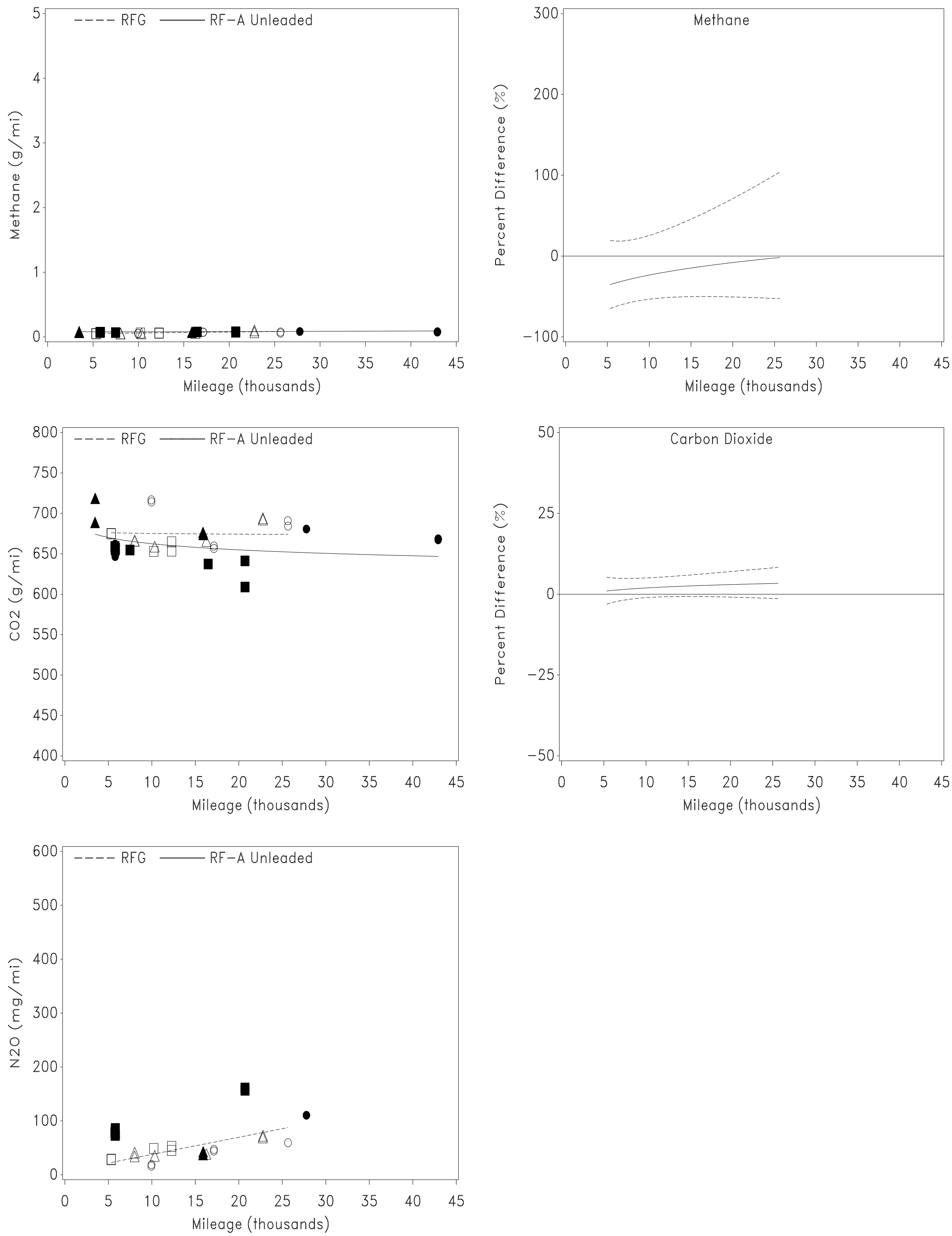

Figure 11d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Dodge RFG and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

M-85

Results for M-85 are presented in Figure 12. Carbon monoxide levels were 42 percent lower at 5,000 miles and 53 percent lower at 25,000 miles. Over the same mileage range the relative ozone reactivity varied from 61 to 58 percent less. Emission levels of NOx and NMOG were about the same from the M-85 and control vans. Formaldehyde levels in the exhaust were factors of 4.0 and 3.0 times higher at 5,000 miles and 25,000 miles. (For this fleet, the change in scale for the plot showing percent difference in formaldehyde, i.e., -100 to 600 percent.) These emission levels reflect the use of a catalyst system built for gasoline-fueled vans; e.g., the emission control system was not designed specifically to remove formaldehyde during cold start. The mean exhaust levels from the M-85 vans at these two mileage levels were 18.2 and 28.0 mg/mi. The formaldehyde was emitted predominantly during the cold start portion of the test cycle (see Figure 13). Emission levels at 25,000 miles from bags 1-3, corresponding to the cold start, stabilized, and hot start phases of the FTP cycle, were estimated to be 103, 8, and 9 mg/mi based upon measurements on three vehicles.

Emission levels of the air toxics acetaldehyde, 1,3-butadiene, and benzene were all less than from the control vans with 95 percent statistical confidence. Emission levels of the two greenhouse gases methane and carbon dioxide were also less in M-85 exhaust than in RF-A exhaust.

Ozone Reactivity

The principal environmental driving force for using alternative motor fuels is the prospect that their use will lead to cleaner vehicle emissions and reduced levels of ambient ozone in the regions of the country that are not in attainment with the National Ambient Air Quality Standard for ozone. The ozone forming potential of exhaust from vehicles used in routine commercial operations was a key factor investigated during the CleanFleet project. This potential or “ozone reactivity” of exhaust is a complicated function of the mass of emissions, their chemical composition, rates of reaction, the ambient levels of pollutants in the atmosphere, and meteorology. The mass of NMOG emissions and chemical composition, result from the combined system of vehicle technology and fuel.

To reduce this complicated set of factors into a more manageable metric for assessing the relative environmental impacts of different fuels, the ARB determines the ozone reactivity of vehicle exhaust using the maximum incremental reactivity approach. The result is plotted in Figures 4a through 12a for each fleet as ozone reactivity in grams of ozone potentially formed in the atmosphere per mile of vehicle travel. Numerical values for the mean ozone reactivity and 95-percent confidence interval, estimated at 20,000 miles, are provided in Table 5. This parameter is governed by both the mass of NMOG emissions and the composition of the emitted NMOG. The percent difference of NMOG emissions on a mass basis was plotted in Figures 4a through 12a along with the ozone reactivity. The composition of NMOG emissions and the resulting effect on the ozone reactivity are discussed below.

NMOG is comprised of hydrocarbons and oxygenated organic gases such as alcohols, carbonyls (e.g., aldehydes and ketones), and ethers. The hydrocarbons in NMOG consist principally of compounds comprised of from two to twelve carbon atoms. They are measured by gas chromatography in two groups characteristic of their weight (or number of carbon atoms). Light-end hydrocarbons, as measured by the ARB, consist of compounds with two to five carbon atoms. Mid-range hydrocarbons consist of heavier compounds with from five to twelve carbon atoms.

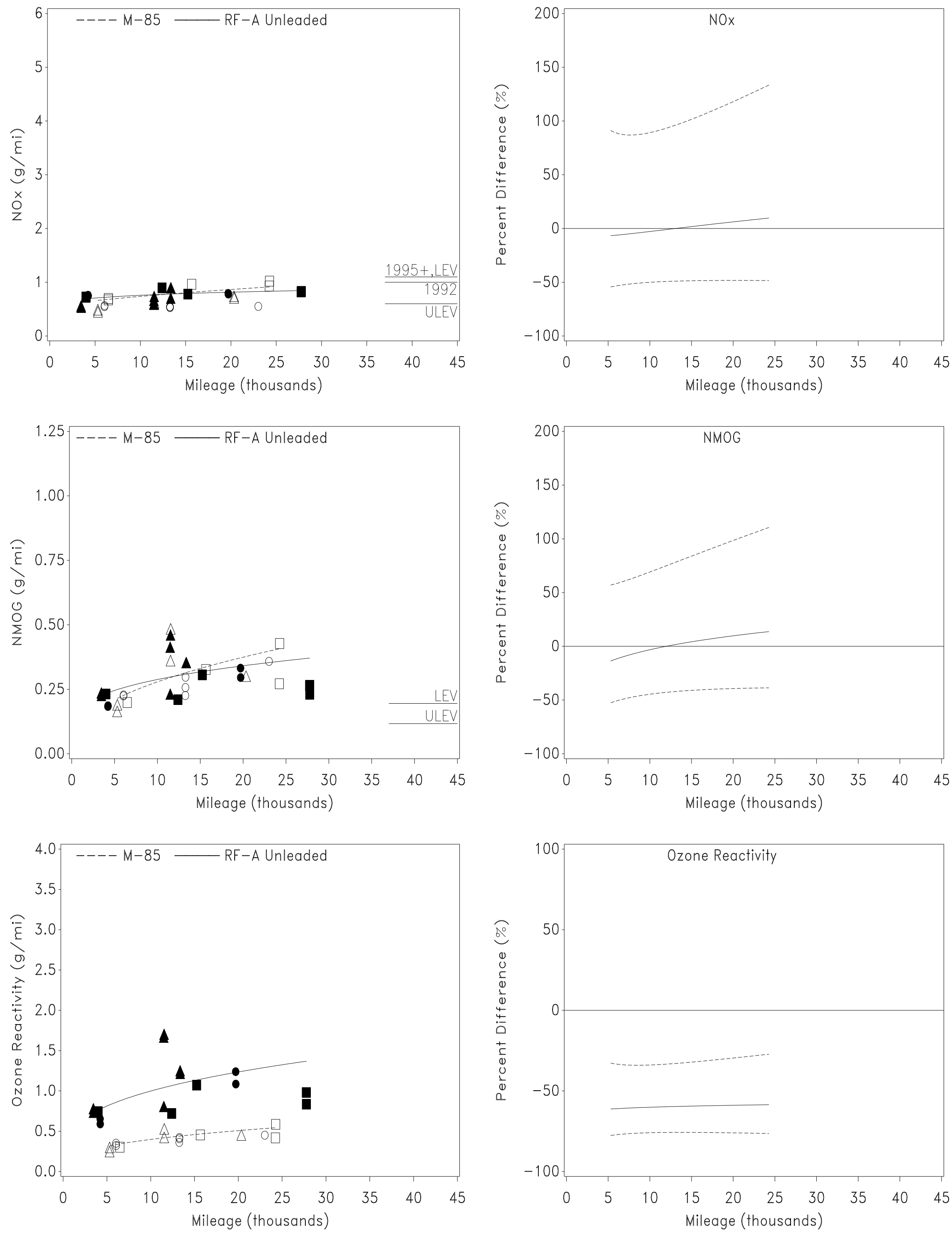

Figure 12a. Estimated Mean Levels of NO_x, NMOG, and Ozone Reactivity of Exhaust Overlaid on Individual Test Results for Ford M-85 and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

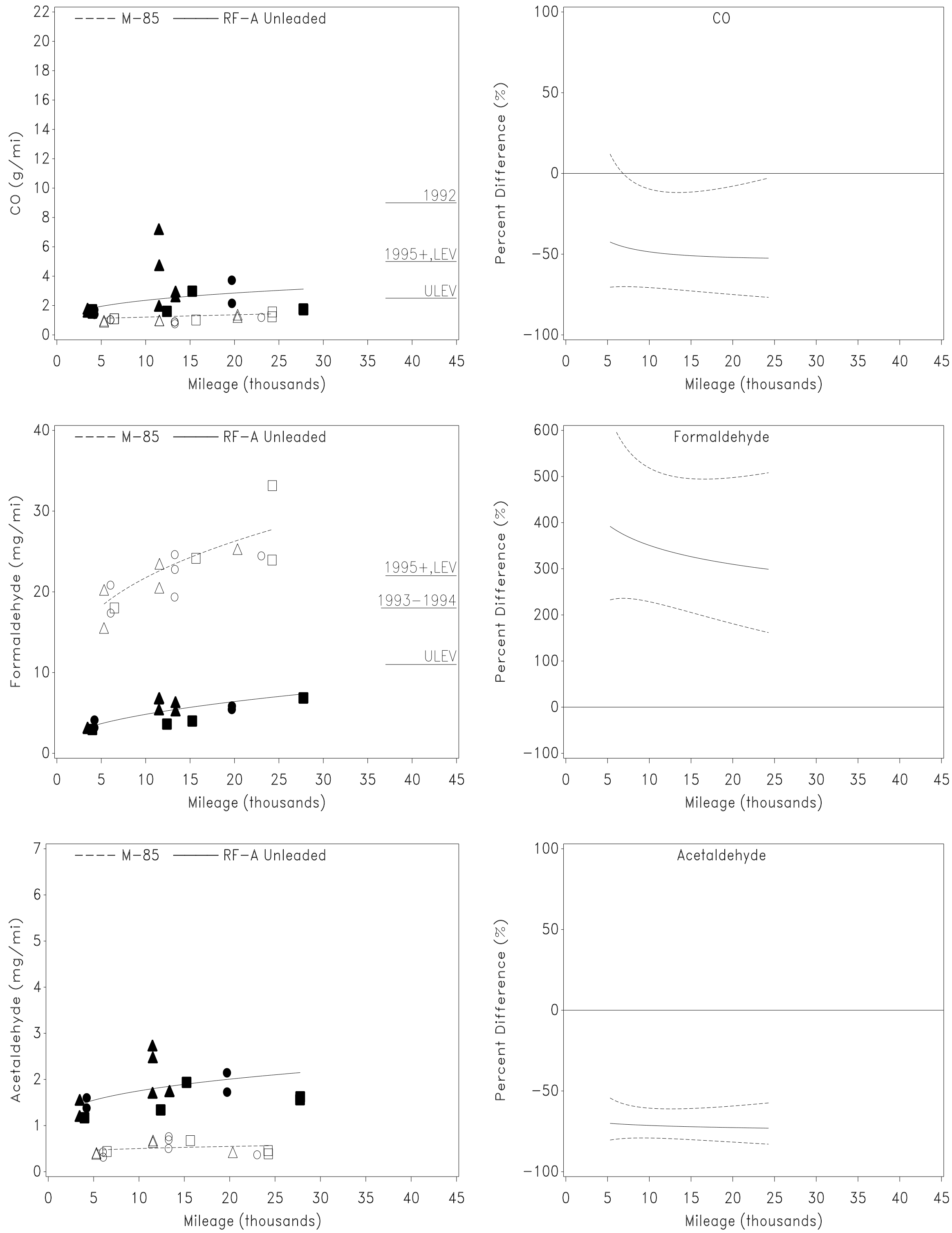

Figure 12b. Estimated Mean Levels of Carbon Monoxide, Formaldehyde, and Acetaldehyde Overlaid on Individual Test Results for Ford M-85 and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

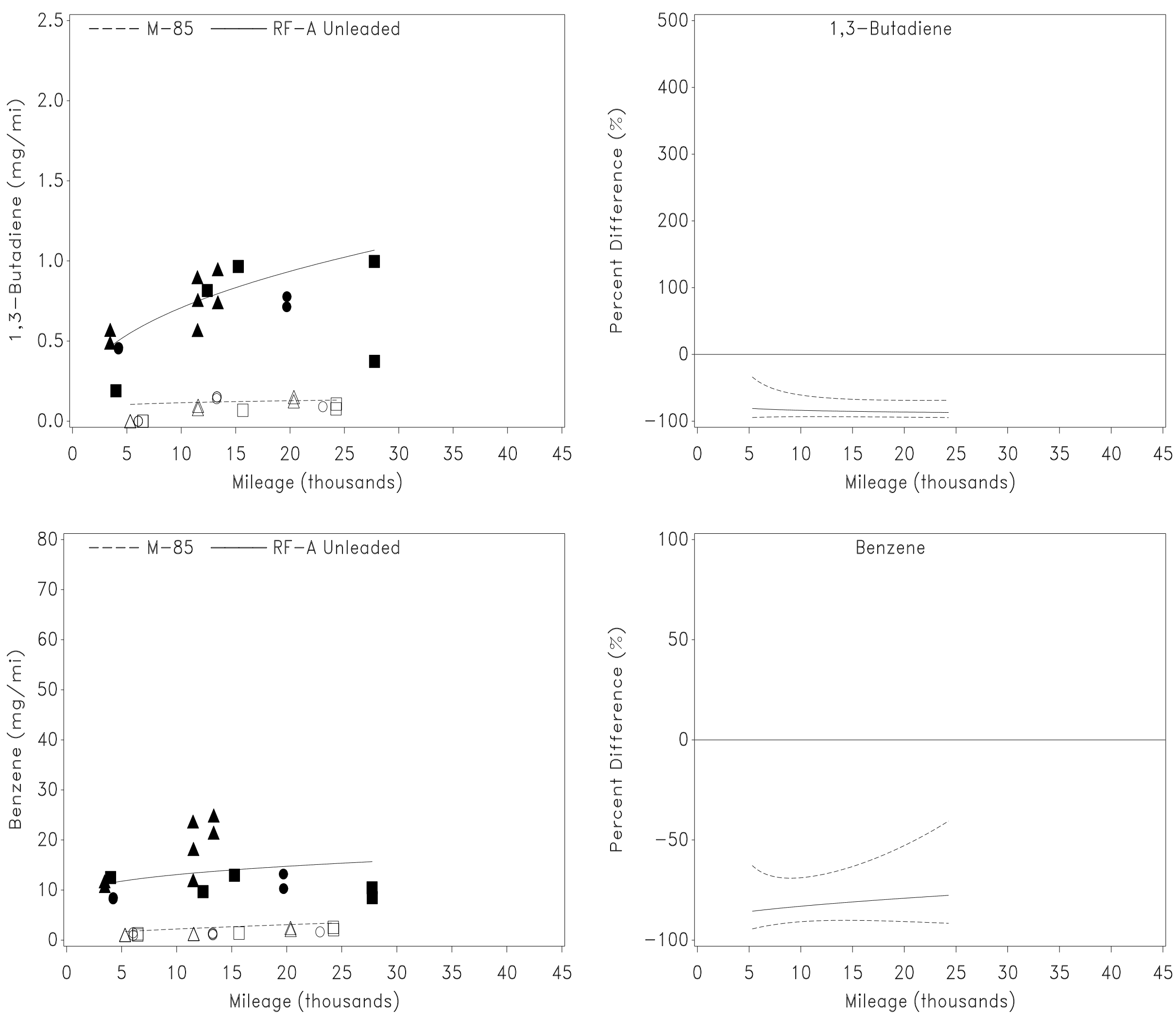

Figure 12c. Estimated Mean Levels of 1,3-Butadiene and Benzene Overlaid on Individual Test Results for Ford M-85 and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

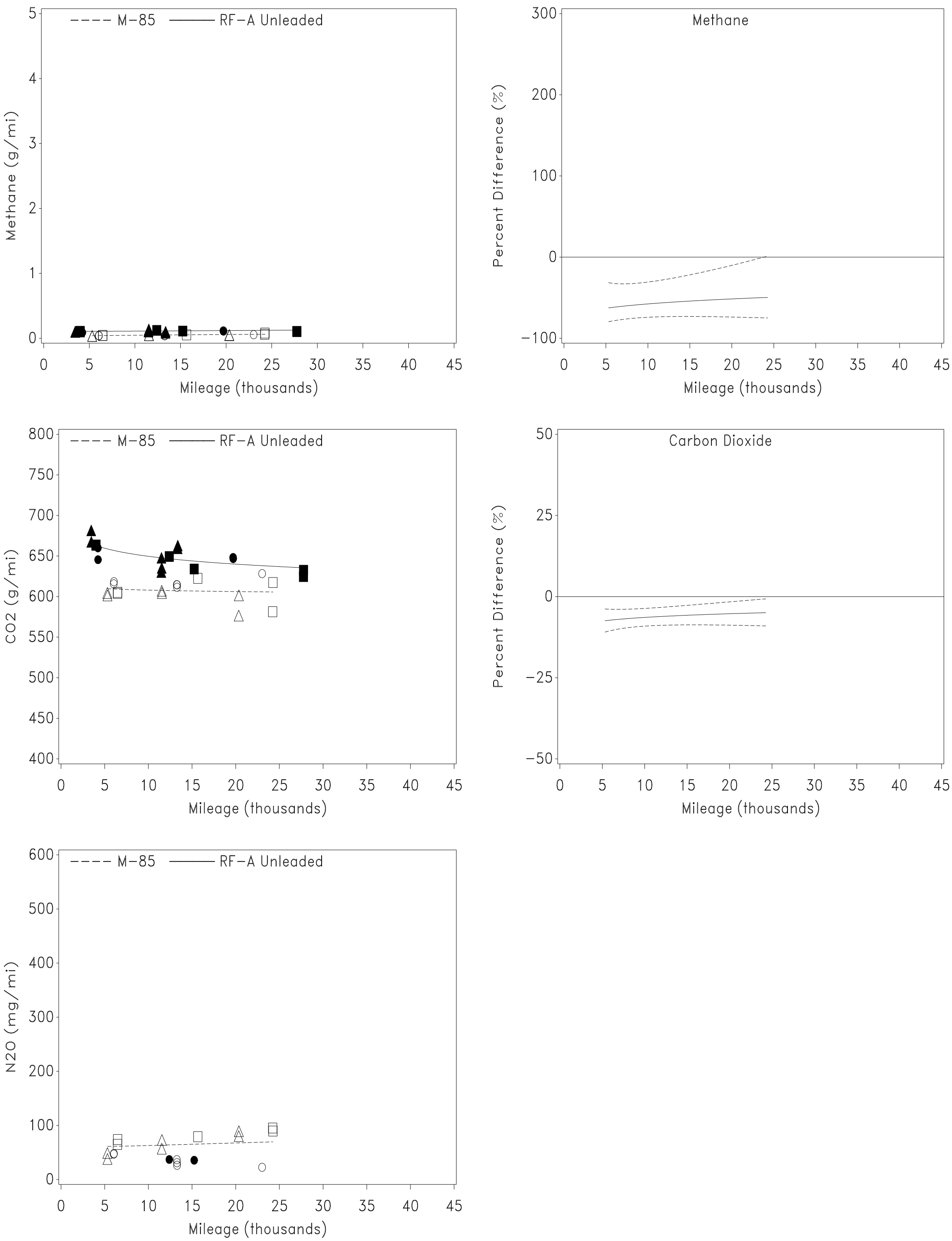

Figure 12d. Estimated Mean Levels of Methane, Carbon Dioxide, and Nitrous Oxide Overlaid on Individual Test Results for Ford M-85 and Control Vehicles; Mean Percent Difference in Emission Levels from Alternative Fuel Vehicles Compared with Control Vehicles, Along with 95 Percent Confidence Bounds

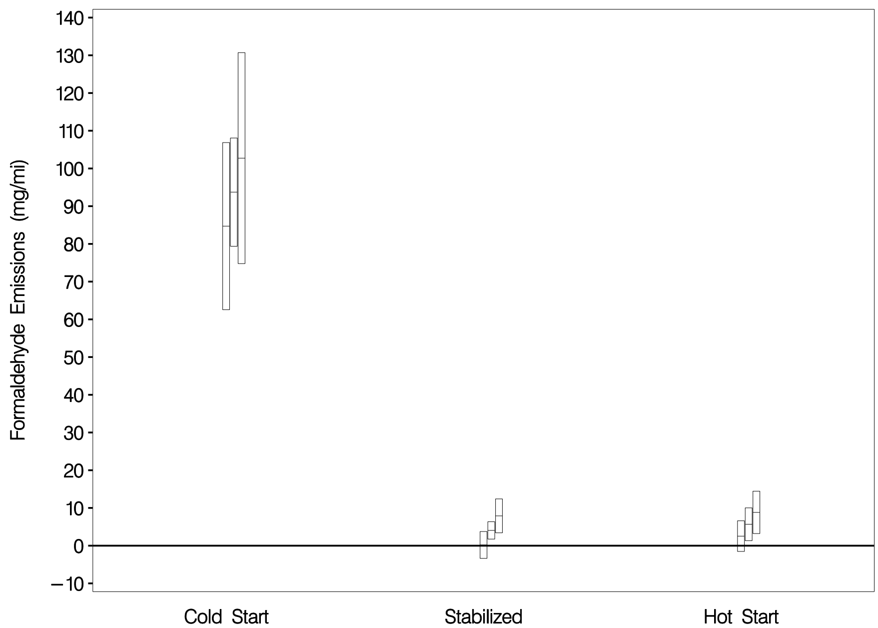

Figure 13. Emission Levels of Formaldehyde from M-85 Vans Measured in the Cold Start, Stabilized, and Hot Start Phases of the Test Procedure (For Each Phase, Mean Emissions are Presented at 5,000, 15,000, and 25,000 Miles, Along with 95 Percent Confidence Intervals)

Table 5. Numerical Results for Ozone Reactivity of Exhaust Estimated at 20,000 Miles

Fuel	Vehicle Manufacturer	Ozone Reactivity (g/mi)		
		Mean	95 Percent Confidence Bound	
CNG	Ford	0.106	0.073	0.153
	Chevrolet	0.170	0.117	0.247
	Dodge	0.109	0.074	0.160
Propane Gas	Ford	0.375	0.260	0.542
	Chevrolet	0.631	0.437	0.911
RFG	Ford	1.01	0.676	1.51
	Chevrolet	1.92	1.30	2.82
	Dodge	1.30	0.886	1.91
M-85	Ford	0.508	0.346	0.745
RF-A	Ford	1.24	0.844	1.81
	Chevrolet	2.44	1.67	3.54
	Dodge	1.70	1.17	2.49

The contribution of light-end hydrocarbons, mid-range hydrocarbons, carbonyls, and alcohols to NMOG is shown in Figure 14. Average values are shown over mileage; the composition of NMOG did not vary significantly with mileage for each of the bars in the figure. Looking across OEM models, the composition of NMOG is distinctive with fuel and to a lesser extent with OEM model. Natural gas exhaust composition was about the same for the Ford and Chevrolet vans. Light-end hydrocarbons accounted for 90 and 91 percent by weight of NMOG for the Ford and Chevrolet vans. The exhaust from the Dodge vans was more enriched in carbonyls and mid-range hydrocarbons compared to exhaust from the other two OEM CNG vans. For example, carbonyls accounted for 15.1 percent of NMOG mass for Dodge exhaust compared to 5.4 and 6.6 percent for the Ford and Chevrolet van exhaust. As a result, the light-end hydrocarbons accounted for only 76 percent of the NMOG by weight for exhaust from the Dodge CNG vans. Propane gas NMOG exhaust was comprised overwhelming of light-end hydrocarbons, principally unburned fuel as propane (83 to 86 percent). Alcohols (i.e., methanol) comprised the majority of the mass of NMOG in M-85 exhaust.

The gasolines had more mid-range hydrocarbons comprising NMOG consistent with the composition of gasoline compared to natural gas and propane gas. Note in Figure 14 that two bars are shown for RFG, labelled RFG 1 and RFG 2. When the composition of NMOG in RFG exhaust as a function of mileage was analyzed, a distinct difference in the composition of NMOG was found between results for the first round of emissions tests and the remaining two rounds. Such a difference was not found for the control gasoline. Results are shown in Figure 15, which shows the contribution of light-end and mid-range hydrocarbons to NMOG segregated according to results obtained in the first round of tests (circles) and rounds 2 and 3 (squares for both). The differences shown are statistically significant. Note the difference in the contribution of light-end and mid-range hydrocarbons to NMOG in RFG exhaust between the first and second rounds of

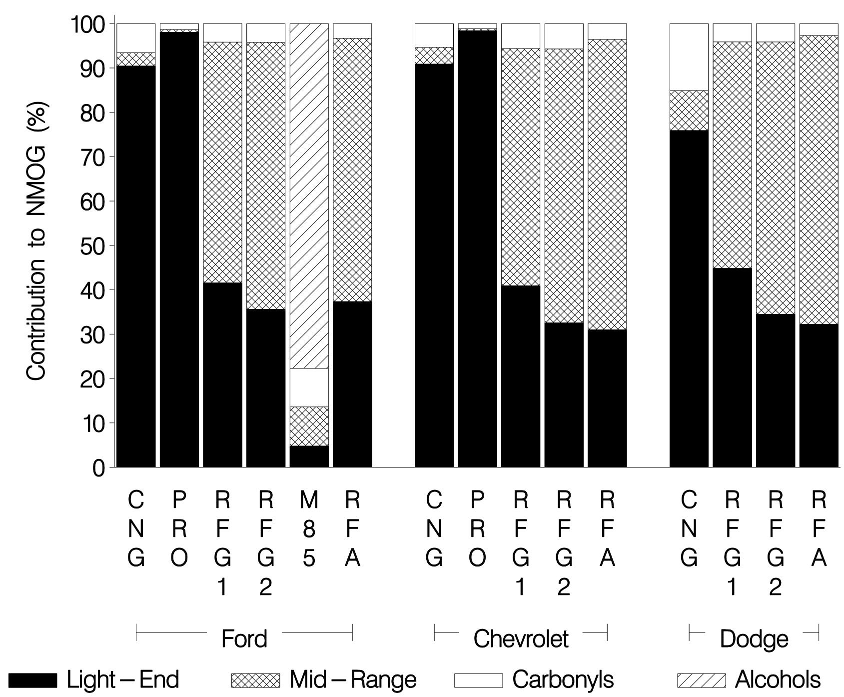

Figure 14. Contribution of Light-end Hydrocarbons, Mid-range Hydrocarbons, Carbonyls, and Alcohols to NMOG Emissions

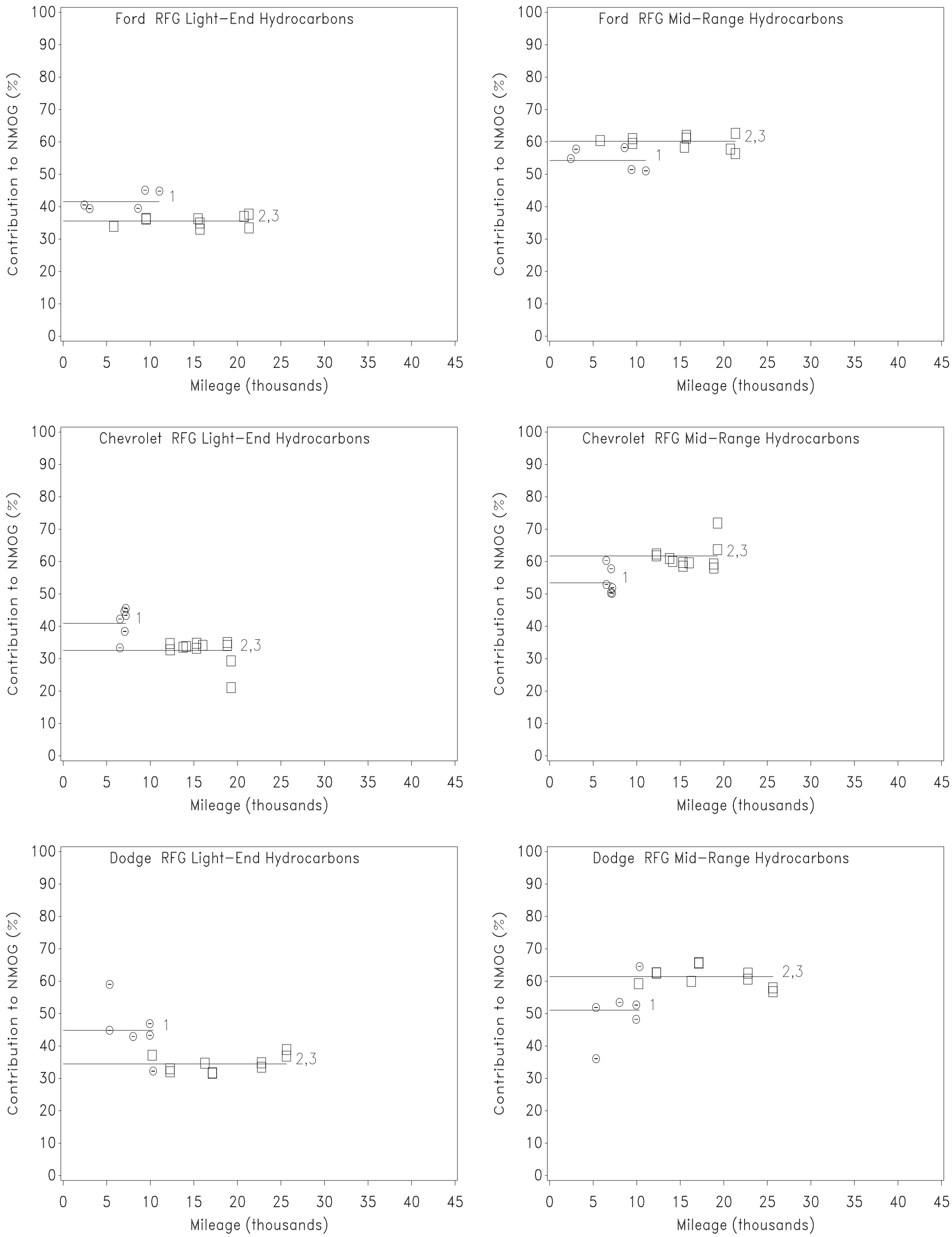

Figure 15. Contribution of Light-end Hydrocarbons and Mid-range Hydrocarbons to NMOG Emissions from RFG Vans Over Mileage

emissions tests, a new batch of RFG was made and supplied to the project. The first batch was used during the period in which the vehicles accumulated up to 7,200 miles (Chevrolet) to 10,000 miles (Dodge). Battelle attributes the step change in composition of NMOG exhaust from RFG vehicles to the differences in chemical composition of the two batches of RFG.

The effect of composition on ozone reactivity was evaluated by normalizing the results for ozone reactivity by the mass emissions of NMOG for each fleet. The resulting ratio is specific ozone reactivity, and it has units of (g ozone potentially formed)/(g NMOG emitted). Values of specific ozone reactivity across mileage are shown in Figure 16. The symbols each refer to an individual vehicle. In computing the mean value and 95-percent confidence bounds (shown as the solid line and dashed lines in each plot), three values for Dodge CNG exhaust were considered outliers and were not incorporated into the statistical analysis. The specific ozone reactivity of exhaust in each of these three tests was in the range 4 to 5 g ozone/g NMOG. To place the values for specific ozone reactivity in perspective, the specific ozone reactivity for each fleet was divided by the specific ozone reactivity for its corresponding control fleet on RF-A gasoline. This calculation yielded the relative specific ozone reactivity.

Relative specific ozone reactivity (RSOR) is analogous to the RAFs developed by the ARB for specific fuels and classes of vehicles. The ARB recognized that, in its clean fuels program, different fuels inherently produce combustion products with different levels of ozone reactivity on a mass basis. Therefore, effectively controlling ozone reactivity of exhaust emissions (in g ozone/mi) was more important than simply controlling mass emissions of NMOG. This led the ARB to control ozone reactivity using standards for mass emissions of NMOG as well as RAF. For example, if a particular fuel used in a class of vehicles has a RAF of 0.9, vehicles operating on that fuel are allowed to emit NMOG at a rate equal to the emission standard for NMOG for gasoline divided by the RAF. In this example, NMOG mass emissions could be about 11 percent higher (1/0.9) because this mass emission rate of NMOG from the fuel is predicted to result in the same generation of ambient ozone as the NMOG emissions from gasoline at the emission standard.

The ARB's purpose in creating RAFs was to ensure a level playing field for all fuels, such that vehicles certified to a particular LEV standard would have the same impact on air quality whether they are powered by one of the alternative fuels or powered by gasoline.

The ARB has found that the SOR of vehicle exhaust can depend upon the mass emission level of NMOG (which depends upon vehicle technology and the exhaust composition). Consequently, the ARB bases its determination of SOR and RAF on sets of vehicles that have (1) technology representative of future, low-emission, production vehicles and (2) about the same mass emissions of NMOG. Neither of these criteria were necessarily met by all CleanFleet vehicles. Hence, the RSOR values reported are not true RAF values.

The mean values for RSOR at 20,000 miles are plotted in Figure 17. Mean values are presented along with the 95 percent confidence interval about each mean. These values are listed in Table 6.

Propane gas exhaust was found to have the lowest value for RSOR, with mean values of 0.25 and 0.23 for Ford and Chevrolet vans. This value reflects the low reactivity of the major component of propane gas exhaust, i.e. propane itself. The practical implication of this finding is that, as the mass emissions of propane gas exhaust are reduced, ozone reactivity will be lowered substantially, assuming that the composition of the exhaust remains about constant. However, constancy of composition (and

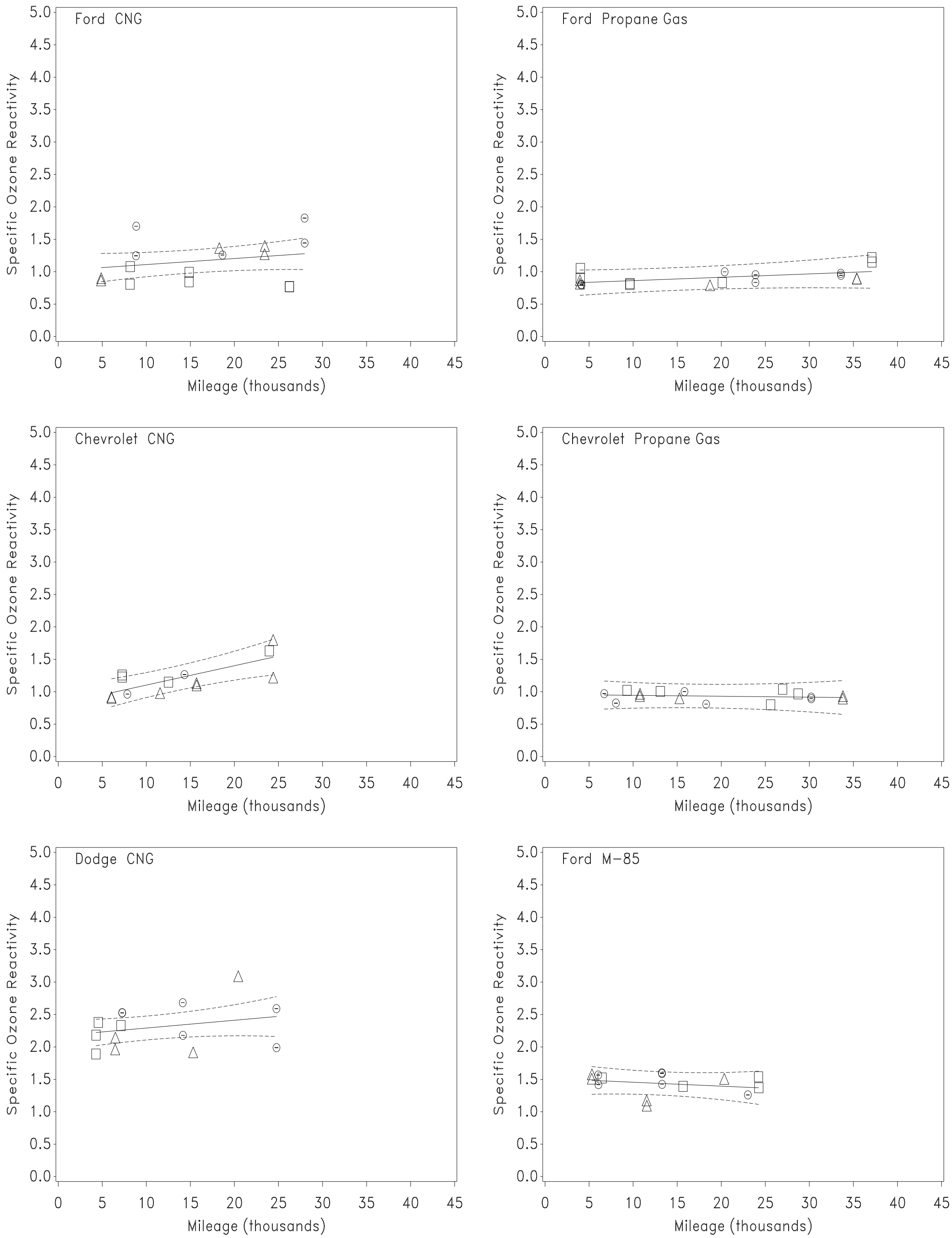

Figure 16a. Estimates of Mean Specific Ozone Reactivity of Exhaust Emissions Versus Mileage from CNG, Propane Gas, and M-85 Vans, Along with 95 Percent Confidence Bounds

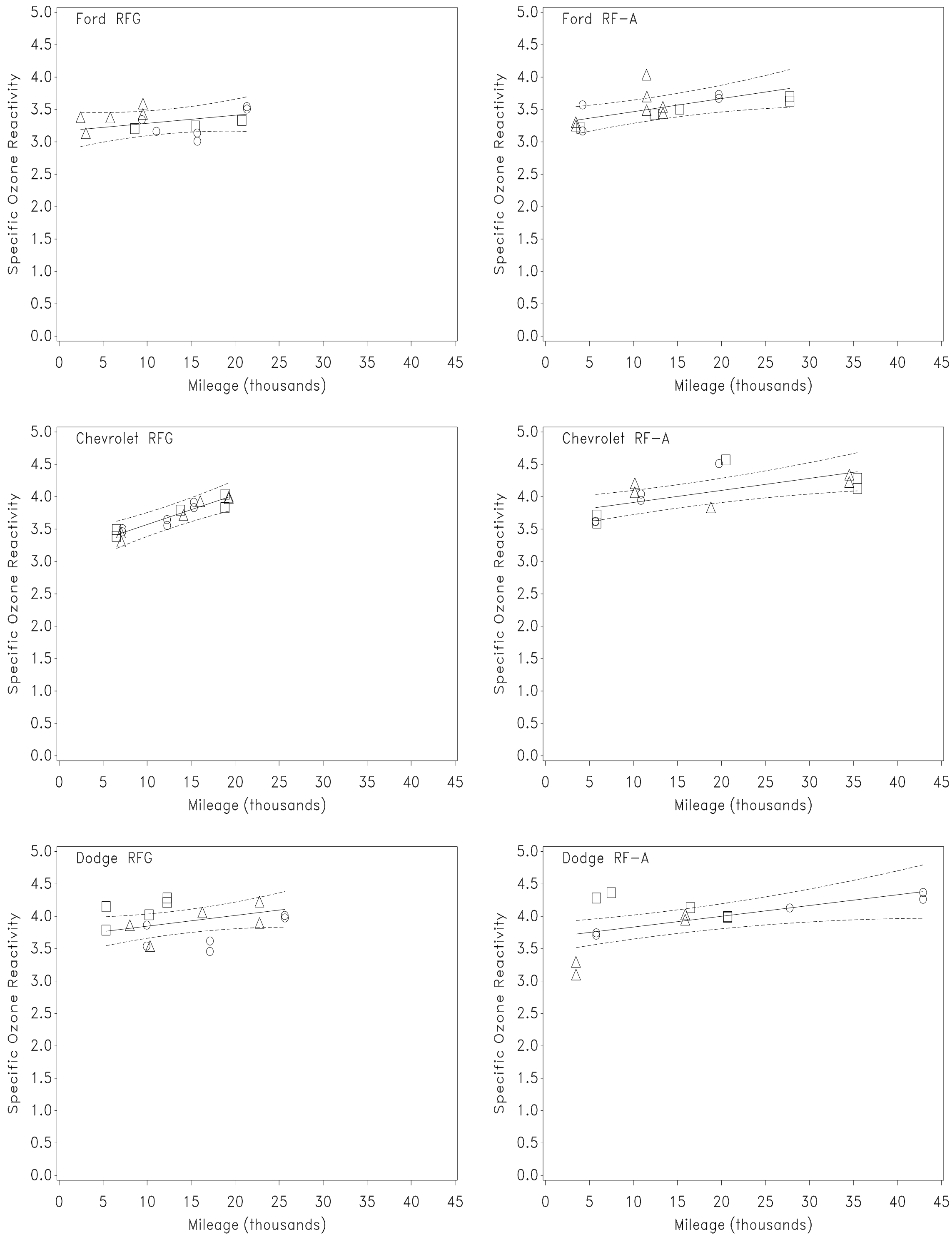

Figure 16b. Estimates of Mean Specific Ozone Reactivity of Exhaust Emissions Versus Mileage from RFG and RF-A Unleaded Vans, Along with 95 Percent Confidence Bounds

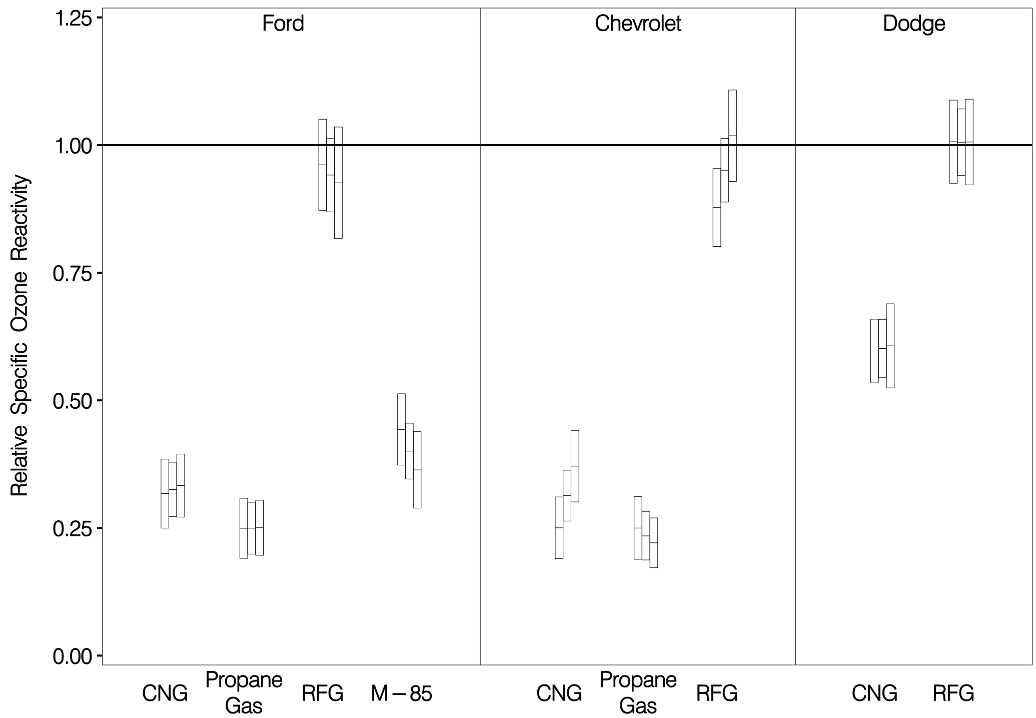

Figure 17. Relative Specific Ozone Reactivity of Exhaust from CleanFleet Vans. (Mean Levels are Presented at 5,000, 15,000, and 25,000 Miles, Along with 95 Percent Confidence Intervals)

Table 6. Numerical Results for Relative Specific Ozone Reactivity of Exhaust Estimated at 20,000 Miles

Fuel	Vehicle Manufacturer	Relative Specific Ozone Reactivity		
		Mean	95 Percent Confidence Bounds	
CNG	Ford	0.33	0.27	0.38
	Chevrolet	0.35	0.29	0.40
	Dodge	0.60	0.54	0.67
Propane Gas	Ford	0.25	0.20	0.30
	Chevrolet	0.23	0.18	0.27
RFG	Ford	0.93	0.85	1.02
	Chevrolet	0.99	0.91	1.06
	Dodge	1.01	0.93	1.08
M-85	Ford	0.38	0.32	0.44

hence SOR) with mass of NMOG may not be achieved. For example, the RSOR values of 0.25 and 0.23 for CleanFleet propane gas vans at 20,000 miles are less than the ARB's preliminary value of 0.46 for a RAF for light-duty vehicles[(4)]. As the mass of NMOG emissions is reduced through optimization of vehicle technology, the mass fraction of propane in the exhaust may decrease, yielding an increase in the RSOR for propane gas exhaust even as the total ozone reactivity (g/mi) decreases.

The value of RSOR for M-85 in CleanFleet vans was about 0.38. This value reflects the combined effects of methanol and the Phase 2 RFG in M-85. A major component of the mass emissions of NMOG from M-85 was methanol (see Figure 14), and methanol is relatively unreactive in the atmosphere. The CleanFleet value of 0.38 ± 0.06 compares well with the ARB's adopted value of 0.41 for transitional low emission vehicles[(4)]. It needs to be remembered that CleanFleet M-85 fuel contained 15 percent RFG; the ARB's RAF for M-85 is based upon a M-85 fuel containing 15 percent regular gasoline.

The CNG exhaust from the Ford and Chevrolet vans had values for RSOR of 0.33 and 0.34, respectively. The value for the Dodge vans was higher at 0.60, reflecting the higher carbonyl content of NMOG compared to exhaust from the Ford and Chevrolet vans. Nevertheless, because the Dodge vans had such a low mass emission rate of NMOG (Figure 6a), the ozone reactivity of its exhaust in g/mi was the lowest measured in the CleanFleet project (Table 5). The CleanFleet values for RSOR at 20,000 miles bracket the ARB's preliminary value of 0.43 for a RAF for low emission vehicles (LEVs) and ultra-LEVs[(4)].

The RFG exhaust had values for RSOR that were not statistically significantly different from 1.0 at 20,000 miles. However, at earlier mileage (5,000 miles) the RSOR for the Chevrolet RFG fleet was slightly (but significantly) lower, having a value of 0.87. Mean values for the Ford, Chevrolet, and Dodge vans were 0.93, 0.99, and 1.01. These results (see Table 6) are consistent with RAF values for reformulated gasoline established by the ARB for light-duty vehicles certified to transitional low emission vehicle (TLEV) standards (0.98) and for light-duty vehicles certified to LEV standards (0.94).

Deterioration of Emission Levels

The measured emissions provide information on deterioration of emission levels over mileage. An analysis of the trends shown in Figures 4-12 was made for carbon monoxide, nitrogen oxides and nonmethane organic gases. The average percent change in emission levels was determined over a common odometer interval, and the statistical significance of the estimated deterioration was assessed.

Results of this analysis are presented in Table 7. For the Chevrolet vans, all three emission parameters (CO, NO_x, NMOG) were found to have a statistically significant change in emission level over the odometer range 10,000 to 20,000 miles for CNG and RF-A. The two parameters NMOG and NO_x increased for RFG. For the Dodge vans, NMOG and NO_x both increased significantly for CNG vans. For the Ford vans, NMOG and NO_x both changed significantly for CNG.

Table 7. Estimated Increase in Emissions from 10,000 to 20,000 Miles

Vehicle Manufacturer	Fuel Type	Percent Increase CO	Percent Increase NMOG	Percent Increase NO_X
Ford	CNG	20	10*	41*
	M-85	13	34	18
	PRO	16	6	-6
	RFG	33*	15*	3
	RF-A	21*	18	8
Chevrolet	CNG	80*	19*	8
	PRO	19	18	12
	RFG	15	50*	23*
	RF-A	24*	37*	35*
Dodge	CNG	18	37*	40*
	RFG	44*	37*	7
	RF-A	23*	16	31*

* An asterisk denotes a statistically significant change in emission level at the 95 percent confidence level over the mileage range 10,000 to 20,000 miles.

Hot Soak Emission Results

Results from the "hot soak" portion of the evaporative tests are presented in Table 8. The data and odometer reading for each SHED test are documented in Appendix C. The results were highly variable across both vehicles within a fleet and across fleets. This is particularly evident for the CNG and M-85 vans. For example, two M-85 vans had SHED tests. The recorded emission of NMOG was 1.68 g for one van and 0.14 g for the other van. The calculated ozone forming potential, or ozone reactivity, was 2.2 g and 0.15 g respectively.

Table 8. Results from SHED Tests

			Mean Values (Standard Deviation), (mg)				
Fuel	**Vehicle Manufacturer**	**Number of Tests**	**THC**	**NMHC**	**NMOG**	**CH_4**	**Ozone Reactivity**
CNG[a]	Ford	5	256 (413)	206 (414)	206 (414)	50 (11)	426 (847)
	Chevrolet	6	346 (219)	28 (11)	28 (11)	318 (221)	36 (19)
	Dodge	5	842 (937)	63 (55)	64 (55)	779 (882)	56 (24)
Propane Gas	Ford	5	621 (210)	620 (209)	620 (209)	0.8 (1.8)	390 (141)
	Chevrolet	4	1,150 (113)	1,150 (113)	1,150 (113)	0.0 (0.0)	678 (165)
RFG	Ford	3	126 (105)	124 (103)	124 (103)	1.5 (1.5)	556 (578)
	Chevrolet	3	284 (114)	284 (114)	284 (114)	0.1 (0.2)	726 (198)
	Dodge	2	178 (16)	178 (16)	178 (16)	0.0 (0.0)	477 (74)
M-85[b]	Ford	2	535 (712)	701 (881)	909 (1,090)	0.0 (0.0)	1,180 (1,450)
RF-A	Ford	4	127 (68)	126 (68)	126 (68)	0.6 (0.9)	504 (235)
	Chevrolet	1	207 (.)[c]	207 (.)	207 (.)	0.0 (.)	633 (.)
	Dodge	2	352 (23)	350 (25)	350 (25)	1.9 (2.7)	1,087 (136)

[a] CNG data
Ford: THC - one value of 994 mg, remaining four below 102 mg
NMHC - one value of 946 mg, remaining five below 50 mg
NMOG - one value of 946 mg, remaining five of 50 mg
Ozone reactivity - one value of 1,939 mg, remaining four below 120 mg
Chevrolet: Methane - one value of 0.0 mg, remaining four above 225 mg
Dodge: Methane - five test results ranged from 19 mg to 2,175 mg

[b] M-85 data
The data are averages for two tests with widely varying results. For example, NMOG measurements were 1,680 and 136 mg for two vehicles; ozone reactivity was 2,200 and 150 mg.
Values under NMHC for M-85 are reported as OMHCE.

[c] Because only one test was conducted, a standard deviation was not calculated.

Concluding Statement

The CleanFleet emissions data provide a comprehensive data set on emissions from in-use delivery vans operating on four alternative fuels and baseline gasoline. To make valid judgments from the data, it is important to remember that the twelve fleets (combinations of vehicle manufacturer and fuel) represent a range of technologies that were available in the 1992 vehicle model year. These technologies were at different stages of development and optimization for the various fuels. The other vehicle technology that was demonstrated in CleanFleet was electric vans. They are classified by the ARB as zero emission vehicles. Finally, the emissions results constitute one of three aspects of importance to decision makers concerning the use of alternative fuels; impact of the fuels on fleet operations and costs of implementation must also be considered to provide a balanced picture.

References

1. Geiss, R.O., Burkmyre, W.M., and Lanigan, J.W., "Technical Highlights of the Dodge Compressed Natural Gas Ram Van/Wagon," 921551, SAE International, Warrendale, PA, 1992.

2. PROC MIXED from the SAS system statistical software package.

3. "California Exhaust Emission Standards and Test Procedures for 1998 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles," Amended September 22, 1993, Appendix VIII, State of California Air Resources Board.

4. "Preliminary Reactivity Adjustment Factors," State of California Air Resources Board, Mobile Source Division, 1994.

APPENDIX A

Applicable Emission Regulations

APPENDIX A

Applicable Emission Regulations

The liquid and gaseous fueled CleanFleet vehicles are all model year 1992 panel vans. They were operated either as production vans certified to California 1992 emissions standards or under experimental permits. A goal established by the Working Group during Phase 1 of the project was that these vans meet California's low emissions vehicle (LEV) standards, if possible. Applicable federal and California standards are summarized in this section.

Classes of Engines/Vehicles

CleanFleet vehicles fall into classes based upon weight. The curb weight, loaded vehicle weight (LVW), adjusted loaded vehicle weight (ALVW), and gross vehicle weight rating (GVWR) of the gasoline vans are listed in Table A-1. Curb weight is defined as the weight of a vehicle filled with fuel, lubricants, and coolant, but with no people or payload. Loaded vehicle weight is defined as curb weight plus 300 pounds. ALVW, a federal term, is the numerical average of curb weight and GVWR. GVWR is the maximum legal weight at which a vehicle can be operated.

The average actual weights of the vans are listed in Table A-2 for comparison. These weights were measured by Battelle.

California Regulations

California regulations that apply to model year 1992 CleanFleet vans and future model year panel vans are listed in Tables A-3 through A-9. These standards are contained in Title 13, California Code of Regulations, Sections (§) 1956.8 and 1960.1. These emissions standards are summarized in the California Air Resources Board's *Mobile Source Emission Standards Summary*, June 30, 1992.

CleanFleet Ford and Dodge panel vans running on gasoline were certified by the manufacturers to California emission standards for medium-duty vehicles (MDV). "Medium-duty vehicle" means any pre-1995 model year heavy-duty vehicle having a GVWR of 8,500 pounds or less, any 1992 and subsequent model-year heavy-duty (greater than 6,000 pounds GVWR) LEV or ultra-low emission vehicle (ULEV) having a GVWR of 14,000 pounds or less, or any 1995 and subsequent model year vehicle having a GVWR of 14,000 pounds or less (Cal. Code Regs, Title 13, § 1900).

Table A-1. Vehicle Weights for CleanFleet Gasoline Vehicles

Vehicle Manufacturer	Curb Weight (lbs)	Loaded Vehicle Weight (lbs)	Adjusted Loaded Vehicle Weight (lbs)	Gross Vehicle Weight Rating (lbs)
Ford	5,031[a]	5,331	6,115	7,200
Dodge	4,590[b]	4,890	6,200	7,500
Chevrolet	4,740[b]	5,040	6,820	8,600

(a) From Ford.
(b) Estimated as average actual weight minus 220 pounds for FedEx upfitting.

Table A-2. Average Measured Weight of CleanFleet Vehicles

Fuel	Vehicle Manufacturer	Weight (lbs)
Control	Ford	5,490
Control	Chevrolet	4,956
Control	Dodge	4,812
M-85	Ford	5,526
CNG	Ford	5,782
CNG	Chevrolet	5,462
CNG	Dodge	4,975/5,122[a]
RFG	Ford	5,546
RFG	Chevrolet	4,980
RFG	Dodge	4,826
Propane gas	Ford	5,337
Propane gas	Chevrolet	5,128
Electric	G-Van	7,756

(a) The production Dodge vans weighed about 4,975 pounds after upfitting for FedEx. After the addition of the fourth fuel tank, these vans weighed about 5,122 pounds.

Table A-3. California Exhaust Emission Standards for Medium-Duty Vehicles (50,000 Mile Standards)[a]

Class	Model Year	Vehicle Weight (lbs)	NMHC (g/mi)	CO (g/mi)	NO_x (g/mi)
Conventional	1989-1994	3,751-5,750[f]	0.50	9.0	1.0
Conventional and Methanol[c]	1995+[b]	5,751-8,500[g]	0.39	5.0	1.1
LEV	1992+	5,751-8,500	0.195[d]	5.0	1.1
ULEV	1992+	5,751-8,500	0.117[d]	2.5	0.6
Gasoline-LEV[e] Gasoline-ULEV[e]	1992+	5,751-8,500	0.39[d] 0.195[d]	5.0 5.0	1.1 1.1

[a] For vehicles in the range 3,751-5,750 loaded vehicle weight (LVW). LVW = curb weight plus 300 pounds.

[b] 1995+ = model year 1995 and subsequent years.

[c] For methanol-fueled vehicles including flexible-fueled vehicles, NMHC means organic material hydrocarbon equivalent (OMHCE).

[d] Standard based on nonmethane organic gases (NMOG). For LEVs and ULEVs certified to operate on any other fuel other than conventional gasoline, including fuel-flexible and dual-fuel vehicles, manufacturers shall multiply NMOG emission levels at 50,000 and 120,000 miles by the applicable reactivity adjustment factor.

[e] Flexible-fuel and dual-fuel LEV and ULEV vehicles must also meet these gasoline standards.

[f] Loaded vehicle weight (LVW).

[g] Test weight equals average of curb weight and GVWR.

Table A-4. California Exhaust Emission Standards for Medium-Duty Vehicles (100,000/120,000 Mile Standards)

Class	Model Year	Applicable Mileage	NMHC (g/mi)	CO (g/mi)	NO_x (g/mi)
Conventional	1989-1994	100,000	0.50	9.0	1.0
Conventional and Methanol	1995+[(a)]	120,000	0.56	7.3	1.53
LEV	1992+	120,000	0.280	7.3	1.5
ULEV	1992+	120,000	0.167	3.7	0.8
Gasoline-LEV	1992+	120,000	0.56	7.3	1.5
Gasoline-ULEV	1992+	120,000	0.280	3.7	0.8

Table A-5. California Exhaust Intermediate Compliance Standards for 50,000 Miles for Medium Duty-Vehicles[(a)]

Class	Model Year	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)
LEV	1992-1999	0.293	5.0	1.1
ULEV	1992-1999	0.156	3.8	0.8
Gasoline-LEV	1992-1999	0.49		
Gasoline-ULEV	1992-1999	0.293		

[(a)] Test weight in the range 5,781-8,500 lbs. Footnotes from Table A-3 apply.

Table A-6. Reactivity Adjustment Factors[a]

Fuel	Parameter	Light-Duty Vehicle RAF		
		TLEV	LEV	ULEV
Gasoline	SOR[a]	3.42	3.13	3.13
Phase 2 RFG	RAF[b]	0.98	0.94	--
M-85	RAF	0.41	--	--
CNG	RAF	--	0.43[c]	0.43[c]
Propane Gas	RAF	--	0.46[c]	--

[a] SOR = specific ozone reactivity.
[b] RAF = reactivity adjustment factor.
[c] Preliminary data.

(From "Preliminary Reactivity Adjustment Factors," State of California Air Resources Board, Mobile Source Division, 1994.)

Table A-7. California Formaldehyde Emission Standards for Medium-Duty Vehicles[a]

Class	Model Year	Vehicle Weight (lbs)	Formaldehyde (mg/mi)	
			Certification	In-Use Compliance[f]
Methanol-fueled[b]	1993-1994 1995 1996+	3,751-5,750[d] 5,751-8,500[e] 5,751-8,500	18 22 22	27 33 22
LEV[c]	1992+ 2000+	5,751-8,500	22	22 40[g]
ULEV[c]	1992+ 2000+	5,751-8,500	11	17 21[g]

[a] 50,000 mile durability basis.
[b] Including fuel-flexible vehicles.
[c] Including fuel-flexible and dual-fuel vehicles.
[d] LVW.
[e] Test weight.
[f] 50,000 mile durability basis.
[g] 120,000 mile durability basis.

Table A-8. Implementation Schedule for Future Model Year LEV and ULEV vehicles

Model Year	Percent of Sales of MDV	
	LEV	ULEV
1998	25	2
1999	50	2
2000	75	2
2001	95	5
2002	90	10
2003	85	15

Table A-9. California Exhaust Emission Standards for Heavy-Duty Engines (1991 and Later)[a]

Emission Component	Standard (g/bhp-hr)
THC	1.1
NMHC	0.9
CO	14.4
NO_x	5.0

[a] For vehicles with gross vehicle weight rating in the range 8,501-14,000 pounds.

The Chevrolet vans (with a GVWR of 8,600 pounds) have two engine families: 5.7 L, V-8 gasoline engines (used in the propane gas and natural gas vans) and 4.3 L heavy-duty V-6 engines (used in the reformulated gasoline and control vans). Both of these engine families were certified by General Motors on engine dynamometers to heavy-duty standards.

Table A-3 lists the 50,000-mile MDV exhaust standards that are applicable to the Ford and Dodge model year 1992 gasoline vans. The 100,000 mile standards are shown in Table A-4. Also shown are future standards for conventional and methanol MDV and LEV and ULEV vehicles. Note that California standards move from vehicle classification based upon LVW to Test Weight. Test Weight is defined by the California Code of Regulations as the average of a vehicle's curb weight and gross vehicle weight. Also, hydrocarbon standards shift from the basis of NMHC to NMOG. Finally, NMOG emission levels are to be multiplied by reactivity adjustment factors (RAF) for fuels other than conventional gasoline.

Adopted and preliminary values for several RAFs are shown in Table A-6. These values take into account the ozone forming potential of exhaust per unit mass emission of NMOG referenced to gasoline exhaust. The value of a RAF is computed as the specific ozone reactivity (SOR) of exhaust for a fuel and vehicle certified to a standard (TLEV, LEV, ULEV) divided by the SOR for gasoline. Values of SOR for gasoline are shown in the table.

Table A-6 lists California intermediate compliance standards (50,000 miles) for MDV. Table A-7 lists formaldehyde standards. Table A-8 lists the implementation schedule for LEV and ULEV vehicles in future years.

Table A-9 lists heavy-duty exhaust emissions standards applicable to Chevrolet gasoline powered CleanFleet panel vans.

California evaporative emission standards apply to gasoline, propane gas, and methanol-fueled vehicles. For model year 1980-1994, the standard applies to the "hot soak plus diurnal" portion of the test at 50,000 miles useful life. The standard is 2 g/test. For model years 1995 and beyond, the hot soak plus diurnal standard of 2.0 g/test applies along with a standard of 0.05 g/mi for running loss. The 1995 standards are phased in with 100 percent of vehicles to be certified to these standards in 1998 and subsequent years.

Federal Regulations

Federal regulations promulgated or planned by the U.S. Environmental Protection Agency (EPA) that apply to model year 1992 CleanFleet vans and future model year vans are listed in Tables A-10 through A-14. Tables A-10 and A-11 list standards applicable to vehicles purchased outside of California (or states that opt into the California program). Note that federal standards move from defining Test Weight as LVW to a new term called adjusted loaded vehicle weight (ALVW). The ALVW is defined as the average of curb weight and GVWR. (It is equivalent to California's definition of Test Weight for 1995 and beyond.) This information is provided for a national perspective.

Tables A-12 and A-13 contain standards for the Clean Fuel Fleet programs as mandated in the Clean Air Act Amendments of 1990. These standards pertain to covered fleets of ten vehicles or more that (1) are located in the 22 non-attainment areas for ozone or carbon monoxide and (2) are capable of being centrally fueled and for which fleet owners desire to include as Clean Vehicles for purposes of the fleet purchase requirements. Optional purchase of Inherently Low Emission Vehicles (ILEV), most likely to be very clean dedicated alternative fuel vehicles, will also qualify for credits.

Federal evaporative emission standards for light-duty trucks are 2.0 g/test. The Clean Fuel Fleet Standard for light-duty ILEVs is the conventional standard over the full test procedure plus an ILEV standard of 5 g/test on an abbreviated test procedure without auxiliary evaporative emission control devices.

Evaporative emission standards for heavy-duty trucks are 3.0 g/test. The Clean Fuel Fleet Standard for heavy-duty ILEVs is 5 g/test on an abbreviated test procedure without auxiliary evaporative emission control devices. The ILEV evaporative test procedures for light-duty and heavy-duty vehicles differ.

Final rules have been published in the Federal Register as follows.

- Final Rule 3-01-93 Credit program and transportation control measure exemptions
- Final Rule 12-10-93 Definitions
- Final Rule 9-30-94 Clean fuel vehicle standards, conversion provisions, California Pilot Program.

Purchase requirements are listed in Table A-14.

Table A-10. Federal Exhaust Emission Standards Applicable to Light-Duty CleanFleet Vehicles[a]

Model Year	Vehicle Weight (lbs)	NMHC (g/mi)	CO (g/mi)	NO_x (g/mi)
1988-1993	>3,750[b]	0.8	10	1.7
1994+	>5,750[c]	0.39	5.0	1.1

[a] Light-duty vehicles have GVWR less than or equal to 8,500 pounds.
[b] Based on LVW.
[c] Heavy light-duty trucks (LDT4) with ALVW greater than 5,700 pounds.

Table A-11. Federal Exhaust Emission Standards for Gasoline-Fueled and Methanol-Fueled (Otto Cycle) Heavy-Duty Engines[a]

Emission Component	Standard (g/bhp-hr)
Hydrocarbons	1.1
CO	14.4
NO_x	5.0

[a] For model year 1991 and later heavy-duty trucks with GVWR less than or equal to 14,000 pounds.

Table A-12. Federal Clean Fuel Fleet Exhaust Emission Standards for Light-Duty Vehicles

Class	Vehicle Weight[a] (lbs)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)
LDT	>5,750	0.195	5.0	1.1
ILEV	>5,750	0.195	5.0	0.6

[a] Based on ALVW.

Table A-13. Federal Clean Fuel Fleet Exhaust Emission Standards for Heavy-Duty Vehicles

Class	NMHC + NO_x (g/bhp-hr)	CO (g/bhp-hr)
HDV	3.50	15.5
ILEV	2.5	15.5

Table A-14. Schedule of Required Purchases for the Clean Fuel Fleet Program

Vehicle Category[a]	Model Year	Purchase Requirement (Percent of New Purchases)
LDV, LDT	1998 1999 2000+	30 50 70
HDV	1998+	50

(a) LDV = light-duty vehicle
LDT = light-duty truck
HDV = heavy-duty vehicle

APPENDIX B

Test Methods

APPENDIX B

Test Methods

Vehicle exhaust sampling was carried out at ARB's facility in El Monte, using dynamometer test cell #1. For this program, the USA three-phase driving cycle was employed. This driving cycle is composed of a cold transient phase, a stabilized phase, and a hot transient phase. The sampling procedures were conducted according to the Federal Test Procedure (FTP) as specified in the Code of Federal Regulations, Title 40, Part 86.

Emissions data consist of the following:

(1) Non-methane organic gases (NMOG) as determined by ARB Methods Nos. 1001 (alcohols), 1002 (light hydrocarbons), 1003 (mid-range hydrocarbons), and 1004 (carbonyls)

(2) Methane, carbon monoxide, carbon dioxide, oxides of nitrogen, and total hydrocarbons as determined by continuous monitoring instrumentation from three bag samples collected during each phase of the test cycle

(3) Nitrous oxide, nitrous acid, and methyl nitrite as determined by an on-line Fourier Transform Infrared Analyzer.

Three Tedlar bags were used to collect time-integrated samples during each phase of the test cycle. The continuous monitoring instruments were valved to each bag following the test run and concentrations were recorded.

Transfer bags were used to remove a portion of exhaust from each bag. These secondary bags were transferred to the analytical laboratory for subsequent analysis of the light (Method 1002) and mid-range hydrocarbons (Method 1003).

Alcohols (Method 1001) were determined using on-line impingers. Carbonyl species (Method 1004) were determined using on-line impingers prior to January 22, 1993, and using Sep-Pak cartridges thereafter. Time-integrated samples were obtained for each phase of the test cycle.

The FTIR instrument was connected on-line. For nitrous oxide, measurements were made in real time as well as in a "static" mode (sample from the Tedlar bag) because of interference from high transient concentrations of carbon monoxide during real time monitoring. The concentration values reported were based on calibrations and procedures established by the instrument manufacturer. ARB staff are currently developing additional quality control procedures which will become part of the laboratory's standard operating procedure for this analysis. As a result, the FTIR-based method and results should be considered developmental.

VEHICLE EMISSIONS

In the first quarter of 1993, ARB changed its operating procedures for gas chromatography to increase sample throughput, to improve chromatographic resolution, and to increase the number of identifiable peaks. The more significant changes were:

1. The GCs used for the light-end and mid-range hydrocarbons (Methods #1002 and 1003) were automated so that bag samples could be analyzed without operator interface.

2. Temperature programming conditions were also changed to improve resolution of normally co-eluting compounds. This change also resulted in the identification of several previously labelled unknown species.

3. For Method #1004 (carbonyls), silica gel cartridges coated with 2,4-dinitrophenylhydrazine (DNPH) reagent were implemented. Previously, DNPH impinger solution was used. The list of identifiable species was also expanded.

4. The data acquisition/processing was changed to allow for more automated operations to be conducted.

The first analytical procedures were used for tests conducted from November 1992 through January 1993. The new procedures were employed beginning in March 1993. Table B-1 shows a listing of the target species measured by ARB during the vehicle exhaust tests conducted in the fourth quarter of 1992. The expanded list for 1993 is shown in Table B-2.

Table B-1. Species Targeted by the ARB During Vehicle Testing Conducted in the Fourth Quarter of 1992

Light-End Hydrocarbons (MLD Method #1002)
Ethane
Ethene
Propane
Ethyne
Methylpropane
Butane
Propene
Methylbutane
Pentane
1-Butene
2-Methylpropene
Mid-Range Hydrocarbons (MLD Method #1003)
t-2-Butene
1-Butyne
c-2-Butene
3-Methyl-1-butene
2-Methylbutane
1-Pentene
2-Methyl-1-butene
1,3-butadiene
2-Methyl-1,3-butadiene
t-2-Pentene
C6H12 Alkene
c-2-Pentene
2-Methyl-2-butene
2,2-Dimethylbutane
Cyclopentene
4-Methyl-1-pentene
Cyclopentane
2,3-Dimethylbutane
C6H12 Alkene 1
2-Methylpentane
C6H12 Alkene 2
3-Methylpentane
C6H12 Alkene 3
n-Hexane
3-Hexene
t-2-Hexene
C6H12 Alkene 4

c-2-Hexene
C6H12 Alkene 5
Methylcyclopentane
C6H12 Alkene 6
2,4-Dimethylpentane
C7H16 Alkane
Benzene
3-Methyl-1-hexene
Cyclohexane
2-Methyl-3-hexene
4-Methyl-2-hexene
2-Methylhexane +Dimethylpentane
C6H10 Cycloalkene
3-Methylhexane
C7H14 Alkene
Dimethylcyclopentane
2,2,4-Trimethylpentane
n-Heptane
C7H12? Cycloalkene
Methylcyclohexane
Trimethylcyclopentane
Dimethylhexane
C8H18 Alkane
Trimethylcyclopentane 1
2,3,4-Trimethylpentane
Toluene
2,3-Dimethylhexane
Methylheptane
Unidentified 1
Dimethylcyclohexane
2,2,5-Trimethylhexane
Ethylmethylcyclopentane
n-Octane
C8H16 Cycloalkane
2,3,5-Trimethylhexane
NNDime-acetamide
C8H14? Cycloalkene
Dimethylheptane
C9H18 Alkene
Ethylbenzene
Trimethylcyclohexane
m & p-Xylenes
C9H20 Alkane

Styrene
Trimethylheptane
o-Xylene
C10H22 Alkane 1
C9H18 Alkene 1
n-Nonane
Ethylmethylcyclohexane
i-Propylbenzene
C10H22 Alkane 2
Dimethyloctane
n-Propylbenzene
3-Ethyltoluene
4-Ethyltoluene
1,3,5-Trimethylbenzene
C10H22 Alkane 3
2-Ethyltoluene
C10H22 Alkane 4
1,2,4-Trimethylbenzene
n-Decane
n-Undecane
C10H14 Aromatic
Alcohols (MLD Method #1001)
Methanol
Ethanol
Carbonyls (MLD Method #1004)
Formaldehyde
Acetaldehyde
Acrolein
Acetone
Propionaldehyde
Butanal
Benzaldehyde
Hexanal

Table B-2. Species Targeted by the ARB During Vehicle Testing Beginning the First Quarter of 1993

Light-End Hydrocarbons (MLD Method #1002)
Ethane
Ethene
Propane
Propene
Methylpropane
Ethyne
n-Butane
Propadiene
Trans-2-butene
1-Butene
2-Methylpropene
cis-2-Butene
2,2-Dimethylpropane
Methylbutane
1-Propyne
n-Pentane
1,3-Butadiene
3-Methyl-1-butene
Cyclopentene
Trans-2-pentene
2-Methyl-2-butene
1-Pentene
2-Methyl-1-butene
cis-2-Pentene
1-Buten-3-yne
2-Butyne
1-Butyne
Mid-Range Hydrocarbons (MLD Method #1003)
2-Methyl-1,3-butadiene
3,3-Dimethyl-1-butene
1,3-Pentadiene
Cyclopentadiene
2,2-Dimethylbutane

3-Methyl-1-pentene
Cyclopentane
2,3-Dimethylbutane
1-Methyl-tert-butyl-ether
2-Methylpentane
4-Methyl-cis-2-pentene
3-Methylpentane
2-Methyl-1-pentene
n-Hexane
Trans-3-hexene
Trans-2-hexene
2-Methyl-2-pentene
3-Methylcyclopentene
cis-2-Hexene
3-Methyl-c-2-pentene
2,2-Dimethylpentane
Methylcyclopentane
2,4-Dimethylpentane
2,2,3-Trimethylbutane
3,4-Dimethyl-1-pentene
1-Methylcyclopentene
Benzene
3-Methyl-1-hexene
3,3-Dimethylpentane
Cyclohexane
4-Methyl-t-2-hexene
2-Methylhexane
2,3-Dimethylpentane
Cyclohexene
3-Methylhexane
1-Heptene
Trans-1,2-dimethylpentane
cis-1,3-Dimethylcyclopentane
3-Ethylpentane
2,2,4-Trimethylpentane
3-Methyl-trans-3-hexene
n-Heptane

2-Methyl-trans-2-hexene
Trans-2-heptene
2-Methyl-cis-2-hexene
cis-2-Heptene
2,4-Dimethyl-2-pentene
Methylcyclohexane
2,2-Dimethylhexane
2,4,4-Trimethyl-2-pentene
2,5-Dimethylhexane
2,4-Dimethylhexane
3,3-Dimethylhexane
2,3,4-Trimethylpentane
Toluene
2,3,3-Trimethylpentane
2,3-Dimethylhexane
2-Methylheptane
3-Methylheptane
2,2,5-Trimethylhexane
1-Methyl-trans-3-ethylcyclopentane
Octenes
n-Octane
Trans-2-octene
Trans-1,3-dimethylcyclohexane
cis-2-Octene
2,3,5-Trimethylhexane
2,4-Dimethylheptane
2,6-Dimethylheptane
3,5-Dimethylheptane
Ethylbenzene
2,3-Dimethylheptane
m- & p-Xylene
4-Methyloctane
3-Methyloctane
Styrene (ethenylbenzene)
o-Xylene
2,2,4-Trimethylheptane
1-Methyl-4-ethylcyclohexane

n-Nonane
(1-Methylethyl)Benzene
2,2-Dimethyloctane
2,5-Dimethyloctane
2,4-Dimethyloctane
2,6-Dimethyloctane
n-Propylbenzene
1-Methyl-3-ethylbenzene
1-Methyl-4-ethylbenzene
1,3,5-Trimethylbenzene
1-Methyl-2-ethylbenzene
1,2,4-Trimethylbenzene
n-Decane
(2-Methylpropyl)Benzene
(1-Methylpropyl)Benzene
1-Methyl-3-(1-Methylethyl)Benzene
1,2,3-Trimethylbenzene
1-Methyl-4-(1-Methylethyl)Benzene
2,3-Dihydroindene (indan)
1,3-Diethylbenzene
1-Methyl-2-(1-Methylethyl)Benzene
1,4-Diethylbenzene
1-Methyl-3-n-propylbenzene
(1,1-Dimethylethyl)Benzene
1-Methyl-2-n-propylbenzene
1,4-Dimethyl-2-ethylbenzene
1,3-Dimethyl-4-ethylbenzene
1,2-Dimethyl-4-ethylbenzene
1,3-Dimethyl-2-ethylbenzene
n-Undecane (hendecane)
1,2-Dimethyl-3-ethylbenzene
1,2,4,5-Tetramethylbenzene
1,2,3,5-Tetramethylbenzene
C11 Aromatic
2-Methylbutylbenzene
n-Pentylbenzene
1-(1,1-Dimethylethyl)-3,5-(1,1-Dimethylethyl)Benzene

Naphthalene
n-Dodecane
Alcohols (MLD Method #1001)
Methanol
Ethanol
Carbonyls (MLD Method #1004)
Formaldehyde
Acetaldehyde
Acrolein (Propenal)
Acetone (2-Propanone)
Propionaldehyde (Propanal)
Butyraldehyde (Butanal)
Methyl Ethyl Ketone
Methacrolein
Benzaldehyde
Crotonaldehdye
Valeraldehyde
m-Tolualdehdye
Hexanal

APPENDIX C

Summary of Maintenance on Vehicles Undergoing Emissions Tests

APPENDIX C

Summary of Maintenance on Vehicles Undergoing Emissions Tests

Maintenance on CleanFleet vans that had emissions tests is summarized in this appendix. Maintenance activities on each fleet are summarized in individual tables. Also shown is the symbol (triangle, square, circle) used in plotting exhaust emission data in Figures 4 through 12 in the body of the report. In Table C-5 for control vans, the location from which each van was taken is listed under the plotting symbol. Control vans were taken from three of the demonstration sites for emissions tests. SHED tests are also indicated. Tables C-1 through C-5 list recorded maintenance activities on the following systems that may influence emissions: ignition, engine group (filters), air intake, exhaust, fuel, and power plant.

The following codes are used in the tables:

AF	Air filter
AIRP	Air injection reaction pump
DPEV	Diaphragm in PEV regulator
EU	E-prom update
GMFS	Gas mass flow sensor
IACG	IAC grommet
IS	Idle speed
MS	Manifold absolute pressure (MAP) sensor
O2	Oxygen sensor
PEV	PEV regulator
OF	Oil filter
PM	Preventive maintenance
S4-7	S4-7 seat in the PEV regulator
TB	Throttle body

Table C-1. Summary of Maintenance Work Performed on CNG Vans

OEM/Van ID	Maintenance	Odometer	Date
Ford/CNF2	PM-OF	3,643	1/18/93
	PM-OF	8,391	4/19/93
o	Emissions Test 1	8,832	4/29/93
	Emissions Test 2	8,858	5/03/93
	Adjust Distributor	10,416	5/26/93
	PM-OF	13,351	7/13/93
	Install Used Cranking System	18,358	10/04/93
	PM-OF	18,560	10/05/93
	Safety/Emissions Inspection	18,575	10/14/93
	SHED	18,650	10/26/93
	Emissions Test 3	18,652	10/26/93
	PM-OF, AF, CVF, FF	21,851	12/28/93
	Adjust Fuel System	25,056	2/11/94
	PM-OF	25,356	3/25/94
	PM-OF	26,626	6/20/94
	Emissions Test 4	27,965	7/28/94
	Emissions Test 5	27,976	7/29/94
	Safety/Emissions Inspection	28,025	8/03/94
	PM-OF, AF	30,006	9/13/94
Ford/CNF4	PM-OF	1,390	11/05/92
	New Fuel Pump	1,938	11/18/92
□	PM-OF	4,418	1/15/93
	Adjust Injectors	6,619	3/04/93
	PM-OF	8,043	4/06/93
	Emissions Test 1	8,158	4/14/93
	Emissions Test 2	8,176	4/16/93
	Safety/Emissions Inspection	9,855	6/03/94
	PM-OF	11,124	7/07/93
	Emissions Test 3	14,853	10/27/93
	SHED 1	14,853	10/27/93
	Emissions Test 4	14,864	10/28/93
	SHED 2	14,864	10/28/93
	PM-OF, AF, CVF, FF	14,912	11/05/93
	PM-OF, AF	17,894	1/18/94
	PM-OF, AF	21,503	4/19/94
	PM-OF, AF	25,608	7/12/94
	Emissions Test 5	26,242	7/28/94
	Emissions Test 6	26,253	7/29/94
	Safety/Emissions Inspection	26,303	8/03/94

OEM/Van ID	Maintenance	Odometer	Date
Ford/CNF6	PM-OF	1,529	2/05/93
	PM-OF	4,095	4/07/93
△	Emissions Test 1	4,864	4/28/93
	Emissions Test 2	4,883	4/29/93
	PM-OF, AF	8,300	7/27/93
	PM-OF	12,296	10/09/93
	Safety/Emissions Inspection	12,760	10/19/93
	PM-OF	16,177	1/12/94
	PM-OF, AF, CVF, FF	16,238	1/13/94
	Emissions Test 3	18,288	2/28/94
	SHED	18,288	2/28/94
	PM-OF	19,127	3/18/94
	Emissions Test 4	23,430	6/10/94
	Emissions Test 5	23,450	6/15/94
	PM-OF, AF	23,503	6/20/94
	Power Plant Other Maintenance	24,184	7/11/94
	Adjust Emission Controls	25,273	7/29/94
	PM-OF, AF	27,347	9/14/94
Chevrolet/CNC1	PM-OF	3,709	12/14/92
	Emissions Test 1	7,830	4/01/93
o	Emissions Test 2	7,848	4/02/93
	PM-OF	7,975	4/06/93
	PM-OF	10,080	6/02/93
	Relocate oil filler tube away from GMFS; remove block learn	10,522	6/15/93
	PM-OF	13,098	8/25/93
	Safety/Emissions Inspection	14,138	9/21/93
	Replace GMS and PEV, and EU; compressor oil in PEV	14,177	9/28/93
	Emissions Test 3	14,334	10/14/93
	PM-OF, AF,CVF, FF	15,322	11/17/93
	PM-OF, AF	18,463	2/07/94
	Replace distributor	19,365	2/28/94
	Replace GMS; remount regulator	Unknown	3/08/94
	PM-OF	21,814	5/11/94
	Emissions Test 4	22,343	5/27/94
	Safety/Emissions Inspection	23,100	6/27/94
	Emissions Test 5	23,128	6/30/94
	SHED	23,128	6/30/94
	PM-OF	24,526	8/03/94
	Adjust Power Plant	25,081	8/23/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/CNC3	PM-OF	2,722	12/16/92
	PM-OF	6,588	3/30/93
□	Emissions Test 1	7,260	4/14/93
	Emissions Test 2	7,271	4/15/93
	PM-OF	9,042	6/04/93
	Relocate oil filler tube away from GMFS	9,049	6/15/93
	Replace GMFS, PEV, S4-7; EU; compressor oil in PEV	Unknown	9/08/93
	PM-OF		
	PM-OF	11,265	9/24/93
	Emissions Test 3	12,262	11/23/93
	SHED 1	12,517	12/02/93
	PM-OF, AF	12,517	12/02/93
	Emission Controls Inspection	17,678	2/16/94
	Adjust propane converter; replace GMS;	18,000	2/22/94
	relocate regulator	18,030	2/22/94
	PM-OF		
	Emissions Test 4	23,031	5/18/94
	Emissions Test 5	23,951	6/09/94
	SHED 2	23,968	6/16/94
	PM-OF	23,968	6/16/94
	Clean air cleaner	25,776	8/10/94
	Install new distributor cap, rotor, wires	25,871	8/17/94
	and plugs	25,871	8/17/94
	Safety/Emissions Inspection		
		26,245	8/26/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/CNC4	PM-OF	3,062	12/10/92
	PM-OF	6,032	3/25/93
△	Emissions Test 1	6,039	3/30/93
	Emissions Test 2	6,058	3/31/93
	PM-OF	9,488	6/02/93
	Emissions Test 3	11,561	7/08/93
	PM-OF	12,434	8/16/93
	Replace GMFS and RS4-7; EU Coil - high voltage leaking	13,304	9/17/93
	PM-OF, AF, CVF, FF	15,495	11/23/93
	Emissions Test 4	15,702	11/30/93
	SHED 1	15,702	11/30/93
	Emissions Test 5	15,713	12/01/93
	SHED 2	15,713	12/01/93
	PM-OF-AF	19,426	2/11/94
	PM-OF	24,029	5/12/94
	Replace spark plugs, rotor, PEV regulator, and fuel lockoff valve	24,230	5/20/94
	Safety/Emissions Inspection; TB Cleaned and Minimum Idle Adjusted	24,295	6/20/94
	Emissions Test 6	24,395	6/23/94
	Emissions Test 7	24,406	6/24/94
	SHED 3	24,406	6/24/94
	Emissions Test 8	24,417	6/29/94
	PM-OF	25,750	8/04/94
	Safety/Emissions Inspection	26,678	8/30/94
Dodge/CND2	PM-OF	5,610	3/03/93
	Emissions Test 1	7,259	5/04/93
o	Emissions Test 2	7,270	5/05/93
	PM-OF	8,386	6/16/93
	PM-OF	11,092	9/13/93
	Emissions Test 3	14,138	12/03/93
	SHED 1	14,138	12/03/93
	Emissions Test 4	14,156	12/07/93
	SHED 2	14,156	12/07/93
	PM-OF, AF	14,475	12/15/93
	PM-OF	18,834	3/10/94
	PM-OF	21,981	5/24/94
	Safety/Emissions Inspection	23,165	6/22/94
	Emissions Test 5	24,767	8/04/94
	Emissions Test 6	24,778	8/05/94
	PM-OF	24,971	8/12/94

OEM/Van ID	Maintenance	Odometer	Date
Dodge/CND4	PM-OF	1,704	11/18/92
	PM-OF	3,206	2/09/93
□	PM-OF	4,247	5/04/93
	Emissions Test 1	4,287	5/10/93
	Emissions Test 2	4,298	5/11/93
	Emissions Test 3	4,558	6/15/93
	PM-OF	5,147	7/23/93
	Install new regulator	5,873	10/07/93
	PM-OF	5,891	10/27/93
	PM-OF	7,076	1/11/94
	Emissions Test 4	7,123	1/13/94
	SHED 1	7,123	1/13/94
	PM-OF	10,716	4/05/94
	Install new fuel tank	10,717	4/05/94
	New catalytic converter and muffler installed	13,551	6/08/94
	Safety/Emissions Inspection	14,172	6/20/94
	Emissions Test 5	14,216	6/23/94
	SHED 2	14,216	6/23/94
	Emissions Test 6	14,227	6/24/94
	PM-OF, AF	14,380	6/29/94
	Safety/Emissions Inspection	16,631	8/15/94
Dodge/CND5	PM-OF	1,370	11/11/92
	Injectors	3,781	1/27/93
△	PM-OF	6,465	5/10/93
	Emissions Test 1	6,468	5/05/93
	Emissions Test 2	6,487	5/06/93
	Adjust electronic engine control	8,169	6/17/93
	PM-OF	9,601	7/29/93
	Safety/Emissions Inspection	10,555	8/18/93
	Safety/Emissions Inspection	11,387	9/10/93
	PM-OF	13,361	10/18/93
	Emissions Test 3	15,323	12/08/93
	SHED	15,329	12/08/93
	PM-OF, AF	16,839	1/12/94
	PM-electronic engine controls	18,177	2/10/94
	Replace emission controls	18,430	2/15/94
	Replace EGR Valve	18,500	2/21/94
	Replace emission controls	18,626	3/24/94
	PM-OF, Replace ignition coil and PCM	18,626	4/04/94
	PM-OF, AF		
	Replace two mechanical injectors	19,429	6/30/94
	Replace emission controls	20,136	7/22/94
	Emissions Test 4	20,136	7/22/94
	Emissions Test 5	20,361	8/05/94
	Emissions Test 6	20,426	8/16/94
	PM-OF, AF	20,437	8/17/94
		21,828	9/19/94

Table C-2. Summary of Maintenance Work Performed on RFG Vans

OEM/Van ID	Maintenance	Odometer	Date
Ford/RFF1	PM-OF	1,852	9/22/92
	PM-OF	4,870	12/8/92
o	PM-OF	7,901	3/03/93
	Emissions Test 1	9,404	4/20/93
	Emissions Test 2[a]	9,430	4/22/93
	PM-OF	10,590	6/01/93
	Safety/Emissions Inspection	11,036	6/15/93
	Emissions Test 3	11,052	6/16/93
	PM-OF	13,533	8/23/93
	Emissions Test 4	15,695	11/16/93
	Emissions Test 5	15,706	11/17/93
	PM-OF, AF, AVF	15,787	11/26/93
	Replace emissions controls	15,845	12/10/93
	PM-OF	16,602	2/08/94
	PM-OF	21,078	7/27/94
	Emissions Test 6	21,334	8/11/94
	SHED	21,334	8/11/94
	Emissions Test 7	21,345	8/12/94
Ford/RFF4	PM-OF	1,668	9/16/92
	PM-OF	3,911	12/23/92
□	PM-OF	5,624	2/25/93
	Emissions Test 1[a]	6,890	4/20/93
	Emissions Test 2[a]	6,912	4/22/93
	PM-OF, AF, PCV	7,606	5/21/93
	Emissions Test 3[a]	8,202	6/16/93
	Emissions Test 4	8,213	6/17/93
	Emissions Test 5	8,599	7/08/93
	PM-OF	9,698	8/17/93
	PM-OF	12,386	11/12/93
	PM-OF, AF, CVF	15,088	2/04/94
	Emissions Test 6	15,487	2/23/94
	PM-OF	17,413	4/20/94
	Safety/Emissions Inspection	18,711	5/25/94
	PM-OF	20,088	7/22/94
	Emissions Test 7	20,765	8/12/94
	SHED	20,754	8/12/94

VEHICLE EMISSIONS

OEM/Van ID	Maintenance	Odometer	Date
Ford/RFF7	PM-OF	1,091	10/28/92
	PM-OF	2,168	4/08/93
△	Emissions Test 1	2,415	5/06/93
	Emissions Test 2	2,433	5/07/93
	Safety/Emissions Inspection	2,804	6/19/93
	PM-OF	3,009	7/06/93
	Emissions Test 3	3,042	7/08/93
	Ignition switch	3,513	9/03/93
	PM-OF	3,861	9/29/93
	PM-OF, AF, CVF	5,025	12/21/93
	Emissions Test 4	5,809	2/10/94
	PM-OF	6,422	3/16/94
	PM-OF	7,995	6/06/94
	PM-OF	9,498	8/29/94
	Emissions Test 5	9,518	9/01/94
	Emissions Test 6	9,529	9/02/94
	SHED	9,529	9/02/94
Chevrolet/RFC2	PM-OF	2,280	11/04/92
	PM-OF	4,412	1/22/93
o	PM-OF	6,703	4/13/93
	Emissions Test 1	7,182	4/30/93
	Emissions Test 2	7,201	5/03/93
	Safety/Emissions Inspection	8,154	6/19/93
	PM-OF, AF	8,426	7/08/93
	PM-OF, AF	8,429	7/08/93
	PM-OF	9,901	10/04/93
	PM-OF	11,386	12/30/93
	Emissions Test 3	12,268	2/16/94
	Emissions Test 4	12,279	2/17/94
	PM-OF	12,813	3/17/94
	PM-OF	14,187	6/13/94
	Emissions Test 5	15,306	8/18/94
	SHED	15,306	8/18/94
	Emissions Test 6	15,318	8/19/94
	PM-OF	15,493	9/01/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/RFC5	PM-OF	3,592	1/06/93
	PM-OF	5,880	4/05/93
□	Emissions Test 1	6,508	4/30/93
	Emissions Test 2	6,527	5/04/93
	PM-OF	7,984	7/07/93
	PM-OF	10,080	9/29/93
	PM-OF	12,095	12/16/93
	Emissions Test 3	13,783	2/23/94
	Safety/Emissions Inspection	13,794	2/18/94
	PM-OF	14,374	3/16/94
	PM-OF	16,505	6/06/94
	Emissions Test 4	18,846	9/01/94
	Emissions Test 5	18,857	9/02/94
	SHED	18,857	9/02/94
	PM-OF	22,267	8/25/94
Chevrolet/RFC6	PM-OF	3,687	12/23/92
	PM-OF	5,714	3/19/93
△	Emissions Test 1	7,027	5/14/93
	Emissions Test 2	7,071	5/17/93
	PM-OF	7,936	6/17/93
	Safety/Emissions Inspection	7,936	6/17/93
	PM-OF	10,155	9/09/93
	PM-OF	12,286	12/01/93
	Safety/Emissions Inspection	14,101	2/07/94
	Emissions Test 3	14,131	2/11/94
	PM-OF	14,447	2/23/94
	Safety/Emissions Inspection	15,993	4/18/94
	Emissions Test 4	16,033	4/22/94
	PM-OF	16,461	5/17/94
	PM-OF	19,165	8/11/94
	Emissions Test 5	19,276	8/18/94
	SHED	19,276	8/18/94
	Emissions Test 6	19,287	8/19/94
Dodge/RFD3	PM-OF	3,248	11/13/92
	PM-OF	5,938	1/27/93
o	PM-OF	9,564	4/27/93
	Emissions Test 1	9,941	5/10/93
	Emissions Test 2	9,959	5/11/93
	Safety/Emissions Inspection	11,660	6/26/93
	PM-OF	12,738	7/26/93
	PM-OF	16,362	10/22/93
	Emissions Test 3	17,130	11/16/93
	Emissions Test 4	17,140	11/17/93
	PM-OF	19,373	1/18/94
	PM-OF	21,811	4/05/94
	PM-OF, AF	24,071	7/05/94
	Emissions Test 5	25,637	9/01/94
	Emissions Test 6	25,658	9/07/94
	PM-OF	25,958	9/21/94

OEM/Van ID	Maintenance	Odometer	Date
Dodge/RFD5	PM-OF	1,777	10/21/92
	PM-OF	3,313	1/12/93
□	PM-OF	4,922	4/02/93
	Emissions Test 1	5,326	4/26/93
	Emissions Test 2	5,340	4/27/93
	Safety/Emissions Inspection	6,145	7/01/93
	PM-OF	6,145	7/01/93
	PM-OF	6,653	9/17/93
	PM-OF	9,429	12/10/93
	Emissions Test 3	10,220	3/01/94
	PM-OF	10,264	3/09/94
	PM-OF	11,182	6/02/94
	Emissions Test 4	12,270	8/17/94
	SHED	12,270	8/17/94
	Emissions Test 5	12,281	8/18/94
	PM-OF	12,309	8/23/94
Dodge/RFD6	PM-OF	2,271	10/27/92
	PM-OF	4,664	1/13/93
△	PM-OF	7,710	4/14/93
	Emissions Test 1[a]	8,022	4/27/93
	Emissions Test 2	8,033	4/28/93
	Emissions Test 3	10,332	7/08/93
	PM-OF	10,407	7/14/93
	PM-OF	12,696	10/04/93
	Emissions Test 4	16,275	2/17/94
	Safety/Emissions Inspection	17,069	2/14/94
	PM-OF	17,513	3/25/94
	PM-OF	20,674	6/13/94
	Safety/Emissions Inspection	21,430	7/01/94
	Emissions Test 5	22,766	8/11/94
	SHED	22,766	8/11/94
	Emissions Test 6	22,777	8/12/94
	PM-OF	23,329	9/01/94

[a] Data are available only for the regulated emissions CO, NO_x, and hydrocarbons.

Table C-3. Summary of Maintenance Work Performed on Propane Gas Vans

OEM/Van ID	Maintenance	Odometer	Date
Ford/PRF4	PM-OF	3,703	11/06/92
	Emissions Test 1	3,995	11/18/92
□	Emissions Test 2	4,006	11/19/92
	PM-OF	6,659	1/28/93
	Emissions Test 3	9,622	3/25/93
	Emissions Test 4	9,640	3/26/93
	PM-OF	11,695	4/22/93
	PM-OF	17,540	7/14/93
	Install ADP diagnostic box; correct tach	18,692	7/29/93
	signal wiring	20,112	9/09/93
	Emissions Test 5	20,112	9/09/93
	SHED	20,112	9/09/93
	Replace FSD, S4-7, and FCV	20,576	9/25/93
	PM-OF	21,024	10/07/93
	Install air valve and set mixture	22,293	11/06/93
	Replace distributor cap, rotor and plugs	23,927	12/15/93
	PM-OF, AF, CVF, FF		
	Replace intake and exhaust manifolds	24,540	12/28/93
	due to warpage	24,677	12/30/93
	Adjust idle		
	PM-OF	26,103	1/30/94
	Install new ADP diagnostic box	28,458	3/17/94
	Safety/Emissions Inspection	31,876	5/21/94
	PM-OF	32,666	6/04/94
	Replace MS	32,744	6/07/94
	Replace MS	35,455	7/20/94
	PM-OF	35,684	7/28/94
	Emissions Test 6	37,041	8/24/94
	Emissions Test 7	37,084	8/31/94
	Emissions Test 8	37,095	9/01/94
		37,106	9/02/94

OEM/Van ID	Maintenance	Odometer	Date
Ford/PRF6	PM-OF	3,395	11/05/92
	Emissions Test 1	3,954	11/24/92
	Emissions Test 2	3,965	11/25/92
	PM-OF	6,010	1/27/93
	PM-OF	12,495	7/09/93
	Install ADP diagnostic box; correct tach signal wiring	13,312	7/28/93
	Replace FCV	14,250	8/13/93
	Replace FSD, S4-7, and FCV	16,559	9/25/93
	PM-OF	16,940	10/05/93
	Emissions Test 3	18,728	11/04/93
	SHED 1	18,728	11/04/93
	PM-OF	21,322	12/20/93
	PM-OF	26,939	3/14/94
	Safety/Emissions Inspection	31,529	5/16/94
	Install new ADP diagnostic box and primary diaphragm	32,104	5/21/94
	PM-OF, AF, Replace PCV Valve	32,989	6/02/94
	Replace distributor cap, rotor, wires and plugs	32,989	6/02/94
	Replace FCV (installed backwards)	33,098	6/04/94
	Emissions Test 4	35,394	7/07/94
	SHED 2	35,384	7/07/94
	Emissions Test 5	35,395	7/08/94
	Upgrade diagnostic box and fuel lockoff	35,694	7/27/94
	PM-OF	37,165	8/23/94

OEM/Van ID	Maintenance	Odometer	Date
Ford/PRF13	PM-OF	3,649	11/09/92
	Emissions Test 1	4,124	11/24/92
o	Emissions Test 2	4,135	11/25/92
	PM-OF	6,400	2/01/93
	Safety/Emissions Inspection	10,123	6/02/93
	Replace S4-7, primary and secondary diaphragms; adjust mixture	10,309	6/08/93
	Replace FCV and ADP computer	10,347	6/09/93
	PM-OF	11,430	7/16/93
	Install ADP diagnostic box; correct tach signal wiring	12,013	7/28/93
	Replace FSD, S4-7, and FCV	17,287	9/25/93
	PM-OF	18,641	10/11/93
	Emissions Test 3	20,389	11/03/93
	SHED 1	20,389	11/03/93
	Emissions Test 4	23,880	12/28/93
	Emissions Test 5	23,891	12/30/93
	SHED 2	23,891	12/30/93
	PM-OF	24,041	1/07/94
	PM-OF, AF, Replace PCV Valve	30,370	3/29/94
	Replace distributor cap, rotor, and plugs	30,370	3/29/94
	Emissions Test 6	32,851	5/21/94
	Emissions Test 7	33,575	6/08/94
	Install new ADP diagnostic box	33,589	6/17/94
	PM-OF	33,642	6/22/94
	PM-OF	36,903	8/17/94
		38,099	9/13/94

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OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/PRC4	PM-OF	1,411	11/16/92
	PM-OF	3,550	2/09/93
o	Emissions Test 1	6,720	4/16/93
	Emissions Test 2[(b)]	6,739	4/19/93
	PM-OF	7,639	5/04/93
	Emissions Test 3[(b)]	8,025	5/12/93
	Emissions Test 4	8,043	5/14/93
	PM-OF	11,465	7/30/93
	Replace GMFS, FSD, S4-7, IACG, MS, MAP, and O_2 Sensor; EU; Clean TB; adjust idle	Unknown	8/04/93
	PM-OF	14,995	10/26/93
	Replace O2, MS; clean TB		
	Adjust IS; EU		
	Emissions Test 5	15,828	11/10/93
	SHED 1	15,828	11/10/93
	Emissions Test 6	18,284	12/29/93
	SHED 2	18,284	12/29/93
	PM-OF	18,816	1/17/94
	Replumb tank lines to assure draw of liquid propane	20,353	2/18/94
	PM-OF	22,979	4/07/94
	Replace AF, Spark Plugs, GMFS, and primary diaphragm	24,281	4/26/94
	Replace oxygen sensor and AF and GMFS	25,408	5/21/94
	Safety/Emissions Inspection	26,671	6/11/94
	PM-OF	27,524	6/23/94
	Emissions Test 7	30,211	8/04/94
	Emissions Test 8	30,221	8/05/94
	PM-OF	32,031	9/15/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/PRC5	PM-OF	3,025	12/08/92
	Emissions Test 1[b]	4,888	1/21/93
□	Emissions Test 2[b]	4,899	1/22/93
	PM-OF	6,927	3/01/93
	Emissions Test 3[b]	9,274	4/08/93
	Emissions Test 4[b]	9,285	4/09/93
	Emissions Test 5	9,303	4/13/93
	PM-OF	11,614	5/20/93
	Replumb tank lines to assure draw of liquid propane	11,621	5/20/93
	Replace GMFS	12,396	5/31/93
	Emissions Test 6	13,085	6/15/93
	Safety/Emissions Inspection	14,850	7/16/93
	Replace IACG, FSD, S4-7, and O_2 sensor; EU; clean TB; adjust idle	15,866	8/04/93
	PM-OF	16,312	8/25/93
	Emissions Test 7	17,426	9/16/93
	SHED	17,426	9/16/93
	PM-OF	20,382	11/17/93
	PM-OF	23,419	2/09/94
	Emissions Test 8	25,611	4/08/94
	PM-OF	26,410	5/03/94
	Replace AF, distributor cap, rotor, spark plugs, GMFS, primary and secondary diaphragms	26,410	5/03/94
	Replace fuel lockoff	26,904	5/24/94
	Replace GMS	26,919	5/26/94
	Emissions Test 9	26,970	6/01/94
	Replace fuel lockoff and ECM	28,207	7/11/94
	PM-OF	28,357	7/18/94
	Emissions Test 10	28,727	7/25/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/PRC7	PM-OF	2,481	12/02/92
	Emissions Test 1[b]	5,053	1/21/93
△	Emissions Test 2[b]	5,064	1/22/93
	Emissions Test 3[b]	8,541	4/08/93
	PM-OF	6,916	2/19/93
	Emissions Test 4[b]	9,292	5/05/93
	Clean throttle body[a]	Unknown	4/09/93
	Emissions Test 5[b]	9,311	5/07/93
	PM-OF	9,367	5/11/93
	Emissions Test 6[b]	10,752	6/29/93
	Emissions Test 7	10,763	6/30/93
	Emissions Test 8	10,774	7/01/93
	PM-OF	11,792	8/03/93
	Replace IACG, FSD, S4-7, and O_2	14,205	9/09/93
	Sensor; EU; Clean TB; adjust idle		
	repair bad ground wire on ECU board	Unknown	9/22/93
	Emissions Test 9		
	PM-OF	15,263	10/13/93
	PM-OF	15,832	10/28/93
	PM-OF	22,202	1/19/94
	Replace AF, GMS	27,626	4/11/94
	Safety/Emissions Inspection	29,987	5/21/94
	PM-OF, AF	31,145	6/11/94
	Replace distributor cap, rotor, and spark	32,180	6/29/94
	plugs	32,180	6/29/94
	Emissions Test 10		
	Emissions Test 11	33,801	7/28/94
	SHED	33,812	7/29/94
	PM-OF	33,812	7/29/94
		35,312	9/19/94

[a] Van PRC7 quit running twice on the chassis dynamometer on April 8 during what would have been emissions test 5. The van was brought to IMPCO where an open vacuum port and dirty throttle body was found.

[b] Data are available only for the regulated emissions CO, NO_x, and hydrocarbons.

Table C-4. Summary of Maintenance Work Performed on M-85 Vans

OEM/Van ID	Maintenance	Odometer	Date
M8F4	Clean fuel tank	1,448	12/03/92
	PM-OF	1,515	12/08/92
o	PM-OF	3,258	2/24/93
	Emissions Test 1	6,039	5/12/93
	Emissions Test 2	6,058	5/13/93
	PM-OF	6,151	5/25/93
	Electronic engine controls	6,355	6/02/93
	PM-OF	8,267	8/10/93
	Replace injectors	10,620	10/18/93
	PM-OF	11,142	11/03/93
	Emissions Test 3	13,255	1/12/94
	Emissions Test 4	13,274	1/19/94
	Emissions Test 5	13,285	1/20/94
	PM-OF	13,452	1/27/94
	Safety/Emissions Inspection	18,665	6/10/94
	PM-OF	19,962	7/13/94
	Emissions Test 6	23,020	9/28/94
M8F5	Clean fuel tank	1,069	11/20/92
	PM-OF	1,505	12/10/92
□	PM-OF	3,335	3/01/93
	Emissions Test 1	6,463	5/13/93
	Emissions Test 2	6,479	5/14/93
	PM-OF	6,611	5/19/93
	PM-OF	10,015	8/13/93
	Replace injectors	12,533	10/18/93
	PM-OF	13,427	11/09/93
	Emissions Test 3	15,665	1/31/94
	PM-OF	15,800	2/07/94
	Safety/Emissions Inspection	19,151	5/06/94
	Safety/Emissions Inspection	20,078	5/31/94
	PM-OF	21,811	7/18/94
	Emissions Test 5	24,263	9/28/94
	SHED	24,271	9/28/94

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OEM/Van ID	Maintenance	Odometer	Date
M8F6	Clean fuel tank	1,693	12/03/92
	PM-OF	1,927	12/14/92
△	PM-OF	3,712	3/02/92
	Emissions Test 1	5,306	5/18/93
	Emissions Test 2	5,317	5/19/93
	Replace fuel pump	5,317	5/19/93
	PM-OF,AF	5,480	5/26/93
	PM-OF	6,955	8/17/93
	Replace injectors	8,329	10/18/93
	PM-OF	9,114	11/10/93
	Emissions Test 3	11,534	1/28/94
	Emissions Test 4	11,550	1/31/94
	PM-OF, AF	11,663	2/04/94
	Safety/Emissions Inspection	16,758	6/14/94
	PM-OF	17,970	7/19/94
	Emissions Test 5	20,344	9/23/94
	Emissions Test 6	20,358	9/26/94
	SHED	20,358	9/26/94

Table C-5. Summary of Maintenance Work Performed on Control Vans

OEM/Van ID	Maintenance	Odometer	Date
Ford/UCF2	PM-OF	2,317	10/19/92
	Emissions Test 1	3,997	12/03/92
□	Emissions Test 2[(a)]	4,008	12/04/92
Irvine	PM-OF	5,509	1/18/93
	PM-OF	7,351	3/12/93
	PM-OF	11,396	6/16/93
	Emissions Test 3	12,395	7/14/93
	PM-OF	14,710	9/13/93
	Emissions Test 4	15,247	9/29/93
	SHED	15,239	9/29/93
	PM-OF, AF, CVF	17,814	12/06/93
	PM-OF, AF	22,032	3/14/94
	PM-OF, AF	25,823	5/21/94
	Emissions Test 5	27,757	7/01/94
	Emissions Test 6	27,773	7/06/94
	PM-OF, AF, CVF	29,241	8/11/94
	Adjust carburetor	29,780	8/22/94
Ford/URF1	PM-OF	2,129	10/08/92
	Emissions Test 1	4,224	12/17/92
o	Emissions Test 2	4,235	12/18/92
Los Angeles	PM-OF	4,392	12/29/92
	PM-OF	6,718	3/22/93
	PM-OF	9,508	6/21/93
	PM-OF	11,497	9/10/93
	PM-OF	13,511	12/02/93
	Emissions Test 3	14,378	1/07/94
	PM-OF	15,742	2/25/94
	PM-OF	18,268	5/18/94
	Safety/Emissions Inspection	18,268	5/18/94
	Emissions Test 4	19,698	7/08/94
	SHED	19,713	7/08/94
	Emissions Test 5	19,713	7/12/94
	PM-OF, AF	20,722	8/11/94

OEM/Van ID	Maintenance	Odometer	Date
Ford/URF3	PM-OF	1,587	9/03/92
	PM-OF	3,251	11/24/92
△	Emissions Test 1	3,458	12/17/92
Los Angeles	Emissions Test 2	3,469	12/18/92
	PM-OF	5,191	5/10/93
	PM-OF	6,935	8/02/93
	PM-OF	8,735	10/27/93
	PM-OF	10,141	1/13/94
	Emissions Test 3	10,186	1/21/94
	Emissions Test 4	10,197	2/01/94
	PM-OF	11,314	4/06/94
	Emissions Test 5	11,490	4/14/94
	Emissions Test 6	11,501	4/15/94
	Emissions Test 7	11,527	4/21/94
	Safety/Emissions Inspection	11,961	5/25/94
	PM-OF	12,763	7/05/94
	Emissions Test 8	13,357	7/25/94
	Emissions Test 9	13,368	7/26/94
	SHED	13,368	7/26/94
	PM-OF	14,366	9/23/94
Chevrolet/UCC3	PM-OF	4,011	11/16/92
	Emissions Test 1[a]	4,450	12/03/92
△	Emissions Test 2[a]	4,461	12/04/92
Irvine	PM-OF	7,890	2/11/93
	Emissions Test 3	10,152	4/06/93
	Emissions Test 4	10,162	4/07/93
	PM-OF	11,485	5/04/93
	PM-OF	15,957	7/28/93
	Emissions Test 5	18,813	9/23/93
	PM-OF	20,060	10/25/93
	PM-OF	25,795	1/18/94
	PM-OF	29,914	4/05/94
	PM-OF	33,977	6/29/94
	Emissions Test 6	34,527	7/20/94
	SHED	34,527	7/20/94
	Emissions Test 7	34,538	7/21/94
	Safety/Emissions Inspection	34,648	8/05/94
	PM-OF	36,608	9/21/94
	Replace muffler	36,754	9/28/94

OEM/Van ID	Maintenance	Odometer	Date
Chevrolet/UPC1	PM-OF	4,675	11/06/92
	Emissions Test 1	5,690	12/02/92
o	Emissions Test 2	5,701	12/03/92
Rialto	PM-OF	7,333	1/19/93
	Replace AIRP	7,733	1/19/93
	PM-OF	7,994	1/28/93
	Emissions Test 3	10,859	3/24/93
	Emissions Test 4	10,878	3/25/93
	PM-OF	12,292	4/22/93
	PM-OF	16,230	7/13/93
	Emissions Test 5	19,734	9/10/93
	PM-OF	21,316	10/05/93
	PM-OF	26,014	12/21/93
	PM-OF	30,702	3/14/94
	Replace AF, distributor cap, rotor and plugs	34,503	5/17/94
	PM-OF	35,390	6/01/94
	Adjust timing	35,404	6/02/94
	Emissions Test 6	36,253	8/12/94
	PM-OF	36,322	8/24/94
Chevrolet/UPC3	PM-OF	5,028	11/16/92
	Emissions Test 1	5,840	12/02/92
□	Emissions Test 2	5,851	12/03/92
Rialto	PM-OF	9,624	2/09/93
	PM-OF	13,517	5/05/93
	PM-OF	17,104	7/28/93
	PM-OF	17,104	7/28/93
	Emissions Test 4	20,511	9/21/93
	PM-OF	21,844	10/22/93
	PM-OF	26,599	1/12/94
	PM-OF	30,893	3/31/94
	Safety/Emissions Inspection	32,941	5/07/94
	PM-OF	34,898	6/13/94
	Emissions Test 5	35,455	6/29/94
	Emissions Test 6	35,466	6/30/94
	PM-OF	38,999	9/07/94
	Emissions Test 7	39,219	9/13/94

OEM/Van ID	Maintenance	Odometer	Date
Dodge/UCD1	PM-OF	3,180	11/05/92
	Emissions Test 1	5,773	12/09/92
o	Emissions Test 2	5,784	12/10/92
Irvine	PM-OF	9,399	1/27/93
	PM-OF	13,517	5/05/94
	PM-OF	17,104	7/28/93
	PM-OF	21,844	10/22/93
	PM-OF	26,599	1/12/94
	Emissions Test 3	27,773	9/23/93
	PM-OF	30,893	3/31/94
	Safety/Emissions Inspection	32,941	5/07/94
	PM-OF	34,898	6/13/94
	PM-OF	38,999	9/07/94
	Emissions Test 4	42,917	7/21/94
	SHED	42,917	7/21/94
	Emissions Test 5	42,928	7/22/94
Dodge/URD1	PM-OF	3,836	1/11/93
	PM-OF	5,626	3/31/93
□	Emissions Test 1[a]	5,757	4/09/93
Los Angeles	Emissions Test 2[a]	5,779	4/12/93
	Emissions Test 3	5,798	4/13/93
	Emissions Test 4[a]	5,817	4/15/93
	Emissions Test 5	7,487	6/22/93
	PM-OF	7,516	6/24/93
	Safety/Emissions Inspection	7,635	7/01/93
	PM-OF	9,538	9/16/93
	PM-OF	11,752	12/10/93
	Emissions Test 6	13,877	2/25/94
	Emissions Test 7	13,892	2/28/94
	Emissions Test 8	13,903	3/01/94
	PM-OF	14,008	3/04/94
	Emissions Test 10	16,477	5/09/94
	PM-OF	17,052	5/25/94
	Emissions Test 11	19,574	8/04/94
	SHED	19,578	8/04/94
	Emissions Test 12	19,585	8/05/94
	PM-OF	19,879	8/17/94
	Emissions Test 13	20,691	9/13/94
	Emissions Test 14	20,707	9/22/94
	Emissions Test 15	20,718	9/23/94

OEM/Van ID	Maintenance	Odometer	Date
Dodge/URD3	PM-OF	2,196	10/21/92
	Emissions Test 1	3,474	12/09/92
△	Emissions Test 2	3,485	12/10/92
Los Angeles	PM-OF	4,348	1/13/93
	Safety/Emissions Inspection	8,298	7/01/93
	PM-OF	8,298	7/01/93
	PM-OF	9,995	9/22/93
	PM-OF	11,853	12/09/93
	Emissions Test 3	12,364	1/11/94
	PM-OF	13,159	3/09/94
	PM-OF	14,605	5/31/94
	Emissions Test 4	15,889	8/03/94
	SHED	15,889	8/03/94
	Emissions Test 5	15,900	8/04/94
	PM-OF	16,324	8/25/94

[a] Data are available only for the regulated emissions CO, NO_x, and hydrocarbons.

APPENDIX D

Detailed Fuel Analyses

APPENDIX D

Detailed Fuel Analyses

To characterize the fuels used in the emission tests, one sample of each fuel was analyzed by the ARB (or by AtmAA under purchase order from the ARB) during each round of emissions tests. Recognizing that the composition of the fuels varied with time (particularly that of propane gas and natural gas), these results need to be seen as a characterization of the fuels, not as detailed analyses of the fuels used for all of the tests. Results are shown in Tables D-1 through D-8.

Table D-1. Distillation Points, Vapor Pressure, and Density of RF-A Gasoline

Distillation Points[a]	Temperature (°F)		
	Round 1[c]	Round 2	Round 3
IBP	92	90	NA[d]
5	95	109	NA
10	118	124	NA
20	147	145	NA
30	170	167	NA
40	195	191	NA
50	217	214	NA
60	236	238	NA
70	259	263	NA
80	288	292	NA
90	335	333	NA
95	370	371	NA
FBP	412	418	NA
Reid Vapor Pressure (psi)	8.60	8.65	NA
API at 60°F[b]	58.4	57.6	NA

(a) IBP = Initial boiling point.
FBP = Final boiling point.
(b) API = Density.
(c) Round of emissions tests.
(d) NA = Data not available.

Table D-2. Distillation Points, Vapor Pressure, and Density of Phase 2 RFG

Distillation Points[a]	Temperature (°F)		
	Round 1	Round 2	Round 3[c]
IBP	99	100	NA
5	120	126	NA
10	135	140	NA
20	152	157	NA
30	169	172	NA
40	186	190	NA
50	204	209	NA
60	220	225	NA
70	234	242	NA
80	252	264	NA
90	294	297	NA
95	337	320	NA
FBP	399	394	NA
Reid Vapor Pressure (psi)	6.85	6.60	NA
API at 60°F[b]	60.8	59.30	NA

[a] IBP = Initial boiling point.
FBP = Final boiling point.
[b] API = Density.
[c] NA = Data not available.

Table D-3. Distillation Points, Vapor Pressure, and Density of M-85

Distillation Points[a]	Temperature (°F)		
	Round 1	Round 2	Round 3[c]
IBP	125	123	NA
5	138	137	NA
10	142	143	NA
20	145	145	NA
30	146	146	NA
40	147	147	NA
50	147	147	NA
60	147	147	NA
70	147	147	NA
80	147	147	NA
90	148	148	NA
95	149	149	NA
FBP	151	152	NA
Reid Vapor Pressure (psi)	6.70	7.20	NA
API at 60°F[b]	48.2	48.20	NA

[a] IBP = Initial boiling point.
FBP = Final boiling point.
[b] API = Density.
[c] NA = Data not available.

Table D-4. Contribution of Compound Classes to Composition of RF-A Gasoline

Compound Class	Concentration (Weight Percent)		
	Round 1	Round 2	Round 3
Alkanes	46.8783	48.293	NA
Alkenes	3.4217	8.200	NA
Aromatics	31.2890	35.892	NA
Naphthenes	4.9527	4.811	NA
Methanol	<0.0001	NR[a]	NA
MTBE	<0.0001	0.107	NA
TOTAL	86.5416	97.303	NA

[a] NR = Not reported.

Table D-5. Contribution of Compound Classes to Composition of Phase 2 RFG

Compound Class	Concentration (Weight Percent)		
	Round 1	Round 2	Round 3[a]
Alkanes	49.1369	52.610	NA
Alkenes	1.1586	4.427	NA
Aromatics	29.1766	28.064	NA
Naphthenes	2.1937	2.736	NA
Methanol	<0.0001	NR[b]	NA
MTBE	10.3081	10.815	NA
TOTAL	91.9738	98.652	NA

[a] NA = Data not available.
[b] NR = Not reported.

Table D-6. Contribution of Compound Classes to Composition of M-85

Compound Class	Concentration (Weight Percent)		
	Round 1	Round 2	Round 3[a]
Alkanes	7.5884	5.823	7.688
Alkenes	0.1540	0.444	0.401
Aromatics	4.0079	4.115	2.895
Naphthenes	0.3055	0.307	1.511
Methanol	86.1248	87.792	86.183
MTBE	<0.001	1.428	0.163
TOTAL	98.1806	99.909	98.841

[a] NA = Data not available.

Table D-7. Composition of Propane Gas

Component	Concentration (Weight Percent)		
	Round 1	Round 2	Round 3
O_2	<0.096	Trace	Trace
N_2	<0.094	Trace	Trace
CO_2	NR[a]	Trace	Trace
Methane	0.1292	0.0459	0.0065
Ethane	3.8765	2.8419	0.7045
Propane	95.3114	90.180	85.7972
Propene	0.0548	6.3834	7.4079
i-Butane	0.5683	0.5053	3.6418
n-Butane	0.0484	0.0427	2.0786
i-Pentane	0.0016	0.0005	0.1906
n-Pentane	0.0012	0.0002	0.1255
n-Hexane	NR	<0.0001	0.0348
n-Heptane	0.0021	<0.0001	0.0096

[a] NR = Not reported.

Table D-8. Composition of a Sample of Compressed Natural Gas

Component	Concentration (Weight Percent)		
	Round 1	Round 2	Round 3
O_2	<0.106	Trace	Trace
N_2	0.785	Trace	Trace
CO_2	2.034	5.4389	4.2405
Methane	91.329	90.9493	88.5095
Ethane	3.7258	2.4943	5.6240
Propane	1.2476	0.7501	0.9893
Propene	NR	NR	0.0084
i-Butane	0.1289	0.1037	0.1528
n-Butane	0.2564	0.1430	0.2466
i-Pentane	0.1328	0.0531	0.0925
n-Pentane	0.1243	0.0419	0.0762
n-Hexane	0.0531	0.0170	0.0329
n-Heptane	0.0063	0.0066	0.0202

[a] NR = Not reported.

APPENDIX E

Statistical Analysis Approach

APPENDIX E

Statistical Analysis Approach

Modeling Mean Emissions

The log-linear model was chosen to describe the data. For each species, emissions were modeled versus mileage, m_{ij}, as

$$\log(E_{ij}) = \alpha + \beta \log(m_{ij}) + v_i + \delta_i \log(m_{ij}) + \epsilon_{ij}.$$

where E_{ij} is the measured emissions in (g/mi) from the jth test on the ith vehicle. The terms α (intercept) and β (slope) represent the systematic fleet-specific effects. The terms v_i and δ_i represent vehicle-specific deviations from the fleet-specific effects. The final term ϵ_{ij} represents testing variability that may include variations in test procedures and chemical analyses. Vehicle and test variability terms, v_i, δ_i and ϵ_{ij}, are assumed to be normally distributed.

Because the model selected for emissions is lognormal (i.e., $\log(E_{ij})$ has a normal distribution), the average emissions within a fleet is

$$E(emissions) = \exp\left(\mu + \frac{\sigma^2}{2}\right).$$

The mean, μ, on the log scale depends on mileage and is expressed in terms of the model parameters as

$$\mu = \alpha + \beta \log(m) \tag{E-1}$$

where m is the mileage/10,000. The variance, σ^2, is expressed in terms of vehicle and test variance as

$$\sigma^2 = \sigma^2_{vehicle} + \sigma^2_{test}.$$

Thus, vehicle variability can be expressed in terms of the modelled random effects as follows:

$$\begin{aligned} \sigma^2_{vehicle} &= var(\nu_i + \delta_i \log(m)) \\ &= var(\nu_i) + \log(m)^2\ var(\delta_i) + 2\log(m)\ cov(\nu_i, \delta_i) \end{aligned} \tag{E-2}$$

It was assumed that ν_i and δ_i are distributed according to a multivariate normal distribution as shown below.

$$\begin{bmatrix} \nu_i \\ \delta_i \end{bmatrix} \sim N \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} var(\nu_i) & cov(\nu_i,\delta_i) \\ cov(\nu_i,\delta_i) & var(\delta_i) \end{bmatrix} \right) .$$

The covariance term cov(ν_i, δ_i) is included to allow for a possible correlation between a vehicle's mean emissions and its rate of degradation with mileage. However, statistical tests suggested very little correlation between these factors. Therefore it was assumed that these factors were independent. Variance estimates were pooled across fleets, except where significant differences in the variability of the transformed levels among fleets were observed. Table E-1 summarizes these instances.

Table E-1. Compounds for Which Variability Estimates Depended on Fleet

Compound	Pool 1	Pool 2
CO, NO_x, benzene	RFG, RF-A	CNG, propane gas, M-85
Formaldehyde	RFG, RF-A, M-85	CNG, propane gas
1,3-butadiene	RFG, RF-A, M-85, Ford propane gas	CNG, Chevrolet propane gas[(a)]
N_2O[(b)]	Chevrolet RFG	All other fleets

[(a)] The CNG and Chevrolet propane gas vehicles had no measurable emissions of 1,3-butadiene. To avoid underestimating variability in emissions levels, these fleets were not included when fitting the model. For these fleets, mean emissions were estimated as zero.

[(b)] There was insufficient data on emissions of N_2O from the unleaded vehicles to fit models versus mileage.

Estimated Percent Increase for Additional 10,000 Miles

In Table 7, estimates were presented of the average percent increase in emissions of CO, NMOG, and NO_x from 10,000 to 20,000 miles. These estimates were based on the fitted models. Based on an analysis simlar to that described above for estimating mean emissions, the estimated increase from mileage m to m+Δ (measured in 10,000 mi) is:

$$100 * \left(\frac{\exp\left(\alpha + \beta \log(m+\Delta) + \frac{var(\nu) + \log(m+\Delta)^2 var(\delta) + \sigma^2_{test}}{2}\right)}{\exp\left(\alpha + \beta \log(m) + \frac{var(\nu) + (\log(m))^2 var(\delta) + \sigma^2_{test}}{2}\right)} - 1 \right)$$

$$= 100 * \left(\exp\left(\beta \log\left(\frac{m+\Delta}{m}\right) + \frac{Var(\delta)}{2}\left[(\log(m+\Delta)^2) - (\log(m))^2\right]\right) - 1 \right)$$

From 10,000 to 20,000 miles, this increase is

$$100 * \left(\exp\left(\beta \log 2 + \frac{Var(\delta)}{2} (\log 2)^2 \right) - 1 \right) .$$

Comparing Alternative Fuel Emissions With a Control

In making comparisons between emissions of alternative fuel (alt) vehicles and control (ctrl) vehicles, ratios of mean emissions were estimated. Thus, the parameter of interest is:

$$\frac{\exp\left(\mu_{alt} + \frac{\sigma^2_{alt}}{2}\right)}{\exp\left(\mu_{ctrl} + \frac{\sigma^2_{ctrl}}{2}\right)} = \exp\left(\mu_{alt} - \mu_{ctrl} + \frac{\sigma^2_{alt}}{2} - \frac{\sigma^2_{ctrl}}{2}\right) . \qquad \text{(E-3)}$$

The effect of mileage, m, on μ_{alt}, μ_{ctrl}, σ^2_{alt}, and σ^2_{ctrl} is suppressed from the notation, but was included in the computations. This effect was illustrated in equations E-1 and E-2.

In most cases, the variance components were very similar, in which case the latter two terms on the right hand side of equation E-3 canceled each other, and confidence intervals were derived based on the standard error of $\mu_{alt} - \mu_{ctrl}$. However, for the compounds indicated in Table E-1, differences in the estimated variance components between the alternative and control fueled vehicles could not be ignored. In these cases, the estimated uncertainty in estimating $\sigma^2_{alt} - \sigma^2_{ctrl}$ was also taken into account.

VEHICLE EMISSIONS

Modeling Proportions

Some of the analyses required modeling of proportions such as the determination of the percent contribution of light- and mid-range hydrocarbons, alcohols, and carbonyls to total NMOG and total ozone. The percent contribution of propane to total NMOG emissions from propane gas vehicles, and methanol from M-85 vehicles was also modeled. For these ratios, observed variability was reasonably constant, so the data were not transformed for analysis. The mixed models, including mileage and vehicle effects, were fit directly to the observed proportions. For these responses, mileage was found to be a significant factor only in the contribution of propane to total NMOG from the propane gas vehicles. The only other caveat is that a significant difference was observed in the contribution to total NMOG from RFG vehicles between the first round of emissions tests and the second and third rounds of emissions tests. This is discussed in the Ozone Reactivity section of this report.

Miscellaneous Modeling

Modeling relative specific ozone reactivity adjustment factors required two steps. First, the measured specific ozone reactivity (SOR: observed ratio of total computed ozone reactivity to total NMOG) was modeled as a linear function of mileage. The impact of mileage was significant for several fleets (all RF-A, Chevrolet and Dodge RFG, and Chevrolet CNG). This provided estimates of SOR for each fleet with confidence intervals as a function of mileage.

Fieller's theorem (see Reference 2) was then used to provide confidence intervals for the relative specific ozone reactivity for each alternative fuel (i.e., the ratio of mean SOR for each alternative fuel to the mean SOR for its respective control fleet). Because of the dependence on mileage, this needed to be performed at multiple mileages.

Formaldehyde Emissions by Bag

Measured emissions of formaldehyde from M-85 vehicles by bag were modeled linearly as a function of mileage. No log transformation to either the response or mileage was deemed necessary.

SHED Tests

Due to the small number of evaporative emissions tests performed, simple averages and standard deviations were calculated for each of the evaporative emissions considered. No attempt was made to separate vehicle-to-vehicle variability from replicate test variability.

1. Searle, S.R., Linear Models, Wiley and Sons, New York, 1976.

2. Kotz, S., and Johnson, N.L., Encyclopedia of Statistical Sciences, Vol. 3, Wiley and Sons, 1983.

APPENDIX F

Tabulated Emission Results

APPENDIX F

Tabulated Emission Results

Emission results are tabulated in this appendix to provide documentation of results. Two sets of numerical results are presented. The first set, contained in Tables F-1 through F-7, is simple mean values and standard deviations (SD) of exhaust emissions for each phase of testing on each fleet. Table F-1 provides information on the number of tests that were conducted and the vehicle odometer readings over which the data were gathered. The second set of tables contains estimated exhaust emissions at selected mileage from the statistical modeling of the data. These numerical data correspond to the plotted lines in Figures 4-12.

Table F-1. Mileage Range and Number of Speciated Tests Available on Exhaust Emissions by Testing Phase

OEM	Fuel	Phase	Mileage	Tests[a]
Chevrolet	CNG	1	6,039 — 11,561	7
		2	12,517 — 15,713	4
		3	22,343 — 24,406	6
	Propane Gas	1	6,720 — 13,085	6
		2	15,263 — 25,611	4
		3	26,970 — 33,812	6
	RFG	1	6,508 — 7,201	6
		2	12,268 — 16,033	5
		3	15,306 — 19,287	6
	RF-A	1	5,690 — 10,878	8
		2	18,813 — 20,511	3
		3	34,527 — 35,466	4
Dodge	CNG	1	4,287 — 7,270	7
		2	7,123 — 15,323	4
		3	14,216 — 24,778	6
	RFG	1	5,326 — 10,332	6
		2	10,220 — 17,140	4
		3	12,270 — 25,658	6
	RF-A	1	3,474 — 7,487	6
		2	16,477 — 27,773	2
		3	15,889 — 42,928	6
Ford	CNG	1	4,864 — 8,858	6
		2	14,853 — 18,652	4
		3	23,430 — 27,976	6
	M-85	1	5,306 — 6,479	6
		2	11,534 — 15,665	6
		3	20,344 — 24,263	5
	Propane Gas	1	3,954 — 9,640	8
		2	18,728 — 23,891	5
		3	33,575 — 37,106	7
	RFG	1	2,433 — 11,052	6
		2	5,809 — 15,706	4
		3	9,518 — 21,345	5
	RF-A	1	3,458 — 12,395	6
		2	11,490 — 15,247	4
		3	13,357 — 27,773	6

(a) These numbers reflect the number of emissions tests for which gas chromatograph (GC) results were compiled and used in the statistical analysis. In some cases species measured on continuous instruments, such as CO, CO_2, NO_x, and methane have higher numbers of tests. However, for a few tests the results obtained from the GC measuring carbonyls were rejected by quality control, so that actual sample sizes can be lower for compounds requiring the quantification of carbonyls.

Table F-2. Exhaust Emissions of CO, NMHC, NMOG, and NO_x (g/mi) by Phase of Testing

			CO		NMHC		NMOG		NO_x	
OEM	Fuel	Phase	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Chevrolet	CNG	1	2.35	(1.32)	0.08	(0.03)	0.08	(0.03)	1.42	(0.16)
		2	3.04	(1.16)	0.08	(0.03)	0.09	(0.03)	1.52	(0.58)
		3	4.99	(2.25)	0.10	(0.02)	0.11	(0.03)	1.59	(0.46)
	PRO	1	5.87	(3.90)	0.56	(0.08)	0.57	(0.08)	0.93	(0.18)
		2	3.43	(1.17)	0.62	(0.26)	0.63	(0.26)	0.96	(0.14)
		3	6.67	(2.59)	0.69	(0.11)	0.69	(0.11)	1.13	(0.22)
	RFG	1	7.99	(2.32)	0.24	(0.04)	0.25	(0.04)	2.57	(0.15)
		2	9.81	(2.53)	0.33	(0.02)	0.35	(0.02)	3.27	(0.17)
		3	9.26	(0.57)	0.40	(0.03)	0.43	(0.03)	3.38	(0.16)
	RF-A	1	9.10	(1.51)	0.34	(0.06)	0.35	(0.06)	2.58	(0.60)
		2	13.56	(4.28)	0.50	(0.07)	0.52	(0.07)	3.78	(0.32)
		3	14.27	(2.79)	0.71	(0.15)	0.74	(0.15)	4.96	(0.48)
Dodge	CNG	1	1.16	(0.20)	0.02	(0.00)	0.02	(0.00)	0.23	(0.03)
		2	1.56	(0.33)	0.02	(0.00)	0.02	(0.00)	0.50	(0.16)
		3	1.54	(0.70)	0.03	(0.01)	0.03	(0.01)	0.46	(0.24)
	RFG	1	3.92	(0.41)	0.20	(0.05)	0.20	(0.05)	0.45	(0.03)
		2	6.24	(0.45)	0.24	(0.00)	0.25	(0.01)	0.53	(0.06)
		3	6.47	(1.85)	0.29	(0.05)	0.30	(0.05)	0.48	(0.06)
	RF-A	1	4.85	(0.68)	0.30	(0.10)	0.31	(0.10)	0.46	(0.18)
		2	8.03	(2.39)	0.42	(0.12)	0.43	(0.11)	0.80	(0.23)
		3	7.62	(1.15)	0.39	(0.08)	0.40	(0.08)	0.88	(0.16)
Ford	CNG	1	0.66	(0.33)	0.11	(0.09)	0.11	(0.09)	1.22	(0.83)
		2	0.74	(0.52)	0.09	(0.05)	0.09	(0.06)	1.60	(0.77)
		3	0.86	(0.42)	0.11	(0.07)	0.12	(0.07)	1.70	(0.89)
	M-85	1	1.02	(0.08)	0.13[a]	(0.01)[a]	0.20	(0.03)	0.57	(0.10)
		2	0.92	(0.10)	0.15[a]	(0.03)[a]	0.33	(0.09)	0.63	(0.17)
		3	1.32	(0.16)	0.16[a]	(0.02)[a]	0.34	(0.07)	0.79	(0.19)
	PRO	1	0.94	(0.21)	0.35	(0.08)	0.35	(0.08)	0.97	(0.23)
		2	4.12	(5.92)	0.35	(0.03)	0.36	(0.03)	0.68	(0.24)
		3	1.79	(1.71)	0.43	(0.09)	0.41	(0.08)	0.81	(0.15)
	RFG	1	1.89	(0.87)	0.23	(0.08)	0.23	(0.09)	0.75	(0.05)
		2	1.66	(0.49)	0.19	(0.02)	0.20	(0.02)	0.77	(0.07)
		3	3.43	(1.12)	0.27	(0.03)	0.28	(0.03)	0.78	(0.15)
	RF-A	1	1.61	(0.14)	0.21	(0.02)	0.21	(0.02)	0.71	(0.12)
		2	4.23	(2.29)	0.34	(0.10)	0.35	(0.10)	0.69	(0.08)
		3	2.49	(0.77)	0.29	(0.05)	0.31	(0.05)	0.80	(0.06)

[a] OMHCE was used for M-85 vehicles.

Table F-3. Exhaust Emissions of Total Hydrocarbons (g/mi) by Phase of Testing

OEM	Fuel	Phase	THC Mean	THC (SD)
Chevrolet	CNG	1	2.11	(0.48)
		2	2.76	(1.04)
		3	3.10	(0.67)
	Propane Gas	1	0.59	(0.11)
		2	0.74	(0.29)
		3	0.82	(0.11)
	RFG	1	0.34	(0.03)
		2	0.42	(0.04)
		3	0.52	(0.03)
	RF-A	1	0.40	(0.07)
		2	0.58	(0.08)
		3	0.82	(0.06)
Dodge	CNG	1	0.52	(0.08)
		2	0.79	(0.18)
		3	1.35	(1.34)
	RFG	1	0.28	(0.03)
		2	0.32	(0.02)
		3	0.36	(0.07)
	RF-A	1	0.41	(0.08)
		2	0.49	(0.06)
		3	0.47	(0.08)
Ford	CNG	1	2.62	(1.67)
		2	3.16	(1.50)
		3	3.53	(1.59)
	M-85	1	0.17	(0.01)
		2	0.06	(0.02)
		3	0.07	(0.02)
	Propane Gas	1	0.48	(0.11)
		2	0.50	(0.08)
		3	0.66	(0.23)
	RFG	1	0.32	(0.06)
		2	0.28	(0.02)
		3	0.38	(0.05)
	RF-A	1	0.33	(0.02)
		2	0.47	(0.11)
		3	0.38	(0.04)

Table F-4. Composition of Nonmethane Organic Gas Exhaust Emissions (mg/mi) by Phase of Testing

			Alcohols		Carbonyls		Light-end HC		Mid-range HC		Total NMOG	
OEM	Fuel	Phase	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Chevrolet	CNG	1	0.00	(0.00)	3.33	(0.22)	77.2	(26.9)	1.8	(1.7)	82.3	(27.0)
		2	0.00	(0.00)	4.32	(1.05)	79.2	(25.7)	3.9	(1.3)	87.4	(27.8)
		3	0.00	(0.00)	10.37	(4.07)	89.8	(23.7)	8.1	(6.2)	108.2	(27.2)
	PRO	1	0.00	(0.00)	6.23	(1.53)	560.2	(80.0)	2.6	(3.5)	569.0	(83.0)
		2	0.00	(0.00)	7.08	(2.53)	616.5	(259.8)	3.0	(1.3)	627.0	(263.0)
		3	0.00	(0.00)	8.04	(0.83)	681.7	(105.9)	3.4	(1.6)	693.0	(107.0)
	RFG	1	0.00	(0.00)	11.81	(1.08)	103.1	(19.2)	134.9	(27.5)	250.0	(42.0)
		2	0.00	(0.00)	18.16	(3.95)	116.6	(8.1)	210.3	(14.7)	345.0	(23.0)
		3	0.00	(0.00)	29.79	(2.34)	135.2	(23.9)	268.2	(32.0)	433.0	(32.0)
	RF-A	1	0.00	(0.00)	10.29	(2.51)	122.4	(33.0)	221.5	(32.5)	354.0	(65.0)
		2	0.00	(0.00)	17.33	(1.04)	134.6	(15.2)	364.6	(58.7)	517.0	(73.0)
		3	0.00	(0.00)	36.73	(3.53)	208.0	(24.7)	497.4	(124.0)	742.0	(150.0)
Dodge	CNG	1	0.00	(0.00)	2.86	(0.44)	14.3	(1.9)	1.5	(1.6)	18.7	(2.2)
		2	0.00	(0.00)	3.28	(0.35)	18.4	(3.4)	2.4	(1.1)	24.0	(3.6)
		3	0.00	(0.00)	6.20	(1.43)	19.4	(11.9)	9.0	(10.5)	34.6	(15.0)
	RFG	1	0.00	(0.00)	7.80	(0.69)	88.3	(13.1)	106.9	(41.5)	203.0	(49.0)
		2	0.00	(0.00)	8.92	(3.32)	84.0	(8.3)	155.5	(5.7)	248.0	(6.0)
		3	0.00	(0.00)	14.00	(1.96)	105.1	(15.4)	184.5	(37.7)	304.0	(53.0)
	RF-A	1	0.00	(0.00)	6.69	(1.89)	106.3	(18.5)	195.3	(87.7)	308.0	(95.0)
		2	0.00	(0.00)	11.72y	(2.44)	113.7	(16.6)	307.4	(88.6)	341.0	(101.0)
		3	0.00	(0.00)	11.81	(3.13)	116.7	(4.7)	261.8	(67.0)	390.0	(72.0)
Ford	CNG	1	0.00	(0.00)	5.11	(3.51)	104.7	(91.6)	0.8	(0.6)	110.6	(94.6)
		2	0.00	(0.00)	5.60	(5.87)	83.8	(51.3)	3.4	(2.3)	92.8	(59.1)
		3	0.00	(0.00)	8.27	(5.92)	104.2	(66.5)	2.9	(1.4)	115.3	(72.3)
	M-85	1	149.0	(22.0)	20.00	(2.11)	12.5	(1.2)	19.4	(5.4)	201.0	(26.0)
		2	266.0	(91.0)	23.93	(2.35)	10.0	(1.0)	25.9	(2.2)	325.0	(92.0)
		3	267.0	(71.0)	28.01	(4.28)	16.2	(3.7)	28.1	(5.5)	340.0	(69.0)
	PRO	1	0.00	(0.00)	3.04	(0.65)	344.7	(79.9)	1.6	(1.0)	349.0	(80.0)
		2	0.00	(0.00)	3.82	(1.01)	351.4	(30.7)	1.6	(1.3)	357.0	(32.0)
		3	0.00	(0.00)	9.17	(3.84)	400.2	(75.1)	4.3	(1.5)	414.0	(80.0)
	RFG	1	0.00	(0.00)	7.46	(1.27)	96.6	(34.1)	129.0	(57.3)	233.0	(92.0)
		2	0.00	(0.00)	9.84	(1.89)	68.8	(9.1)	119.8	(8.1)	198.0	(18.0)
		3	0.00	(0.00)	12.23	(3.57)	101.4	(11.2)	167.4	(24.7)	281.0	(35.0)
	RF-A	1	0.00	(0.00)	5.92	(0.83)	81.5	(11.5)	124.8	(22.0)	212.0	(23.0)
		2	0.00	(0.00)	11.46	(2.91)	127.4	(34.1)	213.9	(68.1)	352.8	(103.5)
		3	0.00	(0.00)	11.10	(1.00)	109.4	(12.2)	184.6	(39.3)	305.0	(50.0)

Table F-5. Calculated Ozone Reactivity of Exhaust Emissions (g/mi) by Phase of Testing

			Alcohols		Carbonyls		Light-end HC		Mid-range HC		Total Ozone	
OEM	Fuel	Phase	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Chevrolet	CNG	1	0.000	(0.000)	0.023	(0.001)	0.057	(0.017)	0.003	(0.003)	0.082	(0.017)
		2	0.000	(0.000)	0.029	(0.007)	0.059	(0.017)	0.013	(0.006)	0.101	(0.030)
		3	0.000	(0.000)	0.071	(0.029)	0.097	(0.059)	0.052	(0.041)	0.221	(0.097)
	PRO	1	0.000	(0.000)	0.039	(0.011)	0.499	(0.095)	0.006	(0.006)	0.544	(0.101)
		2	0.000	(0.000)	0.046	(0.018)	0.479	(0.160)	0.013	(0.009)	0.537	(0.185)
		3	0.000	(0.000)	0.051	(0.006)	0.579	(0.073)	0.018	(0.009)	0.648	(0.074)
	RFG	1	0.000	(0.000)	0.062	(0.004)	0.475	(0.084)	0.320	(0.065)	0.857	(0.132)
		2	0.000	(0.000)	0.091	(0.020)	0.585	(0.056)	0.611	(0.053)	1.288	(0.117)
		3	0.000	(0.000)	0.133	(0.009)	0.667	(0.113)	0.904	(0.156)	1.705	(0.139)
	RF-A	1	0.000	(0.000)	0.054	(0.012)	0.566	(0.157)	0.757	(0.179)	1.377	(0.338)
		2	0.000	(0.000)	0.079	(0.009)	0.608	(0.052)	1.533	(0.310)	2.220	(0.361)
		3	0.000	(0.000)	0.151	(0.013)	0.993	(0.105)	2.002	(0.509)	3.145	(0.615)
Dodge	CNG	1	0.000	(0.000)	0.016	(0.002)	0.021	(0.002)	0.005	(0.005)	0.041	(0.006)
		2	0.000	(0.000)	0.022	(0.002)	0.025	(0.003)	0.008	(0.007)	0.054	(0.008)
		3	0.000	(0.000)	0.041	(0.010)	0.025	(0.010)	0.056	(0.070)	0.122	(0.072)
	RFG	1	0.000	(0.000)	0.041	(0.007)	0.420	(0.079)	0.306	(0.126)	0.767	(0.172)
		2	0.000	(0.000)	0.046	(0.019)	0.399	(0.079)	0.498	(0.003)	0.943	(0.093)
		3	0.000	(0.000)	0.072	(0.010)	0.525	(0.073)	0.648	(0.148)	1.245	(0.218)
	RF-A	1	0.000	(0.000)	0.035	(0.008)	0.449	(0.059)	0.632	(0.226)	1.117	(0.197)
		2	0.000	(0.000)	0.050	(0.005)	0.489	(0.041)	1.249	(0.510)	1.788	(0.464)
		3	0.000	(0.000)	0.047	(0.012)	0.505	(0.024)	1.103	(0.362)	1.655	(0.369)
Ford	CNG	1	0.000	(0.000)	0.035	(0.024)	0.066	(0.055)	0.003	(0.004)	0.104	(0.079)
		2	0.000	(0.000)	0.038	(0.041)	0.056	(0.038)	0.014	(0.011)	0.108	(0.089)
		3	0.000	(0.000)	0.057	(0.042)	0.064	(0.053)	0.015	(0.008)	0.136	(0.099)
	M-85	1	0.084	(0.012)	0.135	(0.016)	0.043	(0.005)	0.043	(0.013)	0.305	(0.038)
		2	0.149	(0.051)	0.165	(0.016)	0.040	(0.002)	0.080	(0.008)	0.433	(0.056)
		3	0.150	(0.040)	0.194	(0.031)	0.054	(0.007)	0.080	(0.015)	0.477	(0.074)
	PRO	1	0.000	(0.000)	0.020	(0.005)	0.265	(0.049)	0.009	(0.007)	0.294	(0.047)
		2	0.000	(0.000)	0.024	(0.006)	0.286	(0.029)	0.004	(0.004)	0.314	(0.034)
		3	0.000	(0.000)	0.060	(0.025)	0.345	(0.108)	0.021	(0.008)	0.426	(0.135)
	RFG	1	0.000	(0.000)	0.037	(0.006)	0.376	(0.142)	0.338	(0.140)	0.752	(0.284)
		2	0.000	(0.000)	0.053	(0.013)	0.243	(0.051)	0.338	(0.017)	0.634	(0.073)
		3	0.000	(0.000)	0.062	(0.018)	0.397	(0.040)	0.518	(0.071)	0.977	(0.108)
	RF-A	1	0.000	(0.000)	0.035	(0.004)	0.255	(0.041)	0.414	(0.059)	0.704	(0.070)
		2	0.000	(0.000)	0.058	(0.014)	0.462	(0.171)	0.792	(0.263)	1.313	(0.444)
		3	0.000	(0.000)	0.057	(0.004)	0.363	(0.057)	0.682	(0.116)	1.102	(0.167)

Table F-6. Exhaust Emissions of Acetaldehyde, Formaldehyde, 1,3-Butadiene, and Benzene (mg/mi) by Phase of Testing

OEM	Fuel	Phase	Acetaldehyde Mean	Acetaldehyde (SD)	Formaldehyde Mean	Formaldehyde (SD)	1,3-Butadiene Mean	1,3-Butadiene (SD)	Benzene Mean	Benzene (SD)
Chevrolet	CNG	1	0.35	(0.04)	2.92	(0.18)	0.00	(0.00)	0.66	(1.18)
		2	0.59	(0.19)	3.45	(0.94)	0.00	(0.00)	0.49	(0.07)
		3	0.41	(0.20)	9.63	(3.90)	0.00	(0.00)	0.12	(0.14)
	PRO	1	1.12	(0.29)	4.32	(1.42)	0.00	(0.00)	0.30	(0.28)
		2	1.32	(0.29)	5.09	(2.43)	0.00	(0.00)	0.28	(0.13)
		3	1.14	(0.11)	5.97	(0.80)	0.00	(0.00)	0.30	(0.16)
	RFG	1	1.87	(0.16)	6.10	(0.43)	0.04	(0.07)	14.47	(3.40)
		2	2.66	(0.42)	9.34	(2.16)	0.31	(0.23)	19.31	(0.67)
		3	3.92	(0.37)	13.18	(0.92)	0.15	(0.33)	20.95	(2.14)
	RF-A	1	2.43	(0.23)	4.56	(1.38)	0.10	(0.14)	30.00	(2.98)
		2	3.34	(0.31)	7.40	(1.06)	0.24	(0.19)	43.24	(12.73)
		3	5.48	(0.52)	12.82	(1.36)	0.28	(0.35)	57.01	(19.58)
Dodge	CNG	1	0.25	(0.11)	2.01	(0.25)	0.00	(0.00)	0.11	(0.09)
		2	0.42	(0.10)	2.63	(0.26)	0.00	(0.00)	0.18	(0.14)
		3	0.42	(0.49)	5.31	(1.56)	0.00	(0.00)	0.14	(0.11)
	RFG	1	1.17	(0.19)	4.28	(0.82)	0.75	(0.14)	8.68	(3.04)
		2	1.37	(0.32)	4.88	(2.27)	1.04	(0.29)	12.30	(1.56)
		3	1.78	(0.26)	8.08	(1.32)	1.49	(0.52)	13.66	(1.96)
	RF-A	1	1.90	(0.47)	2.88	(1.11)	1.08	(0.70)	19.37	(6.85)
		2	2.33	(0.46)	4.65	(0.60)	1.37	(0.19)	34.34	(16y.78)
		3	2.63	(1.37)	4.02	(1.06)	1.57	(0.52)	30.22	(7.65)
Ford	CNG	1	0.35	(0.15)	4.58	(3.25)	0.00	(0.00)	0.08	(0.12)
		2	0.50	(0.10)	4.86	(5.69)	0.00	(0.00)	0.07	(0.02)
		3	0.33	(0.22)	7.63	(5.67)	0.00	(0.00)	0.03	(0.05)
	M-85	1	0.40	(0.05)	18.40	(2.17)	0.00	(0.00)	1.13	(0.19)
		2	0.66	(0.09)	22.48	(2.10)	0.11	(0.04)	1.26	(0.13)
		3	0.41	(0.04)	26.71	(4.33)	0.11	(0.03)	2.15	(0.35)
	PRO	1	0.68	(0.19)	2.09	(0.72)	0.04	(0.03)	0.23	(0.13)
		2	0.88	(0.09)	2.50	(0.69)	0.05	(0.05)	0.39	(0.25)
		3	0.89	(0.21)	7.55	(3.28)	0.03	(0.03)	0.24	(0.15)
	RFG	1	1.11	(0.22)	3.60	(0.62)	0.56	(0.27)	7.41	(3.00)
		2	1.35	(0.19)	6.06	(1.88)	0.55	(0.17)	5.84	(0.82)
		3	1.38	(0.23)	6.93	(2.32)	0.80	(0.16)	9.13	(2.15)
	RF-A	1	1.38	(0.18)	3.36	(0.43)	0.50	(0.20)	10.24	(1.74)
		2	2.22	(0.47)	5.78	(1.35)	0.80	(0.18)	16.70	(5.40)
		3	1.76	(0.20)	6.11	(0.68)	0.76	(0.22)	14.79	(6.75)

Table F-7. Exhaust Emissions of Toluene, o-Xylene, m&p-Xylenes, Styrene, and Acrolein (mg/mi) by Phase of Testing

OEM	Fuel	Phase	Toluene Mean	Toluene (SD)	o-Xylene Mean	o-Xylene (SD)	m&p-Xylenes Mean	m&p-Xylenes (SD)	Styrene Mean	Styrene (SD)	Acrolein Mean	Acrolein (SD)
Chevrolet	CNG	1	0.08	(0.13)	0.03	(0.09)	0.00	(0.01)	0.00	(0.00)	0.00	(0.01)
		2	0.08	(0.05)	0.01	(0.03)	0.08	(0.06)	0.00	(0.00)	0.00	(0.00)
		3	0.12	(0.19)	0.35	(0.27)	0.80	(0.60)	0.00	(0.01)	0.00	(0.00)
	PRO	1	0.13	(0.23)	0.00	(0.00)	0.22	(0.33)	0.00	(0.00)	0.09	(0.02)
		2	0.23	(0.19)	0.13	(0.15)	0.29	(0.37)	0.00	(0.00)	0.06	(0.03)
		3	0.12	(0.15)	0.12	(0.09)	0.15	(0.15)	0.01	(0.02)	0.06	(0.01)
	RFG	1	33.07	(6.55)	2.07	(1.16)	6.56	(1.32)	0.49	(0.46)	0.31	(0.05)
		2	32.94	(2.86)	6.75	(0.65)	21.39	(1.98)	0.60	(0.31)	0.23	(0.05)
		3	35.05	(3.69)	9.19	(1.61)	26.92	(4.32)	0.93	(0.30)	0.59	(0.09)
	RF-A	1	32.82	(4.98)	8.11	(2.38)	28.30	(5.48)	0.79	(0.62)	0.56	(0.12)
		2	51.18	(15.10)	14.95	(2.02)	39.55	(5.21)	1.45	(0.69)	0.54	(0.29)
		3	74.20	(28.10)	20.57	(5.87)	55.43	(17.40)	1.92	(0.20)	1.02	(0.17)
Dodge	CNG	1	0.09	(0.06)	0.00	(0.00)	0.01	(0.01)	0.00	(0.00)	0.00	(0.01)
		2	0.14	(0.11)	0.03	(0.04)	0.16	(0.13)	0.00	(0.00)	0.00	(0.01)
		3	0.28	(0.49)	0.25	(0.41)	0.56	(0.84)	0.00	(0.00)	0.00	(0.01)
	RFG	1	28.92	(11.26)	4.73	(5.54)	6.24	(2.92)	0.68	(0.90)	0.17	(0.04)
		2	26.09	(0.98)	5.61	(0.23)	17.75	(0.85)	1.32	(0.53)	0.08	(0.03)
		3	27.13	(5.19)	6.85	(1.64)	21.12	(4.80)	1.44	(0.33)	0.13	(0.02)
	RF-A	1	29.06	(11.77)	10.64	(5.61)	25.61	(11.20)	2.13	(1.59)	0.31	(0.07)
		2	60.28	(36.28)	14.76	(7.38)	42.74	(21.51)	2.07	(0.41)	0.10	(0.02)
		3	44.32	(13.59)	12.89	(4.68)	35.88	(12.44)	2.15	(0.86)	0.17	(0.04)
Ford	CNG	1	0.09	(0.13)	0.00	(0.00)	0.01	(0.02)	0.00	(0.00)	0.01	(0.01)
		2	0.22	(0.22)	0.16	(0.18)	0.21	(0.26)	0.11	(0.18)	0.00	(0.00)
		3	0.00	(0.01)	0.07	(0.12)	0.06	(0.09)	0.12	(0.18)	0.00	(0.01)
	M-85	1	3.44	(0.74)	0.36	(0.24)	0.69	(0.15)	0.05	(0.12)	0.04	(0.01)
		2	3.10	(0.27)	1.05	(0.21)	2.72	(0.28)	0.15	(0.04)	0.03	(0.01)
		3	2.46	(0.54)	0.62	(0.12)	1.66	(0.40)	0.10	(0.11)	0.03	(0.01)
	PRO	1	0.14	(0.09)	0.03	(0.05)	0.16	(0.10)	0.00	(0.00)	0.11	(0.05)
		2	0.12	(0.09)	0.04	(0.06)	0.03	(0.07)	0.03	(0.06)	0.05	(0.04)
		3	0.05	(0.05)	0.13	(0.11)	0.13	(0.11)	0.04	(0.05)	0.09	(0.09)
	RFG	1	28.41	(11.26)	2.95	(1.22)	7.05	(2.98)	0.01	(0.03)	0.26	(0.24)
		2	15.20	(1.33)	3.48	(0.18)	10.43	(0.85)	0.53	(0.34)	0.06	(0.04)
		3	19.17	(3.26)	5.07	(0.65)	15.45	(2.20)	0.80	(0.13)	0.10	(0.02)
	RF-A	1	15.00	(2.64)	5.59	(0.96)	13.68	(2.52)	1.14	(0.65)	0.27	(0.09)
		2	28.24	(10.07)	8.34	(3.05)	22.11	(8.71)	1.60	(0.18)	0.12	(0.04)
		3	25.31	(10.72)	6.82	(1.73)	18.29	(5.30)	1.00	(0.21)	0.12	(0.02)

APPENDIX G

Emission Levels Vs. Mileage

APPENDIX G

Emission Levels vs. Mileage

Tables G-1 through G-4 contain numerical estimates of mean emission levels at three mileages. These values were estimated using the statistical model fits to the data that are shown in Figures 4 through 12.

Table G-1. Estimated Mean Emission Levels of CO, NMHC, NMOG, and NO_x (g/mi) at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits

			CO			NMHC			NMOG			NO		
				95% Confidence Limit			95% Confidence Limit			95% Confidence Limit			95% Confidence Limit	
OEM	**Fuel**	**Mileage**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Chevrolet	CNG	5,000	1.54	0.78	3.01	0.078	0.049	0.122	0.074	0.047	0.116	1.65	0.81	3.34
		15,000	3.68	2.13	6.33	0.091	0.060	0.137	0.096	0.064	0.143	1.75	0.91	3.38
		25,000	5.78	2.96	11.28	0.099	0.063	0.156	0.109	0.071	0.168	1.88	0.90	3.91
	PRO	5,000	4.86	2.64	8.91	0.497	0.310	0.796	0.500	0.316	0.791	1.02	0.51	2.03
		15,000	6.05	3.55	10.30	0.636	0.421	0.961	0.642	0.430	0.958	1.16	0.60	2.23
		25,000	7.02	3.69	13.34	0.723	0.462	1.132	0.727	0.475	1.114	1.28	0.62	2.66
	RFG	5,000	7.67	5.48	10.73	0.212	0.134	0.335	0.220	0.141	0.343	2.39	1.90	3.02
		15,000	9.63	7.69	12.06	0.388	0.256	0.586	0.411	0.275	0.615	3.33	2.73	4.06
		25,000	10.70	7.83	14.64	0.520	0.326	0.831	0.555	0.354	0.870	3.89	3.09	4.90
	UNL	5,000	8.44	6.49	10.97	0.311	0.198	0.488	0.314	0.203	0.486	2.21	1.70	2.73
		15,000	11.93	9.61	14.82	0.498	0.329	0.753	0.514	0.344	0.768	3.53	2.90	4.29
		25,000	14.02	10.96	17.93	0.628	0.398	0.991	0.651	0.422	1.005	4.39	3.54	5.46
Dodge	CNG	5,000	1.28	0.67	2.42	0.015	0.010	0.023	0.018	0.012	0.027	0.26	0.13	0.52
		15,000	1.55	0.89	2.72	0.023	0.015	0.035	0.029	0.019	0.043	0.41	0.21	0.80
		25,000	1.78	0.89	3.58	0.028	0.018	0.045	0.037	0.024	0.057	0.54	0.26	1.12
	RFG	5,000	3.31	2.37	4.63	0.172	0.108	0.275	0.178	0.113	0.280	0.45	0.35	0.57
		15,000	5.93	4.76	7.39	0.277	0.183	0.420	0.288	0.192	0.431	0.49	0.41	0.60
		25,000	7.78	5.80	10.43	0.350	0.219	0.559	0.363	0.232	0.569	0.52	0.41	0.65
	UNL	5,000	5.01	3.91	6.43	0.303	0.200	0.484	0.319	0.208	0.488	0.48	0.39	0.59
		15,000	6.96	5.58	8.69	0.380	0.254	0.584	0.396	0.264	0.593	0.73	0.60	0.89
		25,000	8.11	6.28	10.48	0.428	0.273	0.681	0.442	0.286	0.684	0.89	0.72	1.11

Table G-1. Estimated Mean Emission Levels of CO, NMHC, NMOG, and NO_x (g/mi) at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits (Continued)

			CO			NMHC			NMOG			NO_x		
				95% Confidence Limit			95% Confidence Limit			95% Confidence Limit			95% Confidence Limit	
OEM	Fuel	Mileage	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
Ford	CNG	5,000	0.64	0.32	1.26	0.071	0.045	0.112	0.075	0.049	0.117	0.79	0.39	1.60
		15,000	0.80	0.46	1.38	0.081	0.054	0.122	0.087	0.058	0.130	1.29	0.67	2.50
		25,000	0.93	0.48	1.80	0.087	0.056	0.137	0.094	0.061	0.144	1.70	0.82	3.52
	M85	5,000	1.13	0.59	1.16	0.141[a]	0.090[a]	0.220[a]	0.210	0.135	0.325	0.66	0.33	1.33
		15,000	1.29	0.95	2.24	0.161[a]	0.107[a]	0.244[a]	0.331	0.221	0.495	0.80	0.42	1.56
		25,000	1.44	0.73	2.84	0.174[a]	0.110[a]	0.275[a]	0.413	0.265	0.642	0.92	0.44	1.92
	PRO	5,000	1.12	0.61	2.07	0.366	0.237	0.566	0.368	0.242	0.559	1.15	0.58	2.31
		15,000	1.34	0.78	2.30	0.399	0.265	0.602	0.401	0.269	0.597	0.98	0.51	1.90
		25,000	1.53	0.81	2.88	0.421	0.270	0.658	0.420	0.275	0.643	0.95	0.46	1.97
	RFG	5,000	1.66	1.29	2.15	0.215	0.136	0.342	0.227	0.144	0.357	0.74	0.60	0.93
		15,000	2.63	2.06	3.34	0.268	0.176	0.408	0.281	0.186	0.423	0.78	0.63	0.95
		25,000	3.25	2.35	4.49	0.300	0.186	0.485	0.313	0.197	0.496	0.80	0.63	1.01
	RF-A	5,000	1.95	1.53	2.48	0.236	0.155	0.372	0.246	0.161	0.374	0.71	0.57	0.87
		15,000	2.63	2.10	3.31	0.296	0.203	0.467	0.318	0.212	0.475	0.79	0.65	0.96
		25,000	3.03	2.31	3.88	0.333	0.222	0.554	0.361	0.233	0.560	0.84	0.67	1.04

[a] OMHCE v[illegible]ed for M-85 vehicles.

Table G-2. Estimated Mean Ozone Reactivity (g/mi) of Exhaust at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits

			Ozone Reactivity		
				95% Confidence Limit	
OEM	Fuel	Mileage	Mean	Lower	Upper
Chevrolet	CNG	5,000	0.063	0.041	0.095
		15,000	0.138	0.096	0.198
		25,000	0.200	0.135	0.296
	PRO	5,000	0.479	0.309	0.744
		15,000	0.595	0.415	0.853
		25,000	0.661	0.452	0.968
	RFG	5,000	0.714	0.470	1.085
		15,000	1.557	1.083	2.239
		25,000	2.250	1.486	3.407
	RF-A	5,000	1.38	0.758	1.709
		15,000	2.075	1.446	2.979
		25,000	2.759	1.867	4.077
Dodge	CNG	5,000	0.037	0.025	0.055
		15,000	0.087	0.060	0.125
		25,000	0.130	0.086	0.195
	RFG	5,000	0.647	0.420	0.998
		15,000	1.124	0.782	1.616
		25,000	1.461	0.968	2.207
	RF-A	5,000	1.187	0.804	1.752
		15,000	1.578	1.096	2.272
		25,000	1.810	1.220	2.687
Ford	CNG	5,000	0.080	0.053	0.120
		15,000	0.099	0.069	0.142
		25,000	0.111	0.075	0.163
	M85	5,000	0.315	0.209	0.473
		15,000	0.459	0.319	0.661
		25,000	0.550	0.367	0.825
	PRO	5,000	0.308	0.211	0.449
		15,000	0.360	0.252	0.514
		25,000	0.389	0.266	0.567
	RFG	5,000	0.708	0.465	1.079
		15,000	0.936	0.644	1.360
		25,000	1.071	0.695	1.649
	RF-A	5,000	0.813	0.585	1.192
		15,000	1.130	0.785	1.628
		25,000	1.325	0.889	1.973

Table G-3. Estimated Mean Emission Levels of Acetaldehyde, Formaldehyde, 1,3-Butadiene, and Benzene (mg/mi) at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits

			Acetaldehyde			Formaldehyde			1,3-Butadiene			Benzene		
				95% Confidence Limit			95% Confidence Limit			95% Confidence Limit			95% Confidence Limit	
OEM	Fuel	Mileage	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
Chevrolet	CNG	5,000	0.41	0.28	0.59	2.29	1.19	4.44	Z[a]	.	.	1.04	0.35	3.11
		15,000	0.44	0.35	0.55	5.86	3.43	10.03	Z	.	.	0.26	0.15	0.45
		25,000	0.45	0.33	0.62	9.21	5.03	16.86	Z	.	.	0.14	0.06	0.34
	PRO	5,000	1.14	0.76	1.70	3.88	1.92	7.82	Z	.	.	0.13	0.03	0.49
		15,000	1.21	0.96	1.52	5.45	3.18	9.32	Z	.	.	0.30	0.17	0.54
		25,000	1.26	0.94	1.67	6.48	3.63	11.56	Z	.	.	0.47	0.22	0.99
	RFG	5,000	1.51	1.05	2.17	4.81	3.50	6.62	0.23	0.08	0.69	13.29	9.09	19.43
		15,000	3.37	2.66	4.27	11.30	8.94	1429	0.41	0.22	0.75	20.70	15.35	27.92
		25,000	4.95	3.46	7.08	16.95	1229	23.39	0.53	0.23	1.21	25.72	17.52	37.77
	RF-A	5,000	2.09	1.50	2.92	3.25	2.41	4.40	0.04	0.03	0.09	28.81	20.01	41.47
		15,000	3.40	2.69	4.30	6.89	5.46	8.70	0.16	0.09	0.28	41.42	30.01	54.44
		25,000	4.31	3.17	5.80	9.86	7.37	13.19	0.28	0.16	0.52	47.84	33.56	68.19
Dodge	CNG	5,000	0.28	0.21	0.38	2.02	1.10	3.69	Z	.	.	0.14	0.06	0.33
		15,000	0.34	0.27	0.43	4.60	2.66	7.96	Z	.	.	0.20	0.11	0.38
		25,000	0.38	0.27	0.53	6.86	3.64	12.95	Z	.	.	0.25	0.09	0.66
	RFG	5,000	1.02	0.70	1.49	3.40	2.43	4.74	0.64	0.33	1.28	7.11	4.78	10.57
		15,000	1.57	1.24	1.99	6.34	5.01	8.02	1.35	0.77	2.38	12.76	9.45	17.22
		25,000	1.93	1.37	2.73	8.55	6.24	11.73	1.92	1.03	3.61	16.93	11.58	24.75
	RF-A	5,000	1.87	1.39	2.53	2.92	2.20	3.86	1.07	0.58	1.96	19.12	13.57	26.95
		15,000	2.20	1.73	2.80	3.82	3.01	4.84	1.50	0.85	2.66	27.43	20.28	37.10
		25,000	2.39	1.75	3.28	4.37	3.25	5.87	1.77	0.93	3.21	32.80	22.89	46.98

[a] Z = reported as zero concentration.

Table G-3. Estimated Mean Emission Levels of Acetaldehyde, Formaldehyde, 1,3-Butadiene, and Benzene (mg/mi) at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits (Continued)

			Acetaldehyde			Formaldehyde			1,3-Butadiene			Benzene		
				95% Confidence Limit			95% Confidence Limit			95% Confidence Limit			95% Confidence Limit	
OEM	**Fuel**	**Mileage**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Ford	CNG	5,000	0.41	0.29	0.58	3.37	1.77	6.41	Z[a]	.	.	0.06	0.02	0.17
		15,000	0.36	0.28	0.45	5.09	2.98	8.69	Z	.	.	0.05	0.03	0.09
		25,000	0.34	0.25	0.45	6.26	3.46	11.2	Z	.	.	0.05	0.02	0.12
	M85	5,000	0.47	0.33	0.65	18.21	13.45	24.65	0.10	0.03	0.33	1.68	0.64	4.36
		15,000	0.53	0.42	0.67	24.25	19.15	30.72	0.12	0.07	0.22	2.67	1.48	4.82
		25,000	0.57	0.40	0.79	27.96	20.52	38.09	0.13	0.07	0.26	3.47	1.34	8.96
	PRO	5,000	0.70	0.53	0.93	2.26	1.27	4.02	0.06	0.03	0.11	0.33	0.16	0.72
		15,000	0.82	0.66	1.02	3.90	2.30	6.64	0.07	0.04	0.12	0.35	0.21	0.57
		25,000	0.89	0.67	1.17	5.11	2.88	9.07	0.07	0.04	0.13	0.37	0.19	0.72
	RFG	5,000	1.11	0.78	1.58	3.44	2.49	4.76	0.53	0.28	1.00	6.65	4.53	9.56
		15,000	1.43	1.11	1.86	6.39	4.98	8.21	0.86	0.48	1.54	8.31	6.08	11.32
		25,000	1.63	1.13	2.35	8.60	6.16	12.02	1.07	0.54	2.10	9.37	6.28	13.98
	UNL	5,000	1.55	1.16	2.06	3.37	2.80	4.81	0.54	0.30	0.97	11.76	8.42	16.42
		15,000	1.89	1.49	2.41	5.69	4.49	7.21	0.83	0.47	1.47	14.01	10.36	18.93
		25,000	2.10	1.52	2.90	7.04	5.21	9.50	1.12	0.56	1.88	15.36	10.69	22.08

[a] Z = reported as zero concentration.

Table G-4. Estimated Mean Emission Levels of Methane (g/mi), Carbon Dioxide (g/mi), and Nitrous Oxide (mg/mi) at 5,000, 15,000 and 25,000 Miles, with 95 Percent Confidence Limits

			Methane			Carbon Dioxide			Nitrous Oxide		
				95% Confidence Limit			95% Confidence Limit			95% Confidence Limit	
OEM	**Fuel**	**Mileage**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Chevrolet	CNG	5,000	1.69	1.07	2.67	593	574	613	47	23	94
		15,000	2.58	1.77	3.76	591	579	604	50	27	95
		25,000	3.29	1.99	5.44	590	572	609	54	24	121
	PRO	5,000	0.09	0.06	0.14	645	628	663	69	35	136
		15,000	0.11	0.07	0.16	641	628	655	87	47	161
		25,000	0.13	0.08	0.21	639	621	658	101	48	213
	RFG	5,000	0.06	0.04	0.09	659	637	682	254	229	282
		15,000	0.07	0.04	0.10	638	624	653	301	276	328
		25,000	0.07	0.04	0.12	629	607	651	326	295	361
	RF-A	5,000	0.05	0.03	0.08	650	632	669	**Insufficient Data**		
		15,000	0.07	0.05	0.10	653	639	668			
		25,000	0.08	0.05	0.13	655	635	676			
Dodge	CNG	5,000	0.44	0.28	0.68	556	540	573	9	5	18
		15,000	0.74	0.51	1.09	557	545	571	24	13	46
		25,000	1.00	0.60	1.67	558	540	577	39	18	85
	RFG	5,000	0.05	0.03	0.08	676	654	699	22	11	43
		15,000	0.07	0.05	0.10	675	660	690	54	39	98
		25,000	0.08	0.05	0.14	674	652	697	86	42	173
	RF-A	5,000	0.08	0.05	0.12	670	652	689	**Insufficient Data**		
		15,000	0.08	0.05	0.12	658	643	673			
		25,000	0.08	0.05	0.14	652	632	673			
Ford	CNG	5,000	1.78	1.12	2.80	504	488	521	26	13	40
		15,000	2.64	1.81	3.85	493	483	504	36	20	66
		25,000	3.34	2.02	5.51	488	474	503	44	22	88
	M85	5,000	0.04	0.03	0.06	610	592	628	61	32	118
		15,000	0.05	0.04	0.08	607	594	621	65	36	118
		25,000	0.06	0.04	0.10	606	587	625	70	35	139
	PRO	5,000	0.12	0.08	0.19	590	574	606	99	36	271
		15,000	0.14	0.10	0.21	601	589	614	74	39	140
		25,000	0.16	0.10	0.26	607	590	624	68	34	136
	RFG	5,000	0.09	0.06	0.14	649	631	669	14	7	26
		15,000	0.11	0.07	0.16	649	633	665	30	16	54
		25,000	0.13	0.07	0.21	649	626	672	44	22	90
	RF-A	5,000	0.11	0.07	0.17	660	642	677	**Insufficient Data**		
		15,000	0.11	0.08	0.17	644	629	659			
		25,000	0.12	0.07	0.20	637	617	657			