Methanol Vehicle Emissions

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1220 L Street, Northwest
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Thomas J. Lareau, Policy Analysis Department
David H. Lax, Health and Environmental Sciences Department
Paul A. Martino, Health and Environmental Sciences Department
Willis E. Bush, Editorial and Special Issues Department

Refining Department

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FOREWORD

This publication was prepared by members of the API Alternative Fuels Group, including Thomas J. Lareau, Policy Analysis Department; David H. Lax and Paul A. Martino, Health and Environmental Sciences Department; and Willis E. Bush, Editorial and Special Issues Department. The data in the report were provided by federal and state regulatory agencies and API member companies.

This report evolved from work initially undertaken by Paul Martino, who reviewed the emissions studies that comprise Appendix C. David Lax organized the emissions data from the various published studies and from many organizations into a spreadsheet. From this he created an initial set of emissions graphics for particular vehicle classes (the precursor to the second-level screening analysis). Thomas Lareau provided the first-level screening analysis and served as overall coordinator of the report in its later stages. Bill Bush provided editorial assistance throughout the process.

Many other API staff members contributed to the preparation and review of this report. In particular, Michael E. Canes, Ronald L. Jones, James E. Williams, and James Vail provided critical reviews and suggestions that clarified and extended the analysis in important ways. External reviews by Bruce Beyaert (Chevron), Sandra Minor (Unocal), B. D. Keller (Amoco), and James Macias (Shell) also served to improve the final version of this report. Finally, we would like to thank Constance Polite, who typed the original drafts of the report, and the API Refining Department editorial staff, who edited the final version and produced the book. The authors appreciate the efforts of all these individuals, without which this report would not have been as clear or technically sound.

Every effort has been made by the Institute to assure the accuracy and reliability of the data and analysis contained in this study. However, the contents of this publication are meant for the purposes of study and discussion of technical and regulatory issues and do not necessarily represent the views of the Institute or any of its members.

CONTENTS

Figures

Tables

Methanol Vehicle Emissions

SECTION 1—EXECUTIVE SUMMARY

This publication (a) identifies and presents empirical data on emissions from methanol vehicles and (b) compares and evaluates emissions trends among various types of methanol vehicles over time. These emissions data are necessary to assess the impact of methanol use on ozone levels.

Researchers have tested emissions from methanol vehicles since the early 1970s, but these data have not been fully and systematically compiled. This report provides a systematic, comprehensive compilation and analysis of these data, taken from every major study of methanol vehicles for at least the last 10 years. It includes emissions measurements for 69 vehicles and organizes the data into logical subgroups that permit analysis of important emissions hypotheses.

Many of the data collected are characterized by significant uncertainties. For example, different techniques were used to measure the same kind of emission. The data are accepted at face value, though there is some indication in the literature that measurement bias has been a problem for some test procedures. Also, the data were collected from vehicles that had received care beyond what vehicles in ordinary, everyday use would receive. For example, these vehicles were more reliably maintained and repaired. This often meant replacement of key engine and emission control components. For this reason, the emissions data reported in this publication probably reflect better performance from the methanol vehicles than would be expected in common, everyday use.

Some of the emissions data collected in this report were not accompanied by odometer readings. This was a key factor in the analysis, since a lack of odometer readings made understanding of the emissions data problematic. Thus, while all of the data collected are included in Appendixes A and B, only the data with odometer readings were analyzed. Tailpipe emissions data with odometer readings were available for 54 of the 69 vehicles. A subset of this data, covering 31 of the 54 vehicles, was also analyzed.

The subset of 31 vehicles included data that were more complete, uniform, and directly comparable. Vehicles were only included when organic emission species and nitrogen oxide (NO_x) emissions were measured, when vehicles were tested in their normal emission control configurations, when emissions were measured following catalyst stabilization, and when either M85 or M100 was used as the test fuel. By applying this more restrictive set of rules, we could learn more about the performance of subsets of vehicles classified by manufacturer, vintage, technology, and type of fuel used. We could also see relationships and trade-offs relating to the control of more than one kind of emission.

Despite the limitations of the data, our analysis supports several conclusions.

For M85 vehicles, those that operate on an 85-percent methanol/15-percent gasoline blend, there are sufficient recent data to characterize emissions. The data show some improvement in emissions performance for the second-generation M85 vehicles. This improvement offers encouragement that utilitarian M85 vehicles could be built that would satisfy most of the emissions criteria of the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB). The data also indicate, however, that a number of emission problems and unanswered questions remain:

a. Even at low mileage, M85 vehicles almost always exceeded the 50,000-mile 1993 California tailpipe standard of 15 milligrams per mile for formaldehyde emissions. Average formaldehyde emissions were about three times higher than this standard. At various test mileages, the older, 1981–1985 models had measured formaldehyde emissions below the California standard level in only 6 percent of the tests. The newer, 1986–1988 models were only slightly better, meeting the standard level in about one of four tests.

b. M85 vehicles typically had nitrogen oxide emissions that were less than the 50,000-mile federal standard of 1.0 gram per mile, but they were only rarely able to meet the more stringent 50,000-mile California standard of 0.4 gram per mile, even at low mileage. Even the 1986–1988 models performed poorly, testing below the 0.4-gram-per-mile level just 10 percent of the time at various mileages.

c. There was substantial improvement in meeting the 50,000-mile federal tailpipe standard of 0.41 gram per mile for organic emissions. Although the 1981–1985 models met this level in only 40 percent of the tests, the 1986–1988 models did so 90 percent of the time. However, even these newer vehicles were able to meet the 50,000-mile 1993 California standard level of 0.25 gram per mile only 40 percent of the time. No methanol vehicle was able to meet the California standards for hydrocarbon and nitrogen oxide emissions simultaneously.

d. There was also substantial improvement in meeting the 50,000-mile federal standard for carbon monoxide of 3.4 grams per mile. The 1981–1985 models met the standard level about 40 percent of the time at various mileages. The 1986–1988 models met the standard level in more than 80 percent of the tests.

e. At the mileages tested, M85 vehicles were generally able to meet the 50,000-mile federal standard of 2 grams per test for total organic evaporative emissions.

For M100 vehicles, that is, methanol vehicles operating on pure methanol, the data are sparse and inadequate. Few

M100 vehicles have been tested, and almost no data exist for M100 vehicles that performed acceptably or were driven more than 15,000 miles in fleet tests. What data exist do not show emissions benefits substantially in excess of those demonstrated on M85 vehicles. Thus, the benefits of a program substituting M100 for gasoline cars are entirely speculative. Further, the driveability and overall utility of dedicated M100 vehicles have yet to be demonstrated.

Very limited, recent data on the more advanced prototype M85 and M100 vehicles and catalysts were analyzed separately. They show very low organic emissions at low mileage. However, these data fail to answer questions about emissions control durability and continue to indicate difficulty in lowering organic and NO_x emissions simultaneously.

This report does not discuss a key question: whether future, practical methanol vehicles could reduce ozone-forming organic compounds more than future, practical gasoline vehicles. The question cannot be answered for M100 vehicles because of a lack of data from utilitarian prototypes. The data for M85 vehicles suggest that they could produce low levels of total organic emissions. However, today's most advanced gasoline vehicles also emit low levels of organic compounds—well below existing standards. Moreover, gasoline fuel reformulation will improve the emissions performance of 1990s gasoline vehicles. Thus, either future gasoline or future M85 vehicles could contribute substantially to pollution reduction.

The following sections present an analysis of methanol emissions data and measurement techniques. Section 2 discusses the methanol emissions data. Section 3 considers the issue of measurement of methanol vehicle emissions. Section 4 analyzes emission trends. Section 5 presents conclusions.

SECTION 2—METHANOL VEHICLE EMISSIONS DATA BASE

Methanol emissions data were collected from 28 studies conducted by federal and state government agencies and by the automobile and petroleum industries. Data from every major study for at least the last 10 years were included. Most of the studies were completed between 1987 and 1989. Two data bases were created from the data contained in the studies: one for exhaust emissions and one for evaporative emissions. No data were available for running losses.

Appendix C contains an annotated review of these studies and a bibliography of the literature on methanol vehicle emissions. Table 1 summarizes basic information about the studies. Appendix A presents the exhaust emissions data from the studies, and Appendix B presents the evaporative emissions data.

Methanol Emissions Studies

The studies reviewed involved the testing of many different types of vehicles. They employed many different test procedures and measurement methods. The lack of consistency partly reflects the varying objectives of the studies and partly the development of method and protocol. Many data are from the U.S. Department of Energy's (DOE's) methanol fleet demonstration program. The primary objective of this program was to evaluate methanol vehicles in terms of consumer acceptance, performance, and durability. Emissions were measured, but according to procedures established independently by the various national laboratories. In other cases—for example, the CARB test program—procedures and measurements were more uniform, and the emissions data are more comprehensive and comparable.

EXHAUST EMISSIONS FOCUS

Most studies have focused on exhaust emissions. There is much less information on evaporative losses and virtually no published data on refueling and running-loss emissions. This accounts for the much larger exhaust emissions data base.

FEDERAL TEST PROCEDURE CONDITIONS

Until recently, most researchers have measured emissions from vehicles operated over either the Federal Test Procedure (FTP) or the Highway Fuel Economy Test (HWFET) driving cycles. Few data are available on emissions collected under non–FTP temperature conditions or under urban driving conditions.

MEASUREMENT PROCEDURES

EPA and CARB have established procedures for measuring methanol vehicle emissions. However, the accuracy of methanol emissions measurement remains problematic. Measurement is discussed in Section 3.

TEST VEHICLES

A variety of first-generation methanol vehicles have been tested for emissions. Most of these vehicles are conversions of existing gasoline-fueled engines and are carbureted, and some are not optimized to run on methanol. Furthermore, most incorporate emissions control equipment that does not represent state-of-the-art technology that will be used in future vehicles, particularly electronic engine management systems and fuel injection. The emissions data from these early vehicles, which generally show higher emissions than from later methanol vehicles, are of questionable use for estimating air quality impacts from future methanol vehicles.

More recent domestic prototype flexible-fuel vehicles (FFVs) have also been tested. Some of these automobiles have now been operated in normal service for more than 30,000 miles. Most are part of centrally managed fleets char-

Table 1—Summary of Emissions Studies

Row	Models	No. of Vehicles	Odometer Range	Fuel Type	Exhaust Procedure			Evaporative Procedure	
					MeOH	HCHO	THC	MeOH	THC
1	'81 Escort	3	50,111–115,590	M95, M90	GC	DNPH	GC	GC	GC
2	'83 Escort	10	5030–54,088	M90, M85	GC	DNPH	GC	GC	GC
3	'84 Escort	1	8580–8620	M100	GC	DNPH	GC	GC	GC
4	'81 Rabbit	2	5344–66,486	M85, M90, M95	GC	DNPH	GC	GC	GC
5	'82 Citation	1	30,692–41,600	M85, M90	GC	DNPH	GC	GC	GC
6	'85 Camry	1	434–26,270	M85	GC	DNPH	GC	GC	GC
7	'86 Camry	1	22,438–22,474	M85	GC	DNPH	GC	GC	GC
8	'86 Carina	1	944–24,589	M85	GC	DNPH	GC	GC	GC
9	'87 Crown Victoria	7	177–26,682	M0, M25, M85, M90, M100	GC	DNPH	GC	GC	GC
10	'88 Corsica	3	3956–20,822	M0, M25, M50, M85, M100	GC	DNPH	GC	GC	GC
11	'87 Crown Victoria	2	2391–15,930	M85	GC	DNPH	GC	GC	GC
12	GM Prototype	3	NA	M0, M15, M50, M85, M90, M100	GC	DNPH	GC	GC	GC
13	'83 Escort	1	NA	M85	GC	DNPH	FID	NA	NA
14[a]	'83 Escort	1	NA	M90	GC	DNPH	NA	NA	NA
15[a]	'83 Escort	1	NA	M90, M100	NA	DNPH	NA	NA	NA
16	'81 Citation	1	28,597–28,669	M88	GC	DNPH	NA	NA	NA
17	'81 Phoenix	1	2325	M88	GC	DNPH	NA	NA	NA
18	'81 Escort	1	6006–6805	M100	GC-I	DNPH	NA	NA	NA
19	'81 Rabbit	1	1770–2360	M100	GC-I	DNPH	NA	NA	NA
20	'81 200 SX	1	1494–1641	M100	NA	DNPH	NA	NA	NA
21	'78 Pinto	3	1250–10,000	M100	NA	MBTH	NA	NA	NA
22	'83 Escort	1	55–850	M90, M100	GC-I	DNPH	NA	NA	NA
23	'83 Escort	1	180–13,299	M90, M100	NA	NA	NA	NA	NA
24	'87 Sentra	1	NA	M100	NA	NA	NA	NA	NA
25	'86 Crown Victoria	1	2500–3645	M85	NA	NA	NA	NA	NA
26	'86 Sentra	1	16,739–17,218	M85	FID	DNPH	FID	NA	NA
27	'86 Carina	1	NA	M85, M100	FID	DNPH	FID	NA	NA
28	'86 Carina	1	1570–10,800	M100	FID	DNPH	FID	NA	NA
29	'86 S-10	2	288–8700	M85	FID	NA	FID	NA	NA
30	'86 Crown Victoria	2	793–32,800	M85	FID	NA	FID	NA	NA
31	'87 Regal	1	323–743	M85	FID	NA	FID	NA	NA
32	'84 Citation	5	NA	M0, M85	NA	NA	FID	NA	NA
33	'88 Corsica	1	NA	M0, M25, M50, M85, M100	GC	DNPH	GC	GC	GC
34[b]	'87 Crown Victoria	3	10,006–26,682	MO, M85	GC	DNPH	FID	NA	NA
35	'88 Corsica	1	10,184–20,822	M0,M85	GC	DNPH	GC	NA	NA
36	'87 Crown Victoria	2	NA[c]	M85, M100	FTIR	FTIR/DNPH	FID/FTIR	NA	NA
37	'85 Escort	2	NA[c]	M0, M50, M85, M100	FTIR	FTIR/DNPH	FID/FTIR	NA	NA

Note: NA = not available; GC = gas chromatograph; DNPH = DNPH-impinger method followed by liquid chromatography; MBTH = MBTH-impinger method; FID = flame ionization detector with methanol subtraction. Sources are as follows: Row 1—California Air Resources Board (1986); Row 2—California Air Resources Board (1988); Row 3—California Air Resources Board ("Quarterly Summary," 12/88–2/89); Rows 4–11—California Air Resources Board ("Quarterly Summary," 6/88–8/88); Row 12—Williams et al. (1990); Row 13—Stump and Braddock (1989); Row 14—Gabele et al. (1985); Row 15—Smuda (1984a); Rows 16 and 17—California Air Resources Board (1984); Rows 18 and 19—Smith (1985); Row 20—Smuda (1984b); Row 21—Edwards and Baisley (1981); Row 22—Smith (1984); Row 23—Mobil Research and Development Corporation (1987); Row 24—Hellman (1989); Row 25—Piotrowski et al. (1987); Row 26—Blair (1988); Row 27—Piotrowski (1987) and Piotrowski and Murrell (1987); Row 28—Piotrowski (1989); Row 29—McGill, Hillis, West, and Hodgson (1989b); Row 30—McGill et al. (1989b); Row 31—McGill, Hillis, West, and Hodgson (1989a); Row 32—McGill et al. (1987); Row 33—Gabele (1990); Rows 34 and 35—Horn and Hoekman (1989); Rows 36 and 37—Nichols et al. (1988).

[a]The same '83 escort was tested in Gabele et al. (1985) and Smuda (1984a).

[b]The three Crown Victorias and the Corsica tested in Horn and Hoekman (1989) are also summarized in California Air Resources Board (1986; 1988; "Quarterly Summary," 6/88–8/88; and "Quarterly Summary," 12/88–2/89).

[c]Tested with catalysts aged on the dynomometer.

acterized by levels of maintenance and care that exceed the attention given by the general public. Both domestic and foreign car manufacturers have tested some vehicles dedicated for use of either M85 or M100. These prototype vehicles have been operated in carefully maintained fleets and have accumulated up to 70,000 miles. However, of the vehicles dedicated to M100 fuel, none has accumulated more than 15,000 miles.

CARB reports that some vehicles—despite high levels of maintenance—appeared to experience intermittent driveability problems caused by frequent fuel injector fouling and/or fuel filter plugging (California Air Resources Board, 1988; see Figure 1). However, design changes appear to have solved the problem of injector fouling. High levels of maintenance, which included modifications of the vehicle fuel systems in attempts to stabilize emissions performance,

as well as replacement of catalysts, raise questions about the emissions results and potential durability of emission control systems.

It should be noted that the same vehicle was sometimes tested in different studies. For example, vehicles tested in the CARB fleet program were often provided to other organizations cooperating with CARB. Also, the same vehicles were sometimes tested with different emission control configurations (for example, with and without the catalytic converter, with and without exhaust gas recirculation). Appendix A identifies the emission controls in place during the exhaust emissions tests.

Two Emissions Data Bases

From the studies, two emissions data bases were created.

Approximately 1300 observations of carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde (HCHO), methanol (MeOH), total hydrocarbons (THC) and organic material hydrocarbon-equivalent emissions (OMHCE) were collected and tabulated to form an exhaust emissions data base (see Appendix A). The data spanned 69 vehicles across 14 model car lines. Other information was also tabulated when available. This included odometer readings, fuel metering system, emission control system configuration, fuel type, measurement procedures, and relevant information about the condition of the vehicle.

In addition, 86 observations of methanol and hydrocarbon evaporative emissions were entered into an evaporative emissions data base (see Appendix B). These measurements were taken on 30 vehicles representing 11 model car lines. As with the exhaust emissions data base, available information on fuel type, vehicle characteristics, and odometer reading was tabulated.

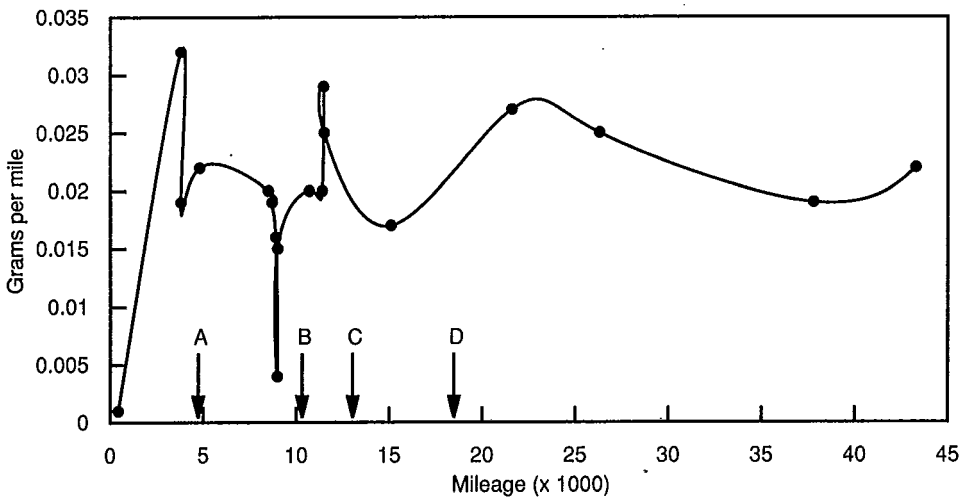
No attempt was made to exclude data representing malperforming vehicles or vehicles subjected to extraordinary levels of maintenance. In the real world, the variability inherent in emissions data is not only a function of vehicle-to-vehicle, test-to-test, and fuel-to-fuel differences; it is also highly dependent on the vehicle's state of maintenance. Thus, for example, some of the data in Appendix A reflect situations in which the emissions may have been affected by clogged fuel injectors, fouled fuel filters, and/or malperforming oxygen sensors in the test vehicle's emission control system. Also, many cars were tested immediately after maintenance or repairs were performed. Figure 1 shows formaldehyde emissions superimposed on maintenance events. Fuel injector replacement is not normal maintenance at low mileage.

Determining Emissions Trends

To track emissions trends, vehicle emissions data for a large number of vehicles of different vintage and technological refinement are desirable. Although we gathered a significant amount of data, most concerned exhaust emissions. Data on evaporative emissions are sparse.

Even the data for exhaust emissions were less than ideal. Data were collected using different measurement procedures. Many more data were recorded for some vehicles than others. And some of the data were recorded without odometer readings.

These limitations made interpretation of the data more difficult. In addition, emissions are influenced by many other variables. Emissions are particularly sensitive to vehicle vintage (emission control technology has improved over time), to age (emission control effectiveness deteriorates as mileage increases), and to fuel type.



Note: A = replaced fuel injectors; B = replaced second set of fuel injectors; C = replaced third set of fuel injectors; D = installed new ball-type fuel injectors and recalibrated computer for full stoichiometric operation.

Figure 1—Formaldehyde Emissions: Dedicated M85 Toyota Camry

It can be difficult if not impossible to distinguish emissions trends without being able to hold some variables constant—either statistically or by screening the data. Screening the data involves a trade-off between the advantages of using all (or as many as possible) of the data and the benefits of clearly seeing emissions trends as a function of single variables. Screening required eliminating some (or sometimes a substantial amount) of the data, all of which are included in Appendix A.

To try to make sense of the data—to control for some of the confounding variability—we applied two screening procedures.

In the first level of screening, we developed frequency distributions. This involved partitioning averaged data (more than one emission measurement for a single vehicle at one mileage interval was averaged) by vintage (1981–1985 and 1986–1988 vehicles) and by fuel (M85 and M100), each as a function of mileage. As shown in Table 2, in the first screening process, observations on 15 of the 69 vehicles were discarded because of the absence of mileage readings.

Restricting analysis to data for which odometer readings were available was unavoidable. Too much is unknown when mileage goes unrecorded. For example, failure to record mileage often indicates that tests were performed to gain engineering knowledge. Such emissions data may reflect unrealistic conditions of vehicle use or emission control configuration. Also, it is unlikely that data without odometer readings were taken from vehicles operated under on-the-road conditions. In the testing of one car (a 1986 Toyota Carina; see Appendix A), 32 test sequences were run without a recorded odometer reading. Test notations indicate that engineering tests were being performed on the vehicle, engine, and emission control systems.

Also, combining emissions data for which odometer readings do not exist with data for which odometer readings do exist raises problems. In the case cited above, the 32 test sequences were probably taken at low mileage. If these are treated as one averaged set of emissions measurements to avoid overrepresentation of low mileage measurements, the number of observations is reduced substantially, though the loss of truly independent data is probably minimal.

In the second level of screening, we applied a more restrictive set of rules to control more precisely for differences in performance among vehicle models. This enabled us to show emissions trends as a function of mileage, fuel, and vintage, one at a time.

Under the second screening process, the data had to satisfy four criteria:

Table 2—Distribution of Vehicles in the Exhaust Emissions Data Base

Model	Technology/Test Fuels	No. of Vehicles	Odometer	Observations		Pollutant Measured With M85 or M100				No. of Vehicles Used In Second Analysis
				Threshold[a]	M85 or M100	CO/NO_x	HCHO	MeOH or THC	OMHCE	
'87 Crown Victoria	FI, FFV, M0–M100	9	8[b]	9	9	9	9	9	8	8
'88 Corsica	FI, FFV/DED, M0–M88	5	4	3	4	5	4	2	3	2
'85 Camry	FI, DED, M85	1	1	1	1	1	1	1	1	1
'86 Carina	FI, DED, M85–M100	2	2	2	2	2	2	2	2	2
'86 Camry	FI, DED, M85	1	1	1	1	1	1	1	1	1
'86 Sentra	FI, DED, M85	1	1	1	1	1	1	1	1	1
'87 Sentra	FI, DED, M100	1	0	0	1	1	1	1	0	0
'81 200SX	FI, DED, M100	1	1	0	1	1	1	0	0	0
'81 Rabbit	FI, DED, M85–M100	4	4	3	3	4	4	4	2	2
'81 Phoenix	CARB, DED, M88	1	1	0	0	1	1	1	0	0
'81 Citation	CARB, DED, M88	1	1	1	1	1	1	1	0	0
'82 Citation	FI, DED, M85–M90	1	1	1	1	1	0	1	0	0
'84 Citation	CARB, DED, M0–M88	5	0	0	0	5	0	5	0	0
'78 Pinto	CARB, DED, M100	3	3	3	3	3	3	0	0	1
'86 Crown Victoria	FI, DED, M85	5	5	5	5	5	3	5	4	3
'87 Regal	FI, DED, M85	2	2	0	2	2	0	2	2	0
'86 S-10	FI, DED, M85	2	2	2	2	2	0	2	2	0
GM Prototype	FI, FFV, M0–100	3	0	0	2	3	3	3	3	0
'81 Escort	CARB, DED, M85–100	4	4	4	2	4	3	4	0	1
'83 Escort	FI, DED, M85–M90	3	3	3	3	3	3	3	3	3
'83 Escort	CARB, DED, M85–M100	11	9	8	9	11	10	11	2	5
'84 Escort	FI, DED, M100	1	1	1	1	1	1	1	0	1
'85 Escort	FI, DED, M0–M100	2	0[b]	2	0	2	2	2	2	0
Totals		69	54	50	54	69	54	62	36	31

Note: FI = fuel injected; CARB = carbureted; FFV = flexible-fuel vehicle; DED = dedicated-fuel vehicle.

[a]Requires at least one measurement of emissions above 2500 miles.

[b]One Crown Victoria and two Escorts reported catalysts aged on a dynamometer (that is, the mileage listed is for the emissions system, not for the vehicle operated on the road).

a. At a minimum, CO, NO_x, and HCHO were measured for a vehicle more than once. This ensured that the data were not "tuned" to minimize one emission at the expense of another. It also provided a complete and uniform data base. As a result, different emissions for the same vehicle could be compared.
b. The vehicles were tested in their normal emission control configurations. This eliminated measurements taken with emission control equipment disconnected. Such measurements often yielded data outliers, which did not reflect on-the-road performance.
c. To allow for catalyst stabilization, at least one set of emissions data was recorded with mileage greater than 2500.
d. Either M85 or M100 was used as the test fuel. M25 and M50 are not relevant alternatives to gasoline, and fuels like M90 and M95 are not quite the same as M85 and M100. Thus, tests of M90 and M95 cannot be aggregated with tests of M85 and M100.

These rules provided a basis for the graphic depiction of emissions trends as a function of vintage, fuel, and mileage. In addition, the second screening process encouraged examining the emissions performance of individual vehicles, many of which—as it turned out—were equipped with recent-technology engines and emission control systems. The performance of such vehicles, in particular, may help indicate the future emissions potential of methanol vehicles. As shown below, screens of the type proposed above do not materially affect the distribution of emissions and do not bias the conclusions that can be derived from the more restricted data subset.

Following the criteria above, complete exhaust emissions data were available for 31 vehicles (see Table 2). Fifteen of the 69 vehicles in the exhaust emissions data base did not have odometer information. Four more sets of emissions data were discarded because they included no measurement above 2500 miles. Moreover, although all 69 vehicles were tested for CO and NO_x, only 62 were tested for methanol or total hydrocarbons, and only 54 were tested for formaldehyde. (As discussed in Section 3, the measurement of total hydrocarbons was confounded by measurement problems.) Finally, only 54 of 69 vehicles were tested on either M85 or M100. Simultaneous application of the four criteria accounts for substantial attrition of usable observations.

Only one complete data set existed for the latest generation of vehicles that were operated on pure methanol (M100), and this was not a vehicle that had been used in ordinary service.

The odometer information collected presented some special challenges in tabulating the data for graphic presentation. Logistical difficulties associated with vehicle availability, procurement, operation, and maintenance rarely allow emissions testing to be performed at fixed mileage intervals. To introduce a degree of clarity in the data presented in the figures accompanying the text and to eliminate overrepresentation of measurements at low mileage, arithmetic averages were calculated for all emissions tests on a single vehicle within a fixed mileage interval. For example, all emissions tests recorded on a given vehicle with less than 2500 accumulated miles were averaged, and the result was plotted at the zero-mile level. All tests between 2500 miles and 7500 miles were averaged and plotted at the midpoint of the range, the 5000-mile interval. This procedure was followed for the remaining data that fell within each successive 5000-mile increment. Without this averaging, graphs of emissions trends would look like Figure 1, in contrast with the subsequent figures.

Unadjusted data not subject to this simplifying step are presented in Appendixes A and B.

SECTION 3—MEASURING METHANOL VEHICLE EMISSIONS

For a number of reasons, measuring emissions from methanol vehicles is different and more challenging than measuring emissions from gasoline vehicles:

a. The chemical composition of methanol vehicle exhaust organics is fundamentally different from that of exhaust organics in gasoline vehicle emissions. Methanol vehicle exhaust, unlike gasoline vehicle exhaust, contains significant amounts of oxygenated compounds, primarily methanol and formaldehyde. Because EPA believes that photochemical processes are carbon dependent, it has chosen to compare methanol and gasoline vehicle emissions by calculating a "hydrocarbon equivalent" for methanol organic emissions, in which the mass of oxygen is excluded for purposes of meeting the emission standard (*Federal Register*, 1989). Also, when flame ionization detection (FID)—the traditional method of measurement—is used, data are often adjusted to offset the insensitivity of the technique to methanol and formaldehyde. Some laboratories have used gas chromatographic and high-pressure liquid chromatographic techniques to measure methanol and formaldehyde more accurately.
b. Methanol emission test samples contain a high percentage of water vapor. If emission vapors condense, not all the emissions can be measured.
c. Methanol emission samples are more unstable, especially when sample lines are heated to reduce condensation, and degraded samples give false measurements.
d. Taking a single sample for measuring formaldehyde over the three-phase FTP provides a result that is different from what would be obtained by taking a sample during each phase of the FTP.

Organic Material Hydrocarbon–Equivalent (OMHCE) Emissions

To adjust for the contribution that oxygen makes to the mass emission rates of formaldehyde and methanol, EPA has developed an organic carbon exhaust standard for methanol vehicles, computed as follows (all emissions measured in grams per mile):

$$OMHCE = HC + (13.876/32.042)(MeOH) + (13.876/30.026)(HCHO)$$

The denominators of the coefficients are the molecular weights for methanol and formaldehyde, respectively. The numerators of the coefficients represent the molecular weight of the reference hydrocarbon fuel (carbon:hydrogen ratio of 1:1.85). The equation removes the contribution of oxygen and relates total organic emissions on a carbon basis. This allows total organic emissions from methanol-fueled vehicles to be compared with those from conventionally fueled cars on a carbon-equivalent basis.

Flame Ionization Detection

Until recently, there have been no standardized procedures for testing and evaluating emissions from methanol-fueled vehicles. Consequently, researchers in government, academia, and industry have adopted a variety of techniques for collecting, measuring, and reporting methanol vehicle emissions.

For years, FID was used to measure hydrocarbon emissions from both methanol and gasoline vehicles. However, FID has low sensitivity to oxygenated compounds in methanol emissions, and researchers have had to compensate for this insensitivity. Compensation is complicated because the correct adjustment depends on the levels of both methanol and formaldehyde in the sample.

Recently, a better test standard has been used. Methanol and formaldehyde are separated from vehicle emissions and measured independently by chromatographic and spectrophotometric analysis. Although this procedure is a major improvement, measurement error and bias have not been eliminated.

Measurement Bias

A paper by Horn and Hoekman (1989) concludes that use of the current EPA- and CARB-specified test procedures for methanol vehicles likely results in an underestimation of organic emissions for fuels containing methanol. This is because methanol exhaust emissions contain a high percentage of water vapor. Emission samples tend to condense and cannot be measured. This is not generally a factor in tests of conventionally fueled vehicles, where water vapor content is much lower.

It is difficult to assess the degree to which measurement bias is controlled, even for recent studies using chromatographic methods. Horn and Hoekman also compare the effects of obtaining samples in bags with those of acquiring samples continuously. The results for methanol indicate an increase of about 25 percent for continuous measurements, compared with bagged samples above 300 parts per million (0.03 percent). This result may be due to the condensation of samples on the walls of the sample bags or to the migration of methanol to the sampling bags' walls. Methanol condensation on the trap inlets of impingers is termed "significant," although no quantitative estimate of possible sample loss is given.

Carryover effects are reduced by the heating of the sample system. For formaldehyde, this error is reduced from 26 percent to less than 4 percent at a test temperature of 45°F and from 5 percent to less than 1 percent at a test temperature of 75°F. Stability of methanol samples appears to be sample dependent. Results ranged from excellent stability to complete loss of the sample over a period of 40 days. Degradation may be most severe at low methanol concentrations.

According to CARB, measurements of aldehyde emissions from reference methanol vehicles may vary by as much as 20 percent, depending on the number of samples collected during the FTP. Before June 1988, CARB measurements were based on single samples being taken during the FTP. However, taking samples during each phase of the FTP allows one to weight aldehyde emissions data in the same way the other exhaust emissions are weighted. In June 1988, CARB changed the formaldehyde procedure to require the taking of three samples, which matches the procedure used by EPA. CARB estimates that the current procedure gives results that are about 20 percent lower than those obtained using the former procedure.

SECTION 4—METHANOL EMISSIONS TRENDS

This section provides a more detailed analysis of methanol emissions and is divided into five parts. The first part looks at all of the exhaust data with odometer readings. The second part describes the vehicle technology classes represented within the restricted data subsets. The third part then analyzes the restricted data subsets (by vehicle classes, fuel, and so forth). The fourth part looks at subsidiary engineering data, including recent research involving prototype vehicles, advanced catalysts, and emissions measurements taken under non–FTP conditions. The fifth part looks at the evaporative emissions data.

Analysis of All Emissions Data With Odometer Readings

All of the emissions data associated with odometer readings were analyzed. The analysis included data for 54 of the 69 vehicles tested in the studies. As described above, for purposes of analysis and graphic display, the data were converted to average emissions levels per vehicle for each major mileage category (0, 5000, 10,000, and so on). Thus, if a vehicle had more than one emissions level observation within an interval of 5000 miles, those levels were averaged.

The data unaccompanied by odometer readings were not analyzed because, as discussed, these observations could not be compared in any meaningful way with measurements associated with odometer readings. Further, the significance of the observations lacking odometer readings is highly uncertain. Vehicles without odometer readings were often part of an engineering test program and were not operated under on-the-road conditions.

The data analyzed were considered first as a function of vehicle vintage—1981–1985 or 1986–1988 model cars—and second as a function of fuel type—M85 or M100. Four frequency distribution tables were created for each emission type—formaldehyde (HCHO), nitrogen oxides (NO_x), carbon monoxide (CO), and organics (OMHCE)—showing the impact of the two vehicle vintages and the two fuel categories on emissions levels over 5000-mile intervals. (These tables are not included.) The tabular data are summarized in Figures 2–9, which show the relative frequency of various emission levels. Because mileage varies in the data presented in these bar graphs, it is not always clear whether observed differences by vintage or fuel are partly due to the association of higher mileage with higher emissions. Only a few of the data were recorded at high mileages. To examine the overall impact of mileage, the emissions performance for each of the four emissions components of all the vehicles (without respect to vintage or fuel) was averaged as a function of mileage. This analysis is presented in Table 3.

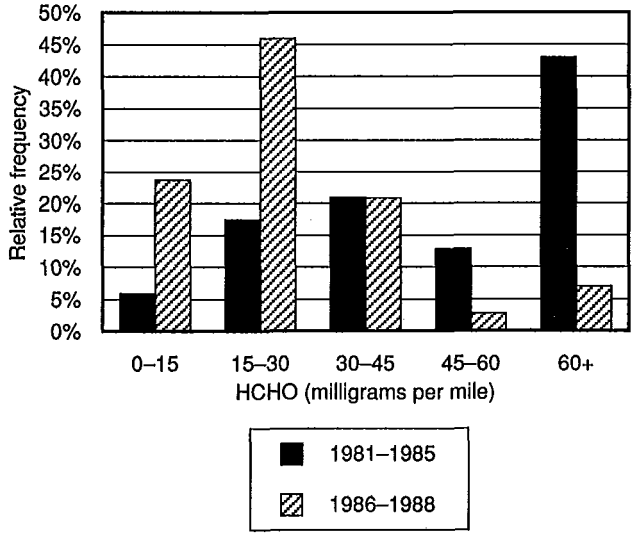


Figure 2—Formaldehyde Emissions: 1981–1985 vs. 1986–1988 Models

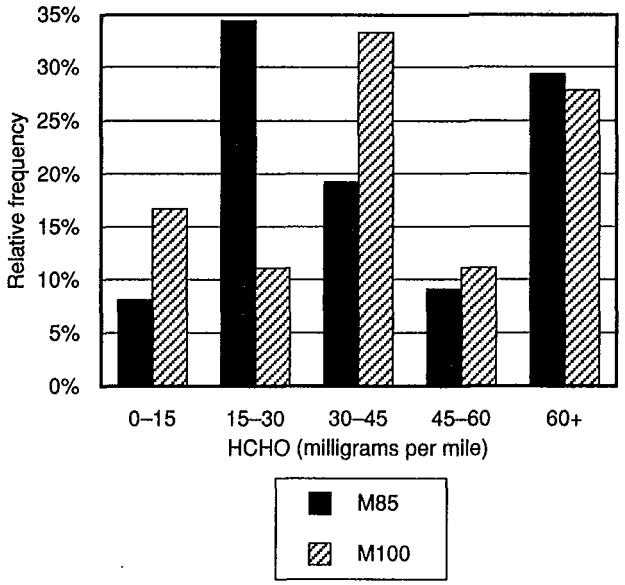


Figure 3—Formaldehyde Emissions: M85 vs. M100

Vehicle vintage is important because newer vehicles tend to have emission control systems that use more advanced technology. These vehicles should therefore tend to have lower emissions. However, most of the data for the newer vehicles are for low mileage, so it is difficult to separate the effects of technology and mileage, as discussed below. Fuel type is also important because different fuels have different emission characteristics. Emission levels on M85 and M100 fuels were analyzed because proposals to substitute methanol for gasoline vehicles focus on these fuels.

Analyzing the data according to these two basic variables and with respect to mileage provided basic information about methanol emissions, but it also raised questions about interpretation of the results. One problem arose from the correlation of vehicle vintage and mileage. Both affect emissions. As shown by the mileage distribution in Figure 10, the data are concentrated at low mileages. In addition, the emissions measurements for newer vehicles are concentrated at lower mileages, whereas the opposite is true for older vehicles. The tests at mileages greater than 40,000 miles were all performed on 1981–1985 vehicles. When we compare emissions as a function of vintage, we are really observing vintage effects and high-mileage/high-emissions effects together. Another problem arose in part from comparisons and implicit aggregation across dissimilar models of vehicles. The analysis of the first-level screen, which used data with odometer readings for each emissions type, follows.

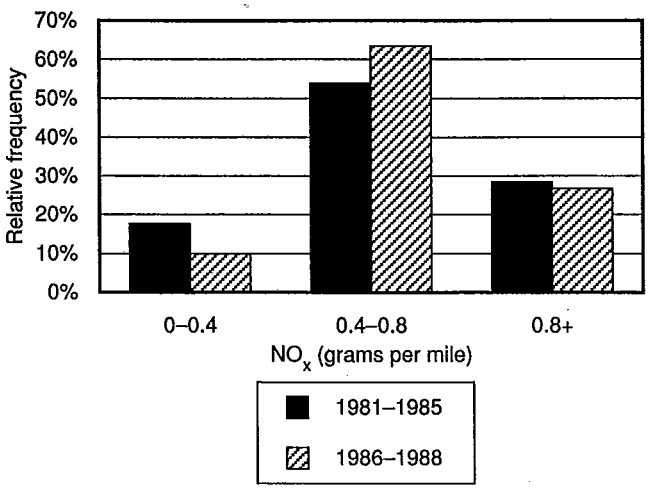


Figure 4—NO_x Emissions: 1981–1985 vs. 1986–1988 Models

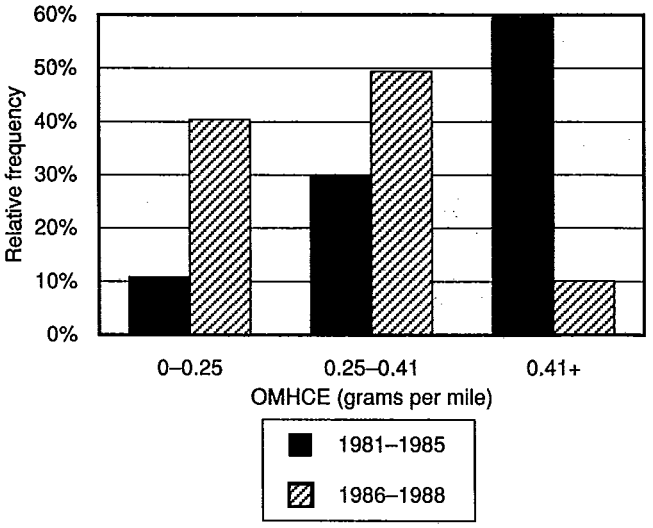


Figure 6—OMHCE Emissions: 1981–1985 vs. 1986–1988 Models

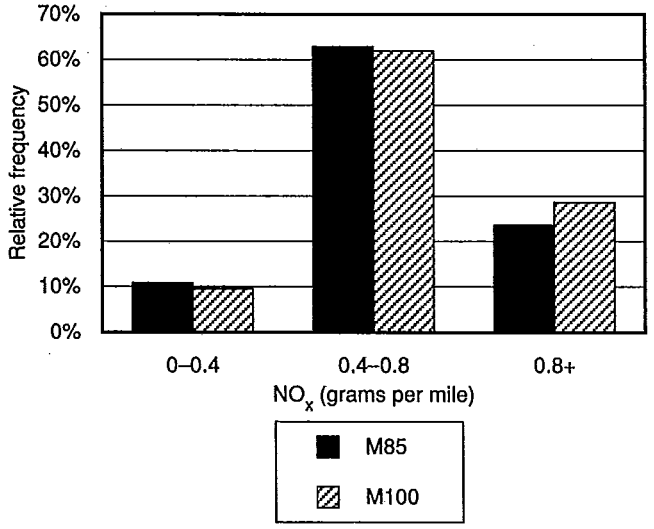


Figure 5—NO_x Emissions: M85 vs. M100

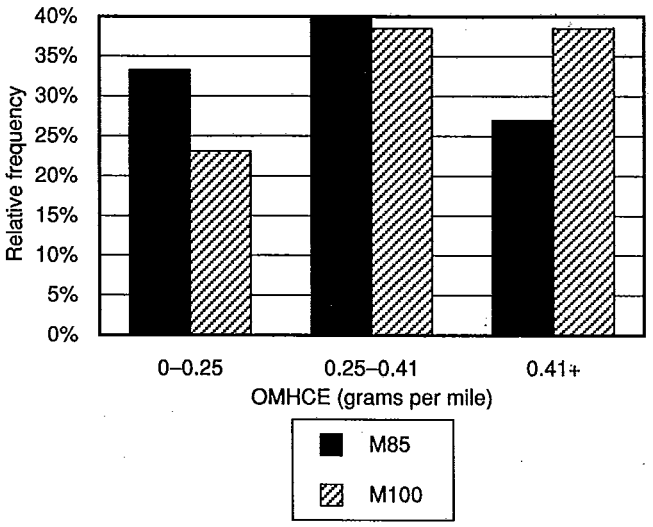


Figure 7—OMHCE Emissions: M85 vs. M100

FORMALDEHYDE

The average formaldehyde emissions level for all vehicles through the 5000-mile interval was nearly triple the new 50,000-mile California formaldehyde standard of 15 milligrams per mile, and the average level increased to three to four times the standard at higher mileages (see Table 3).[1] In general, both older and newer cars operating on either fuel had difficulty meeting the California standard (see Figures 2 and 3).

Newer cars registered formaldehyde levels that met the new 50,000-mile standard of 15 milligrams per mile less than 24 percent of the time (see Figure 2). Older cars were able to meet this emissions level less than 6 percent of the time, exceeding 60 milligrams per mile more than 40 percent of the time (see Figure 2). As noted above, some of this effect may be caused by the concentration of higher mileage (thus, higher emitting) vehicles in the older car class. At low mileages, formaldehyde emissions from M100 vehicles were lower than the standard more often than formaldehyde emissions from M85 vehicles, but M100 vehicles still only met the standard about 17 percent of the time. The number of instances in which the California standard was exceeded was substantial for all categories, with many exceedances at levels four times the standard or higher.

[1]Some of these data were gathered using the old formaldehyde procedure, which CARB believes gives results that could be overstated by 20 percent.

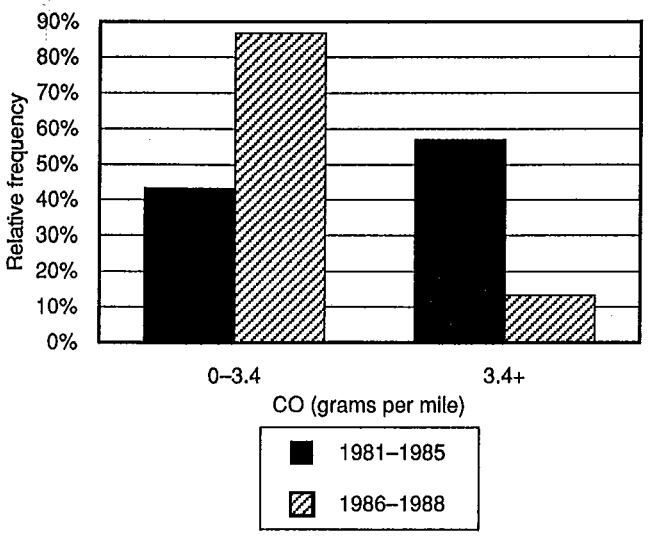


Figure 8—CO Emissions: 1981–1985 vs. 1986–1988 Models

NITROGEN OXIDES

On average, at all mileage intervals, the test cars met the 50,000-mile federal NO_x standard of 1.0 gram per mile but not the California standard of 0.40 gram per mile (see Table 3). Older cars met the California NO_x standard level only about 18 percent of the time (see Figure 4). The newer cars showed about the same NO_x performance as the older vehicles, with emissions below the 0.40-gram-per-mile level only 10 percent of the time (see Figure 4). However, not all of the vehicles (new or old) were designed to meet a standard of 0.40 gram per mile.

As shown in Figure 5, M100 vehicles performed no better than did M85 vehicles in meeting the tighter California NO_x standard. In fact, the NO_x emissions performance of cars operating on M100 was essentially identical to that of cars operating on M85.

ORGANICS (OMHCE)

For all cars, the average level of organic emissions was less than the 50,000-mile federal standard of 0.41 gram per mile only through 15,000 miles and then rose slightly above it at the 20,000- and 25,000-mile intervals (see Table 3). A significant increase to more than double the standard level at 30,000 miles and above can be accounted for by two outlier observations that appreciably affected the averages. (Without these outlier measurements, average OMHCE emissions at 30,000 or more miles would be similar to the averages at lower mileages.)

The newer cars, tested only to about 25,000 miles, met the 50,000-mile federal OMHCE standard about 90 percent of the time (see Figure 6). About 40 percent of the time they met the tighter California standard level of 0.25 gram per mile, which takes effect in 1993. Almost 60 percent of the time the older cars did not meet the 50,000-mile federal standard (see Figure 6). Again, this result may be partly attributable to the higher mileages accumulated by older, compared with newer, vehicles.

The performance of cars operating on M85 and M100 was similar (see Figure 7). However, M85 vehicles had organic emissions less than the 50,000-mile California standard level 33 percent of the time, but M100 vehicles (which included more older than newer vehicles tested on the fuel) had lower emissions only 23 percent of the time.

CARBON MONOXIDE

The average CO level for all cars was below the 50,000-mile federal standard of 3.4 grams per mile through the 25,000-mile interval and then jumped more than 2.0 grams per mile above it at 30,000 miles and above (see Table 3). Newer cars met the 50,000-mile federal standard level 87 percent of the time—twice as frequently as did the older cars (see Figure 8). A greater proportion of lower mileage readings in new cars probably accounts for part of this difference. There was almost no difference in the performance of M100 and M85 vehicles (see Figure 9). Both met the federal standard about two-thirds of the time.

Classes of Vehicles Providing Data for Analysis

The 31 vehicles whose emissions data satisfied all of the data criteria can be grouped in several general classes. The idea was to group models using similar technology and to separate models using different technologies or different fuels. This reduces the scatter of emissions as a function of mileage and clarifies differences in performance for different

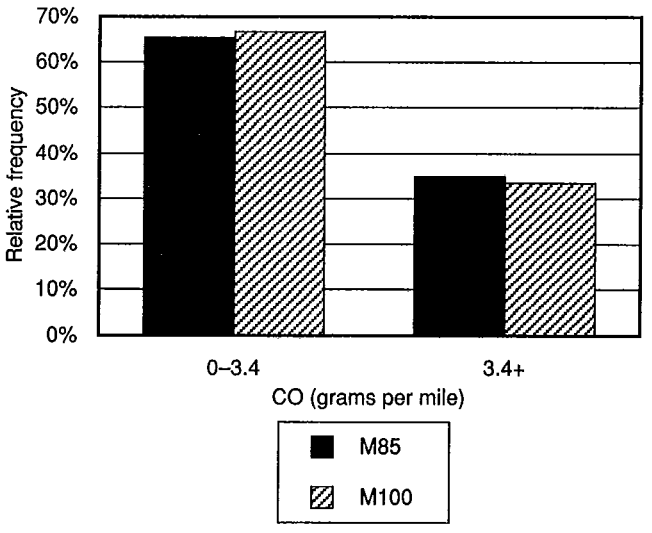


Figure 9—CO Emissions: M85 vs. M100

Table 3—Mileage Dependence of Emissions

Compound	Emissions (grams per mile)			
	0–5000 Miles	10,000–15,000 Miles	20,000–25,000 Miles	≥30,000 Miles
CO	3.05	3.17	3.41	5.92
NOx	0.63	0.68	0.74	0.77
OMHCE	0.35	0.36	0.43	1.0[a]
HCHO	0.042	0.045	0.057	0.062

[a]Strongly influenced by two outliers.

kinds of methanol vehicles. These vehicle classes are described below.

DEDICATED M85 VEHICLES (OLDER U.S. AUTO MANUFACTURER TECHNOLOGY)

The dedicated M85 vehicles that used older U.S. auto manufacturer technology included eight model-year (MY) 1983 Ford Escorts, all designed to meet California exhaust emissions certification passenger car standards of 0.41 gram per mile HC, 7.0 grams per mile CO, and 0.4 gram per mile NO_x at 50,000 miles. Three MY 1981 Escorts were not included because they were operated on M90 or M95 fuels.

The eight MY 1983 1.6-liter Escorts included three that were equipped with multipoint electronic fuel injection, had increased compression ratios, and used a three-way closed-loop catalyst system with exhaust gas recirculation (EGR) and air injection. The five carbureted MY 1983 Escorts also used a three-way catalyst system, EGR, and air injection but no feedback.[2] The MY 1983 Escorts had been operated primarily on M85, accumulating up to about 45,000 miles in California state government fleet service.

[2]The results of emissions tests were confounded by the replacement of catalysts on some of the carbureted and fuel-injected Escorts.

DEDICATED M85 VEHICLES (OLDER FOREIGN AUTO MANUFACTURER TECHNOLOGY)

The dedicated M85 vehicles that used older foreign auto manufacturer technology included two MY 1981 1.6-liter VW Rabbits designed to meet California certification standards of 0.41 gram per mile HC, 7.0 grams per mile CO, and 0.4 gram per mile NO_x. The Rabbits used multipoint fuel injection with high compression ratios, three-way catalysts, and closed-loop fuel control. They had been operated on fuels ranging from M95 to M85 in California state government fleet service, with one vehicle accumulating 70,000 miles.

DEDICATED M85 VEHICLES (RECENT U.S. AUTO MANUFACTURER TECHNOLOGY)

The dedicated M85 vehicles that used recent U.S. auto manufacturer technology included three MY 1986 Ford Crown Victorias and one MY 1988 GM Corsica. The three Crown Victorias were gasoline-fueled vehicles converted for

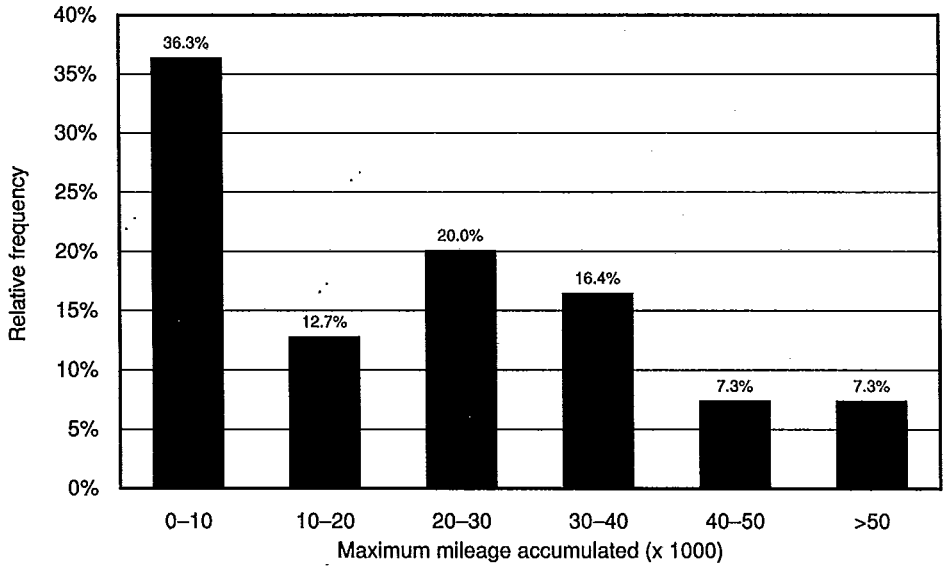


Figure 10—Distribution of Maximum Mileage Accumulated

operation on M85. They were equipped with 5.0-liter feedback-controlled sequentially fuel-injected V-8 engines with modified compression ratios. The MY 1988 GM Corsica was equipped with a 2.8-liter gasoline engine modified for operation on M85 only (by increasing the compression ratio, reprogramming for lean operation, and modifying the camshaft). These four vehicles had accumulated 5000–30,000 miles of service.

DEDICATED M85 VEHICLES (RECENT FOREIGN AUTO MANUFACTURER TECHNOLOGY)

The dedicated M85 vehicles that used recent foreign auto manufacturer technology included three Toyotas for which sufficient odometer information was available: a MY 1985 Camry, a MY 1986 Camry, a MY 1986 Carina, and one MY 1986 Nissan Sentra. The two Camrys were both equipped with 2.0-liter engines and employed EGR, lean air–fuel ratio control (under some operating conditions), multipoint electronic fuel injection, high compression ratios, and three-way catalysts with closed-loop fuel control systems. Mileage accumulation on the Camrys ranged from 22,000 to 44,000 miles.

The MY 1986 Carina used a 2.0-liter engine, close-coupled catalyst, sequential electronic fuel injection, and high compression ratio and was designed for full-time lean operation to improve fuel economy. This vehicle had accumulated 26,000 miles in California state government fleet service.

DEDICATED M100 VEHICLES

The dedicated M100 vehicles included three older Ford vehicles—a MY 1981 Escort, a MY 1984 Escort, and a MY 1978 Pinto—and one second generation vehicle, a MY 1986 Toyota Carina. The exhaust emissions data base tabulated in Appendix A contains information on 11 non-flexible-fueled vehicles tested on M100. The data available on these vehicles are summarized in Table 4. As shown in the table, no emissions data are available on dedicated M100 vehicles at high mileage (that is, above 13,000 miles). In fact, only one dedicated M100 vehicle—the 1986 Toyota Carina—met the criteria for analysis by providing a complete spectrum of emissions (CO, NO_x, formaldehyde, methanol, total organics) data at several mileage increments up to 10,000 miles. Also, some of the tested vehicles ran very poorly. To date, there are no utilitarian vehicles in use dedicated for operation on M100.

FLEXIBLE-FUEL VEHICLES

Emissions data were analyzed for eight FFVs—MY 1987 Ford Crown Victorias—and one variable-fuel vehicle (VFV)—a MY 1988 GM Corsica. Seven of the Crown Victorias were being operated in fleet service for state and local government agencies in California. The remaining one was operated by Ford Motor Company. All of the Crown Victorias were equipped with 5.0-liter V-8 engines with closed-loop controlled sequential port fuel injection. Emission controls included four three-way catalysts, air injection, and EGR. The seven California-based Crown Victorias were designed to meet California's emission standards of 0.41 gram per mile HC and 7.0 grams per mile CO and a NO_x emission level of 0.7 gram per mile. These vehicles had been operated on gasoline, methanol, ethanol, and combinations of these fuels. (Emission tests on ethanol blends are neither reported nor analyzed in this paper.) Most of the testing on these vehicles has focused on M85.

The variable-fuel Corsica was equipped with a 2.8-liter V-6 engine with sequential fuel injection, a three-way catalyst system, and EGR. It was operated by CARB in fleet service and was designed to meet California's emission standards of 0.41 gram per mile HC, 7.0 grams per mile CO, and 0.4 gram per mile NO_x using any mixture of gasoline and methanol.

Table 4—Dedicated M100 Vehicles

Model	Odometer Range	Emissions Data Recorded for				
		CO	NO_x	HCHO	MeOH	OMHCE
'84 Ford Escort[a]	8500-8600	Y	Y	Y	Y	Y
GM Prototype	NA	Y	Y	Y	N	N
'83 Ford Escort[b]	NA	Y	Y	Y	Y	Y
'81 Ford Escort[b]	6000–7000	Y	Y	Y	Y	N
'81 VW Rabbit[a]	1700–2400	Y	Y	Y	Y	N
'81 Nissan 200 SX[a]	1500–1600	Y	Y	N	N	N
'78 Ford Pinto	1250–10,000	Y	Y	Y	N	N
'83 Ford Escort[b]	700–1000	Y	Y	Y	N	N
'80 Ford Escort[b]	400–13,000	Y	Y	N	N	N
'87 Nissan Sentra[a]	NA	Y	Y	Y	Y	N
'86 Toyota Carina[a]	1500–10,000	Y	Y	Y	Y	Y

[a]Fuel injected.
[b]Carbureted.

Emissions Trends From Restricted Data

More detailed analysis of the narrower subset of complete data (developed as a result of the second-level screening) provides insight into the performance of the specific methanol-fueled vehicles described above.

Before performing this analysis, however, we checked the validity of narrower subsets of the data in general by comparing distributionally the larger data set (all observations with mileage readings) with a second restricted subset of data (emission results for M85 and M100 fuels only). The second restricted subset of the data is close but not identical to the data base resulting from screening with the four criteria described above. The comparison of the large and small data bases is shown in Figures 11–14. The similar frequency distributions shown in these figures suggest that the more restrictive screening process did not introduce biases into our analysis.

Our analysis of the emissions from the 31 vehicles selected by the second-level screening is as follows.

FORMALDEHYDE EMISSIONS (SEE FIGURES 15–22)

Current-generation FFVs and dedicated M85 and M100 vehicles generally exceeded the 50,000-mile California tailpipe formaldehyde emissions standard level of 15 milligrams per mile (there is no federal standard), as shown in Figures 18–22. The exceptions were one dedicated M100 vehicle—a 1986 Toyota Carina shown in Figure 20[3]—and one dedicated M85 vehicle—a different 1986 Toyota Carina shown in Figure 19. The dedicated M100 Toyota, an experimental vehicle, consistently tested below the 50,000-mile California standard of 15 milligrams per mile. However, this vehicle accumulated only 10,000 miles and did not meet the NO_x standard of 0.4 gram per mile. In some tests, it exceeded an NO_x level of 1.0 gram per mile. The dedicated M85 Toyota also tested below the California formaldehyde standard up to 10,000 miles but then exceeded it at 20,000 and 25,000 miles. Like the M100 Toyota, this was a lean-burn vehicle and did not meet the California NO_x limits. Reducing catalysts do not function when the engine operates at a lean air–fuel ratio.

[3]The reader is advised to look at the averages (denoted by solid lines) shown in the figures to gain an overall impression of emissions. At times the data are sparse, so the average tracks the data for only one vehicle as mileage accumulates. Obviously, such an average may not reflect a general trend. Figures 20, 28, and 36 each contain two lines, one for the average of the older Ford vehicles and one for the second-generation 1986 Toyota Carina.

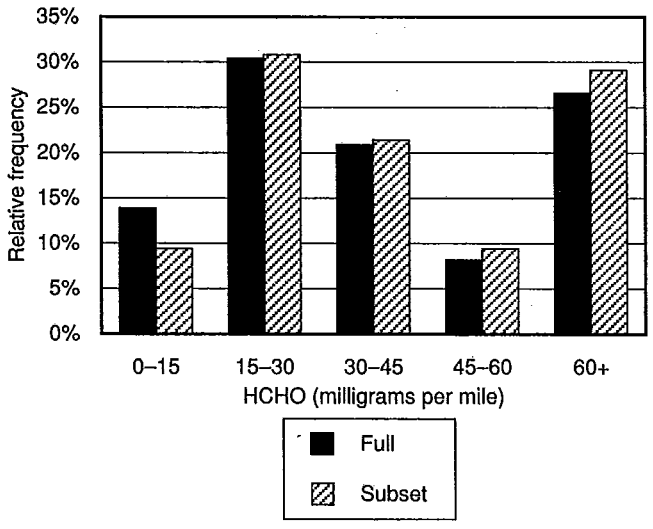


Figure 11—Formaldehyde Emissions: Full vs. Subset Data

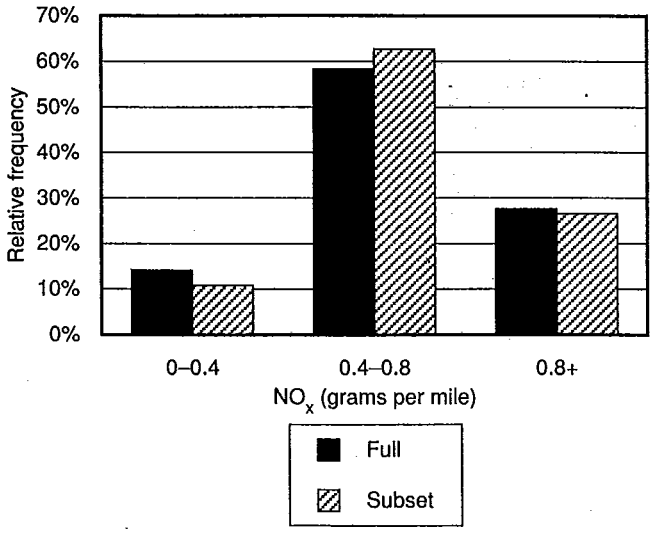


Figure 12—NO_x Emissions: Full vs. Subset Data

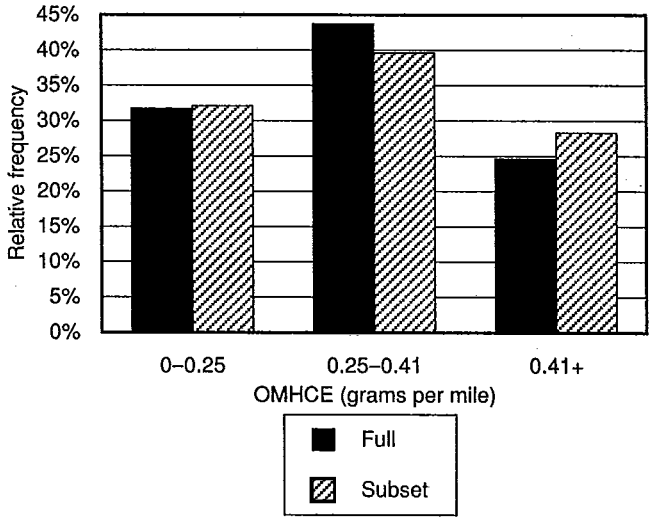


Figure 13—OMHCE Emissions: Full vs. Subset Data

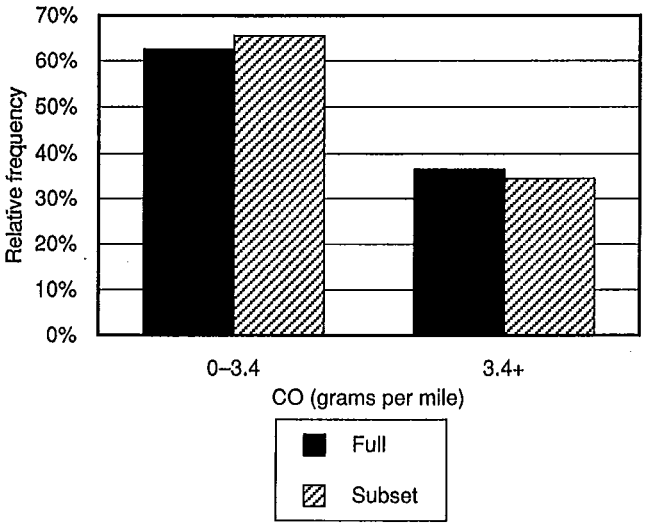


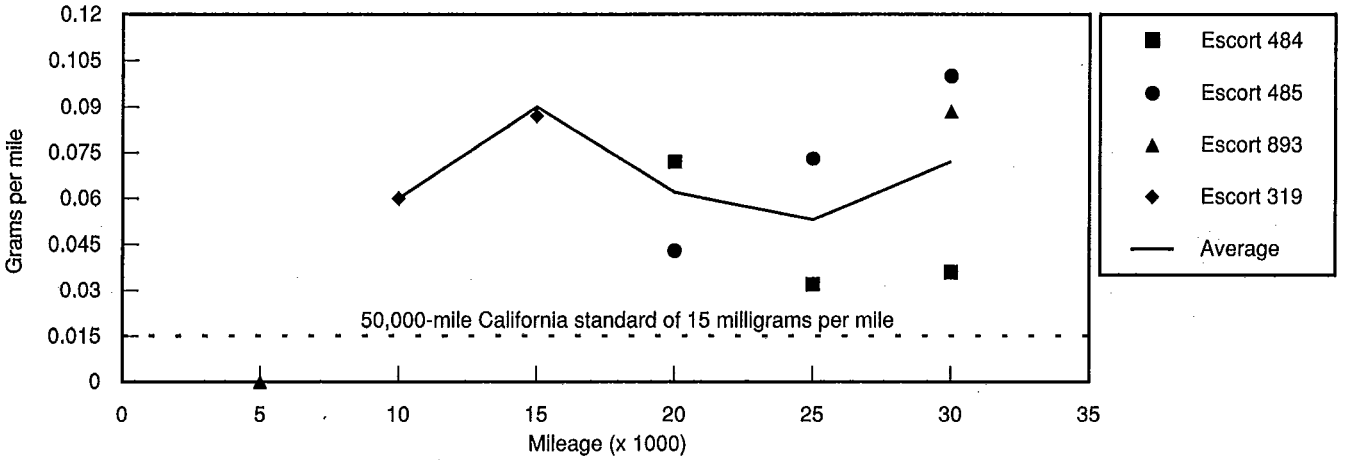
Figure 14—CO Emissions: Full vs. Subset Data

The newer vehicles (see Figures 18–20) had considerably improved formaldehyde emissions performance, compared with the older carbureted and fuel-injected Ford Escorts (see Figures 15 and 16), including two dedicated M100 vehicles (see Figure 20), and the older fuel-injected VW Rabbits (see Figure 17). Whereas the older vehicles frequently emitted five and six times what the California standard permits, the newer vehicles emitted no more than three times that amount. Note, however, that formaldehyde emissions were tested in the older cars at mileages that were generally much higher. The superiority of the newer vehicles supports the same earlier finding based on analysis of all of the data for which odometer readings were available.

NITROGEN OXIDE EMISSIONS (SEE FIGURES 23–30)

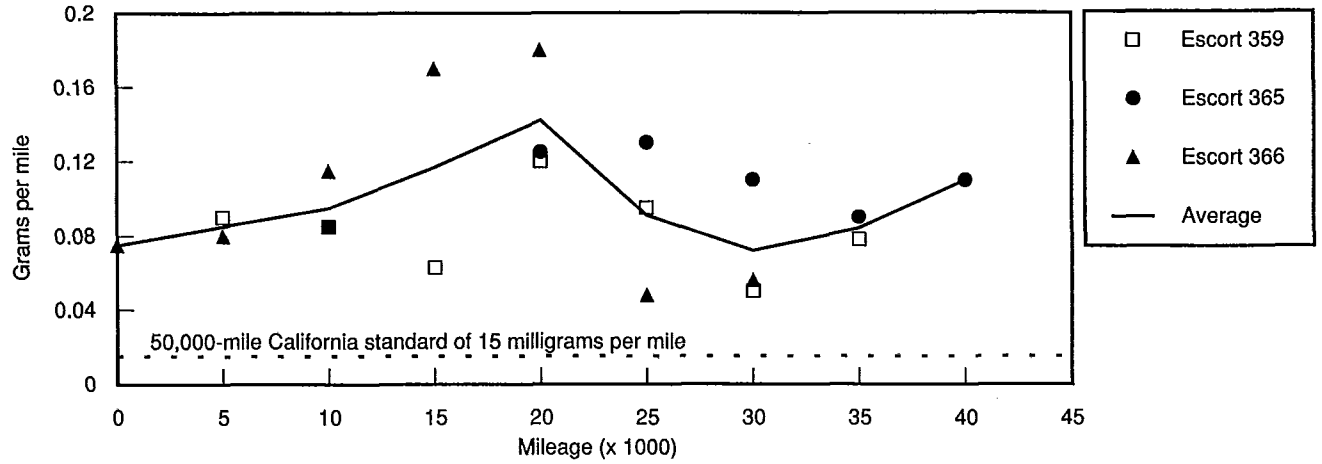
Most vehicles tested below the 50,000-mile federal NO_x standard of 1.0 gram per mile most of the time but did not meet the new 50,000-mile California standard of 0.4 gram per mile, which will be fully implemented in 1994. The more stringent standard was met infrequently by a few cars. These included carbureted and fuel-injected Ford Escorts (primarily at low mileage and with new catalytic converters), two dedicated M85 Crown Victorias, and a flexible-fuel Chevrolet Corsica that was designed to meet the standard of 0.4 gram per mile (see Figures 24, 26, and 30).

In contrast with formaldehyde emissions performance, newer cars did not perform better than older cars with respect to NO_x control. This finding is consistent with the conclusions in the earlier analysis of the larger group of vehicles. Importantly, a few cars had trouble consistently meeting even the less stringent federal NO_x standard. These included recent-technology dedicated M85 and M100 Toyotas, particularly those with lean air–fuel ratios (see Figures 27 and 28). The two 1986 Toyota Carinas that were almost alone in meeting the California formaldehyde standard (see Figures 19 and 20) were among the vehicles with unacceptable NO_x performance. This is because at lean air–fuel ratios, a reduction catalyst is not effective in controlling NO_x emissions. These data suggest that meeting tighter NO_x emissions may involve sacrificing some of the organic emissions performance described below.



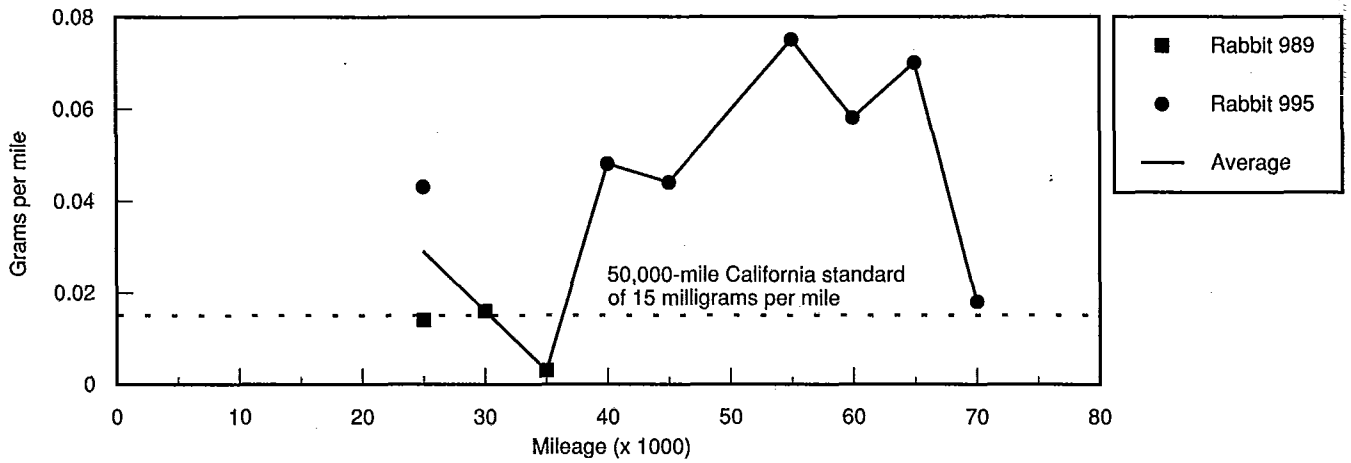
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 484 at 19,600 miles and on Escort 485 at 18,000 miles. The data in the figure are from the California Air Resources Board (1986; 1988; "Quarterly Summary," 12/88–2/89).

Figure 15—Formaldehyde Emissions: Five 1983 Carbureted Ford Escorts (M85)



Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 359 at 27,000 miles, on Escort 365 at 27,600 miles, and on Escort 366 at 20,100 miles. (See Appendixes A and B for additional maintenance notations.) The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 16—Formaldehyde Emissions: Three 1983 Fuel-Injected Ford Escorts (M85)



Note: Mileages are adjusted to the nearest 5000-mile interval. The catalyst was changed on Rabbit 995 at 68,000 miles. The data in the figure are from the California Air Resources Board (1988, 1989).

Figure 17—Formaldehyde Emissions: Two 1981 Fuel-Injected Volkswagen Rabbits (M85)

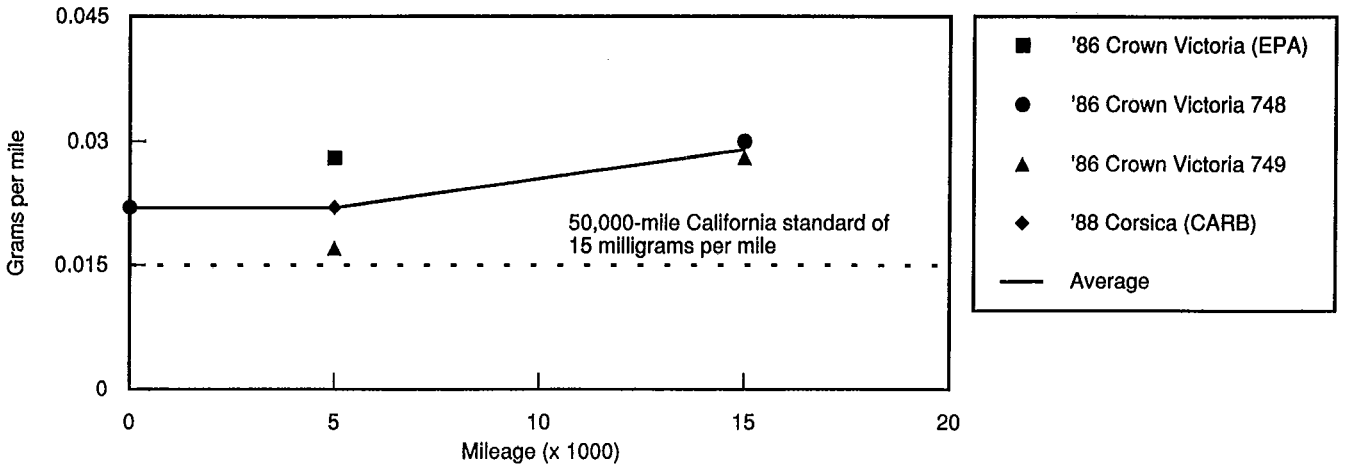
CARBON MONOXIDE EMISSIONS (SEE FIGURES 31–38)

The analysis of the CO data presented graphically essentially parallels the earlier analysis of the distributional data. Average CO emission levels from the newer dedicated M85 and M100 vehicles and FFVs generally fell well below the 50,000-mile federal standard of 3.4 grams per mile (see Figures 34–38). This was a substantial improvement over the performance of the older vehicles, which often exceeded the standard (see Figures 31–33). However, some of the outliers in Figures 31–33 can be explained by equipment malfunction or maladjustment. Among the newer vehicles, there was little difference in the performance of M100 dedicated, M85 dedicated, and flexible-fuel vehicles (see Figures 34–38).

ORGANIC EMISSIONS (SEE FIGURES 39–45)

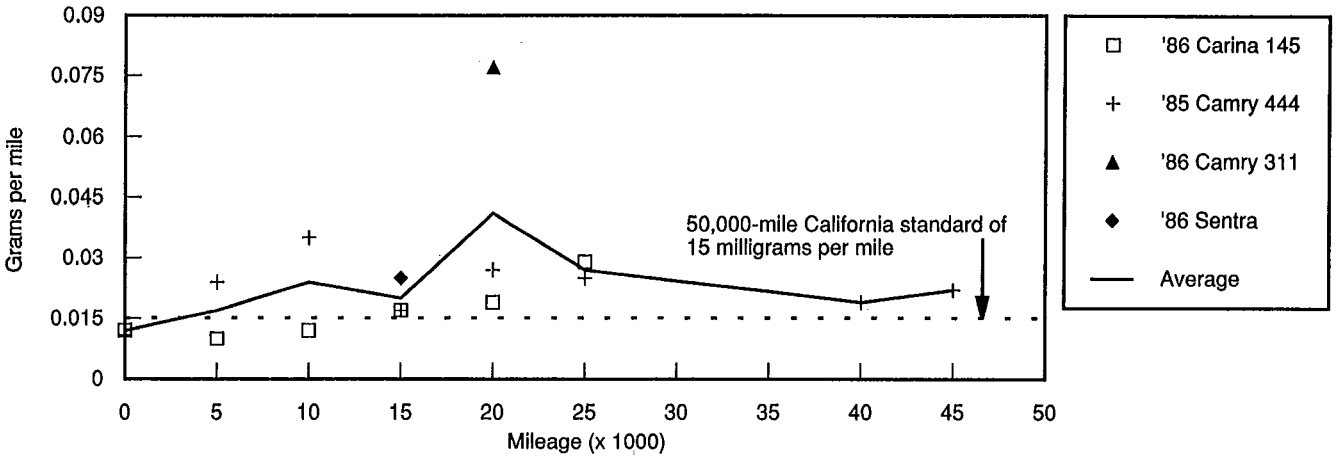
In general, the data for OMHCE emissions are more sparse, with fewer vehicles and fewer data points for a given vehicle. The newer vehicles performed well, with emissions at most mileages less than the 50,000-mile federal hydrocar-

(text continued on page 30)



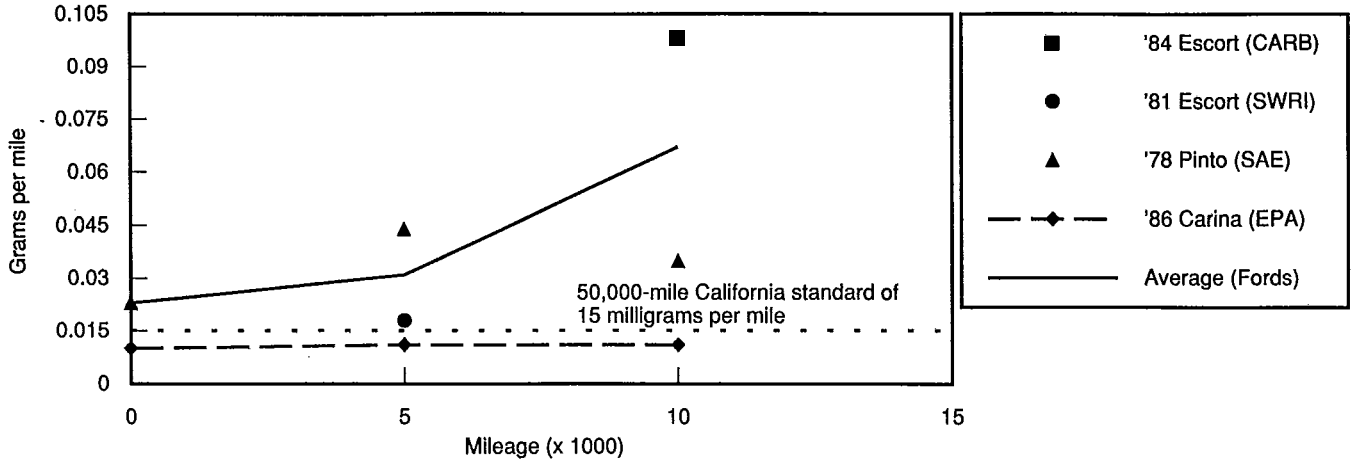
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89) and Piotrowski et al. (1987).

Figure 18—Formaldehyde Emissions: Four Domestic Dedicated Vehicles (M85)



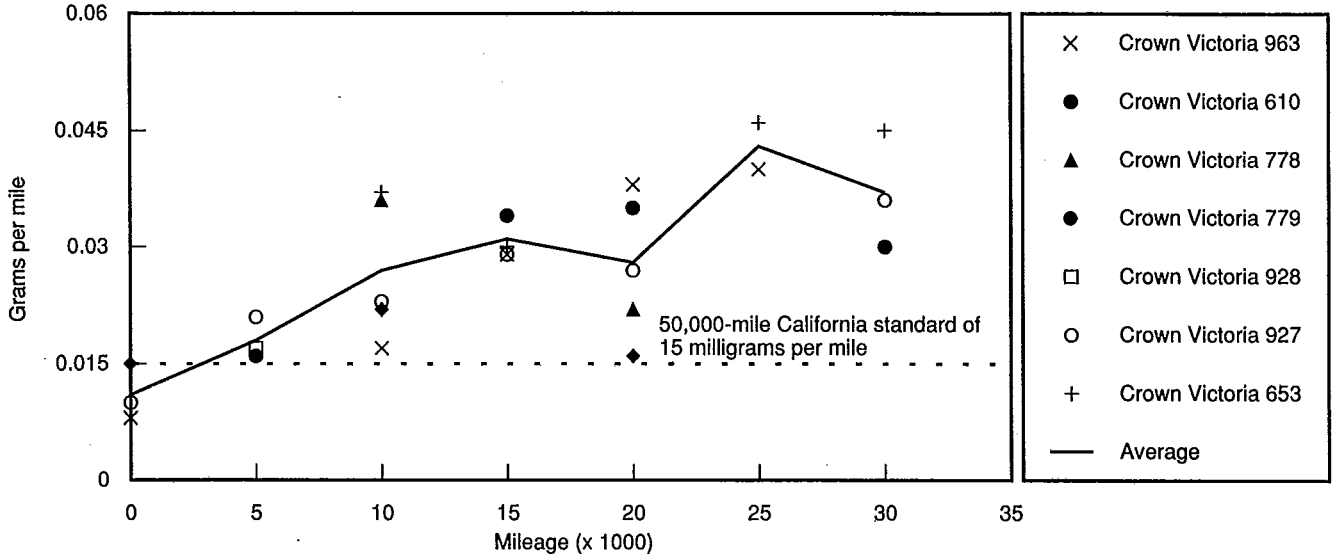
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from Blair (1988) and the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 19—Formaldehyde Emissions: Four Dedicated Toyotas (M85)



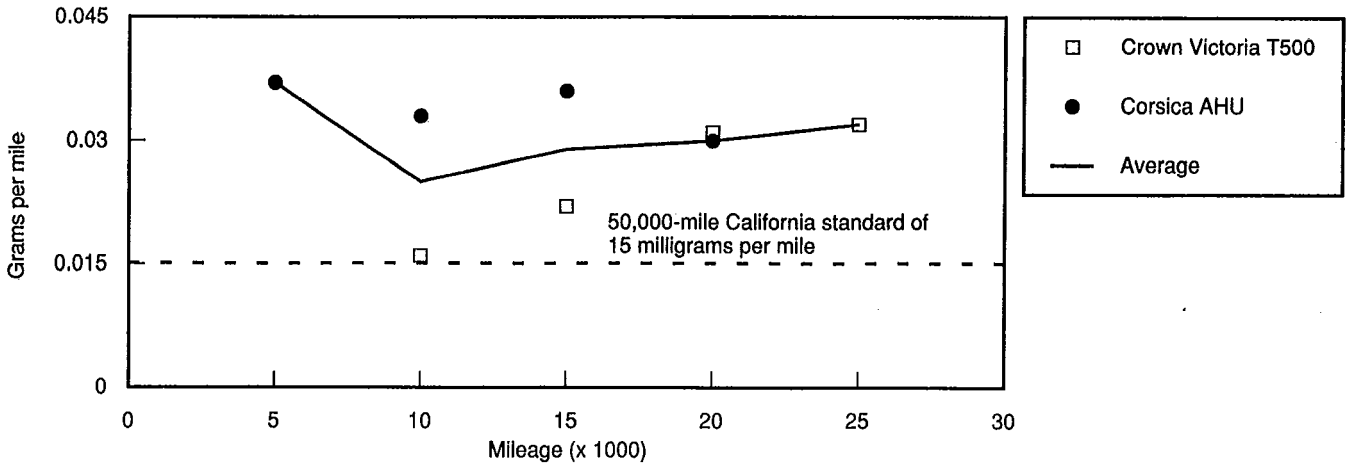
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1986), Edwards and Baisley (1981), Piotrowski (1987), Piotrowski et al. (1987), Piotrowski and Murrell (1987), and Smith (1985).

Figure 20—Formaldehyde Emissions: Four Dedicated Vehicles (M100)



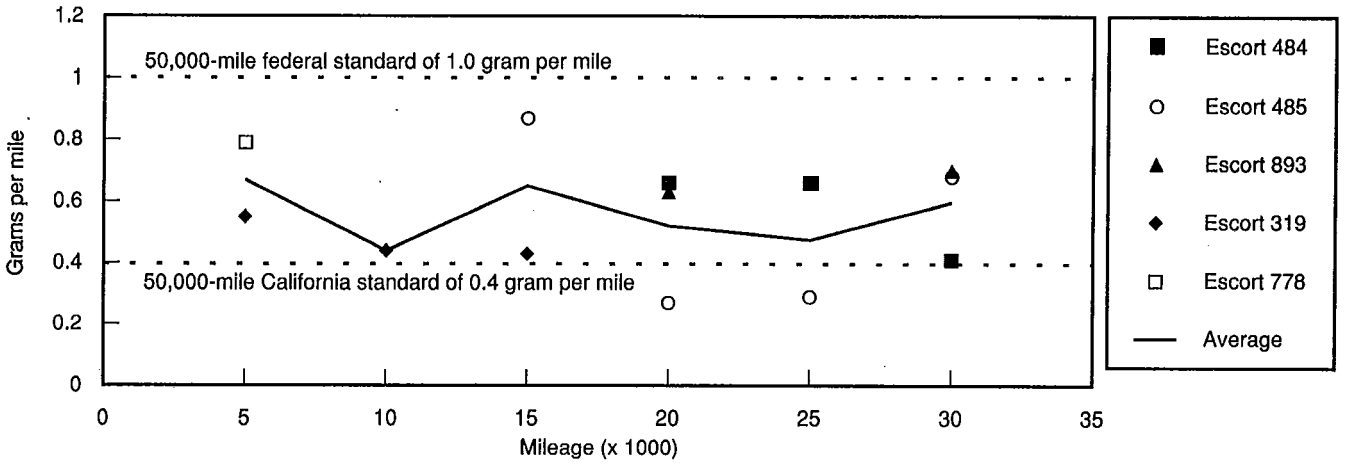
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 6/88–8/88; "Quarterly Summary," 12/88–2/89) and Horn and Hoekman (1989).

Figure 21—Formaldehyde Emissions: Seven 1987 Ford Crown Victorias (M85 Flexible-Fuel Vehicles)



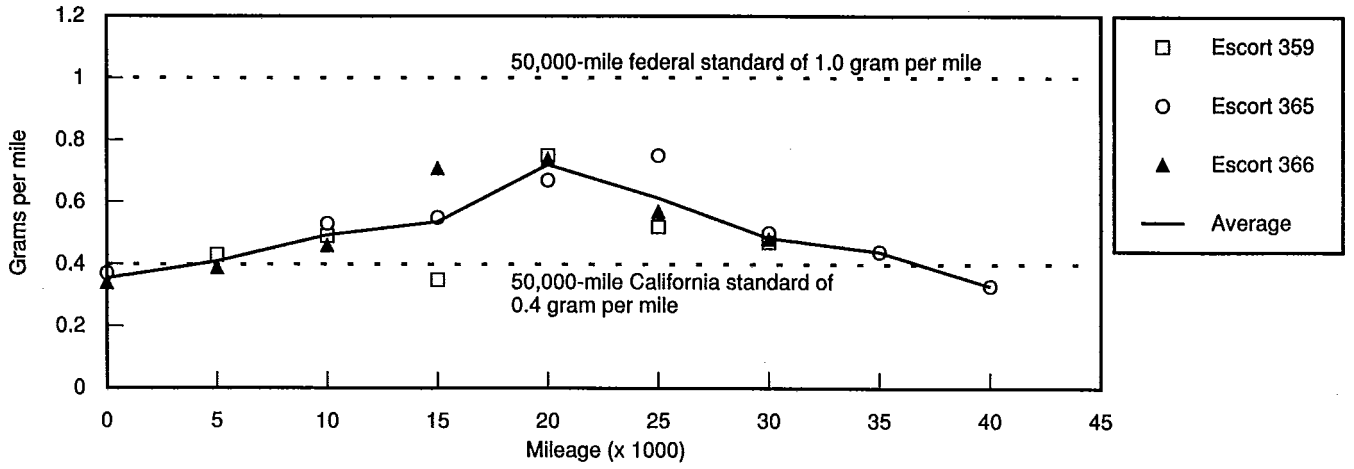
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988, 1989), Horn and Hoekman (1989), and Nichols et al. (1988).

Figure 22—Formaldehyde Emissions: 1987 Ford Crown Victoria and 1988 Chevrolet Corsica (M85 Flexible-Fuel Vehicles)



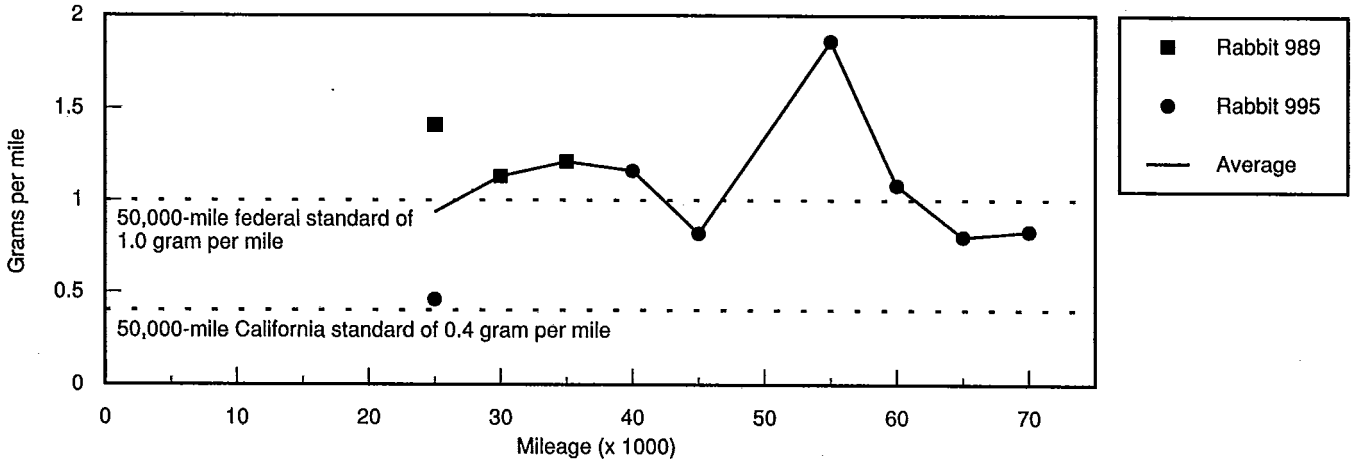
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 484 at 19,600 miles and on Escort 485 at 18,000 miles. The data in the figure are from the California Air Resources Board (1986; 1988; "Quarterly Summary," 12/88–2/89).

Figure 23—NO_x Emissions: Five 1983 Carbureted Ford Escorts (M85)



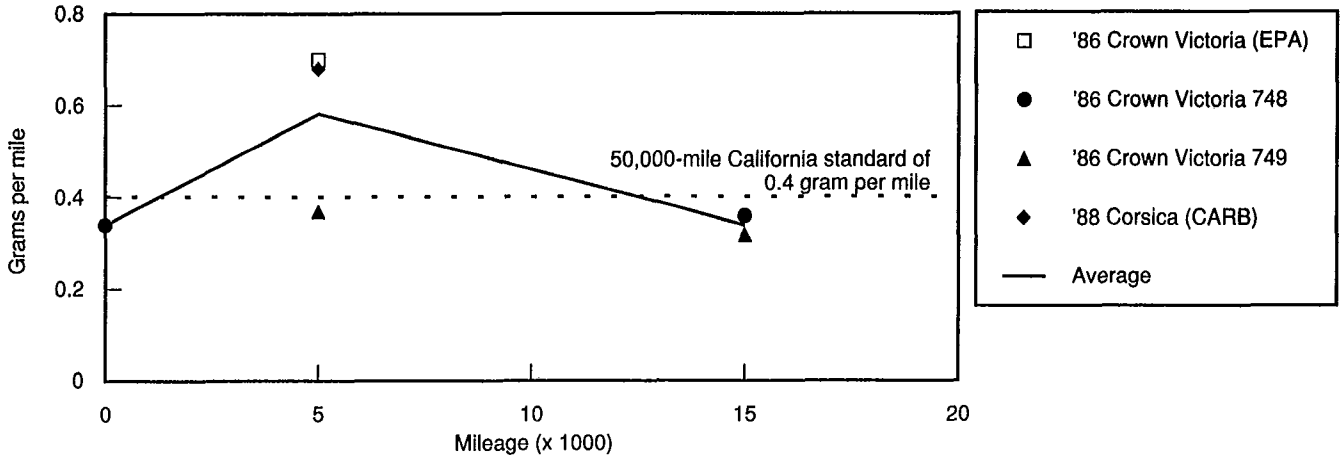
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 359 at 27,000 miles, on Escort 365 at 27,600 miles, and on Escort 366 at 20,100 miles. (See Appendixes A and B for additional maintenance notations.) The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 24—NO_x Emissions: Three 1983 Fuel-Injected Ford Escorts (M85)



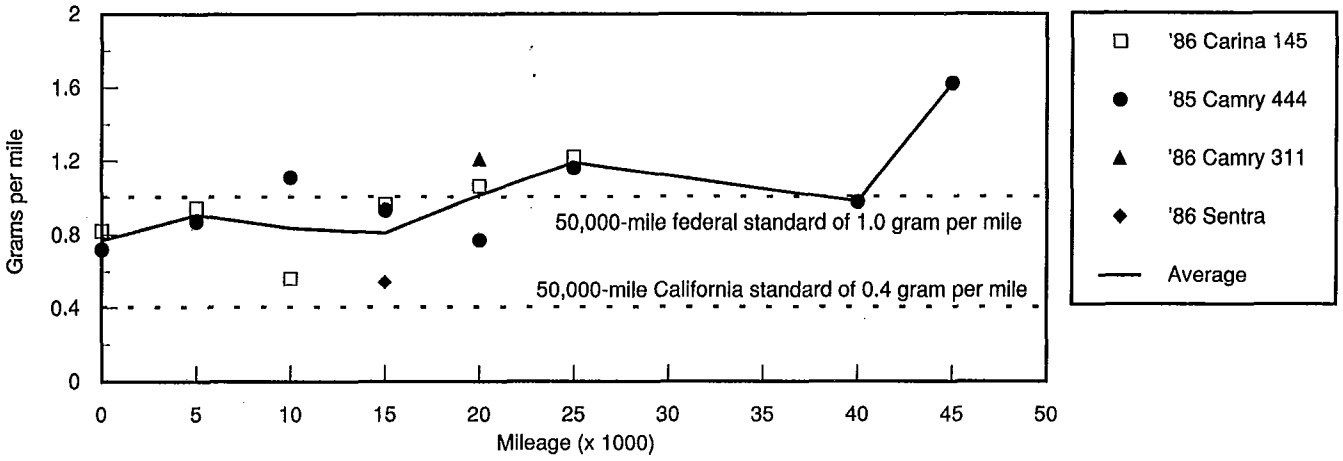
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalyst was changed on Rabbit 995 at 68,000 miles. The data in the figure are from the California Air Resources Board (1988, 1989).

Figure 25—NO_x Emissions: Two 1981 Fuel-Injected Volkswagen Rabbits (M85)



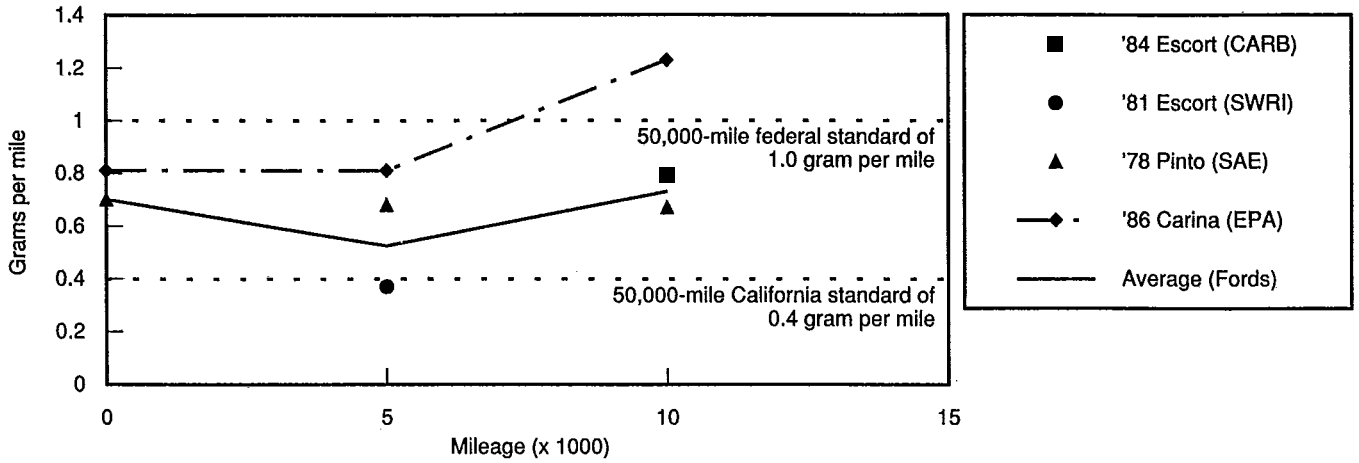
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89) and Piotrowski et al. (1987).

Figure 26—NO_x Emissions: Four Domestic Dedicated Vehicles (M85)



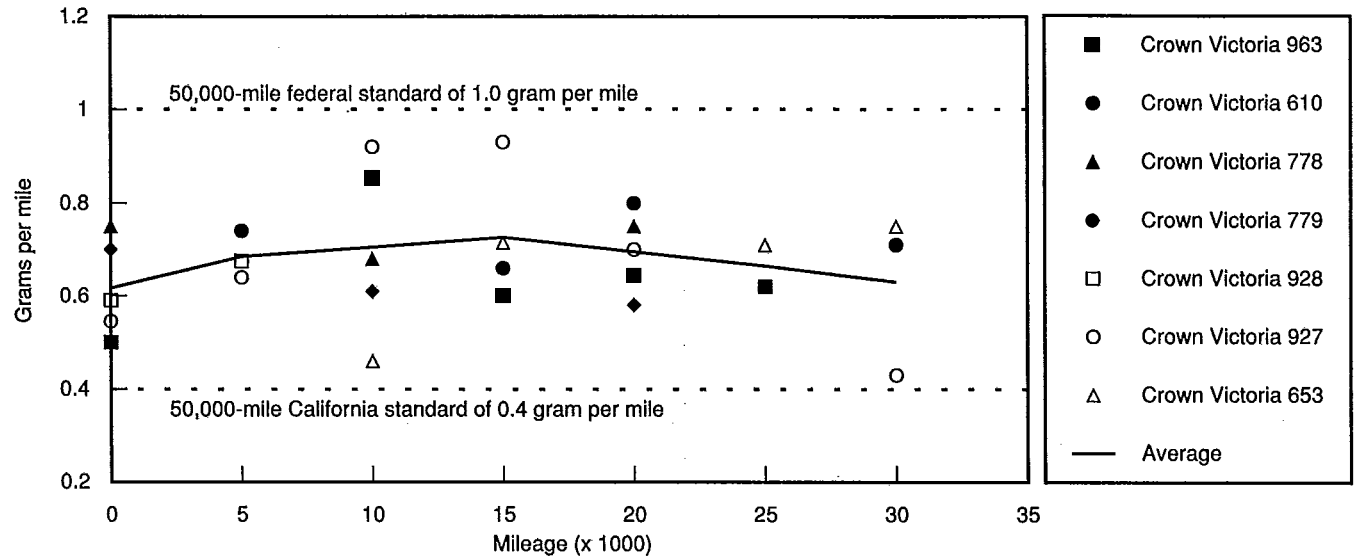
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from Blair (1988) and the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 27—NO_x Emissions: Four Dedicated Toyotas (M85)



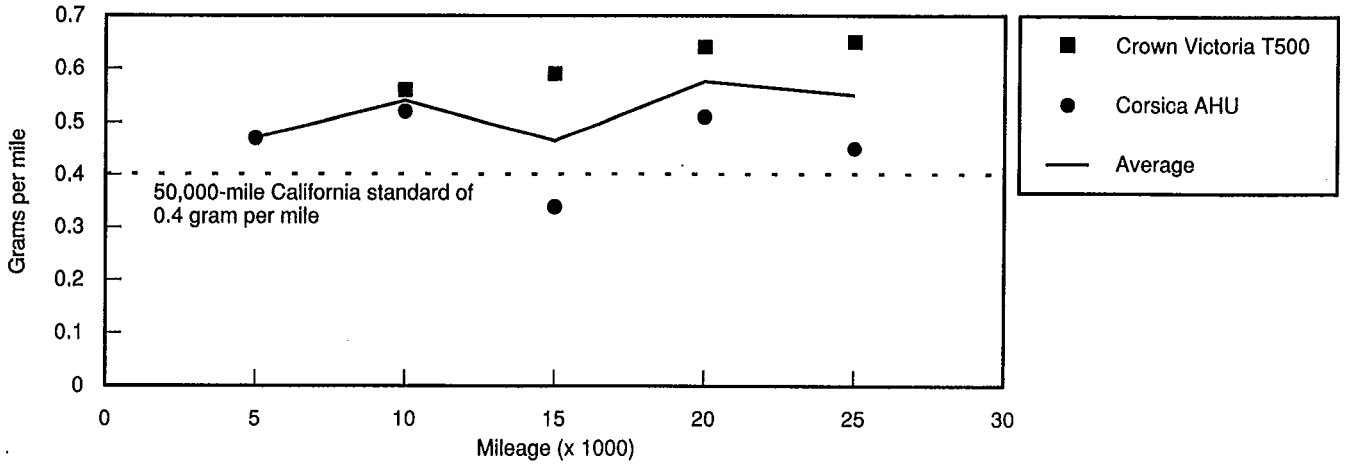
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1986), Edwards and Baisley (1981), Piotrowski (1987), Piotrowski et al. (1987), Piotrowski and Murrell (1987), and Smith (1985).

Figure 28—NO_x Emissions: Four Dedicated Vehicles (M100)



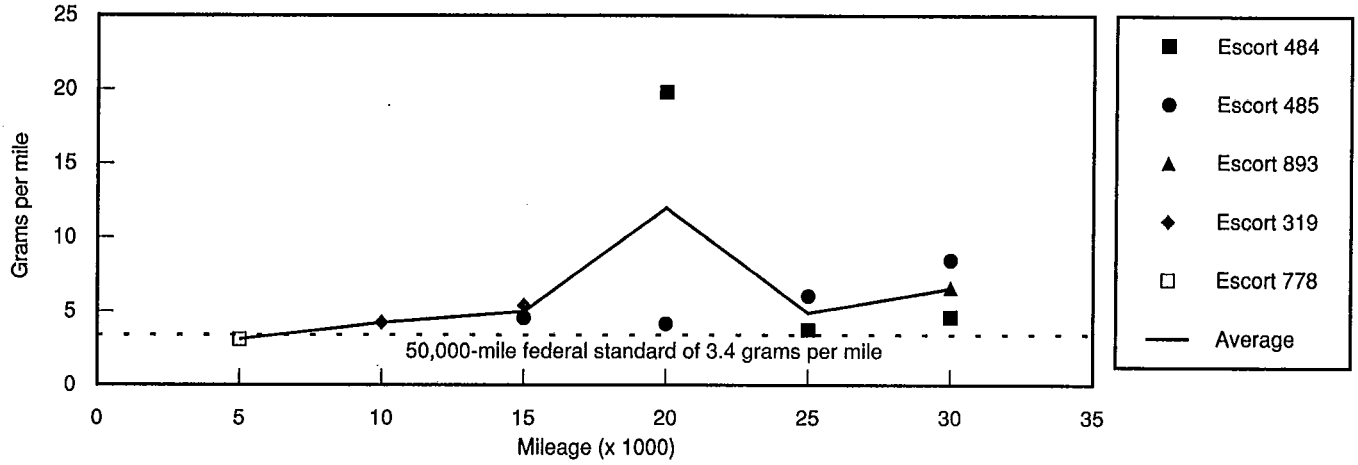
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 6/88–8/88; "Quarterly Summary," 12/88–2/89) and Horn and Hoekman (1989).

Figure 29—NO_x Emissions: Seven 1987 Ford Crown Victorias (M85 Flexible-Fuel Vehicles)



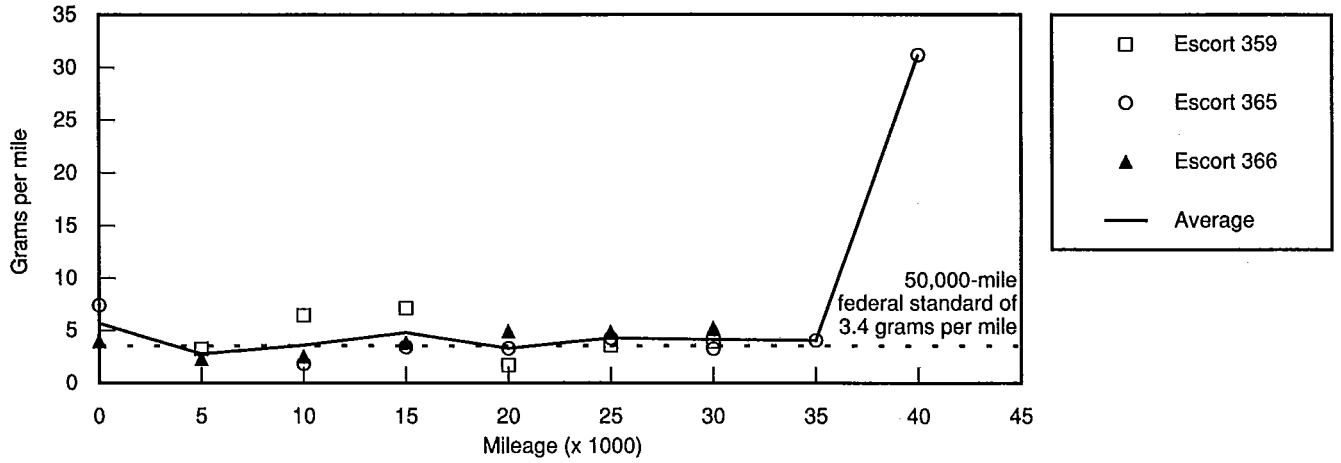
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988, 1989), Horn and Hoekman (1989), and Nichols et al. (1988).

Figure 30—NO_x Emissions: 1987 Ford Crown Victoria and 1988 Chevrolet Corsica (M85 Flexible-Fuel Vehicles)



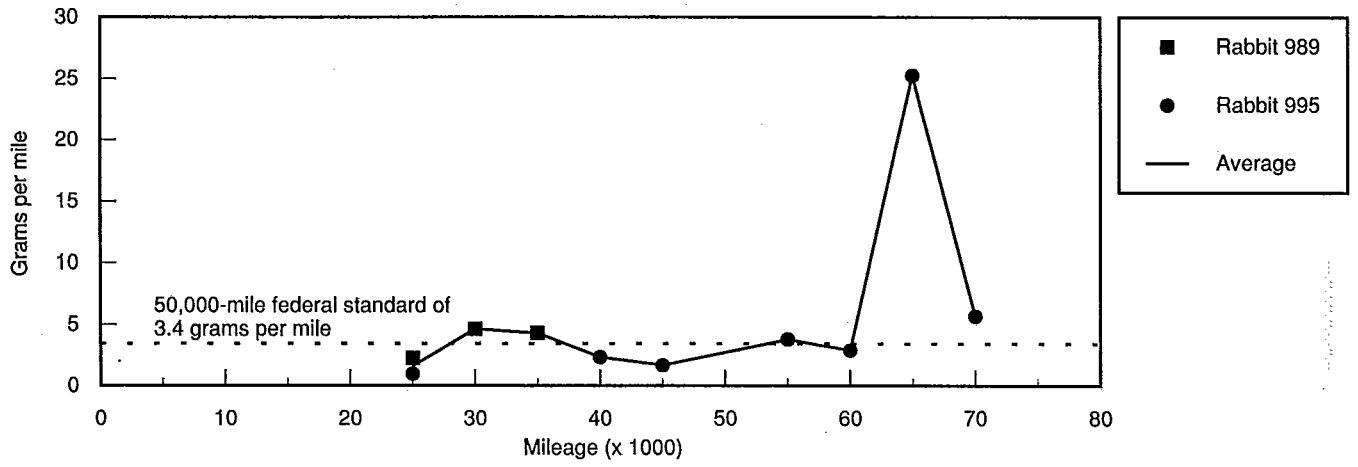
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 484 at 19,600 miles and on Escort 485 at 18,000 miles. The data in the figure are from the California Air Resources Board (1986; 1988; "Quarterly Summary," 12/88–2/89).

Figure 31—CO Emissions: Five 1983 Carbureted Ford Escorts (M85)



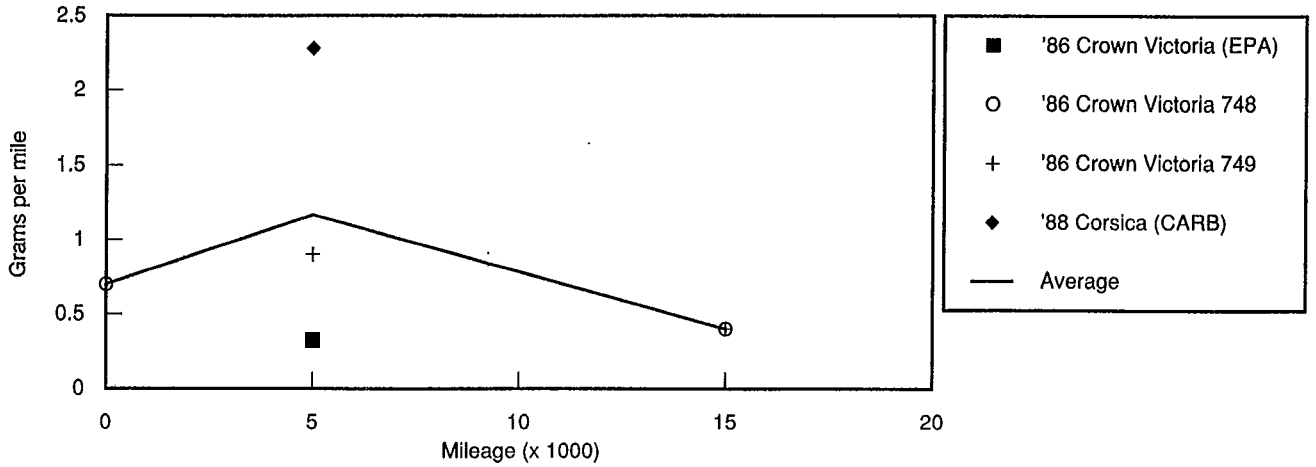
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 359 at 27,000 miles, on Escort 365 at 27,600 miles, and on Escort 366 at 20,100 miles. (See Appendixes A and B for additional maintenance notations.) The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 32—CO Emissions: Three 1983 Fuel-Injected Ford Escorts (M85)



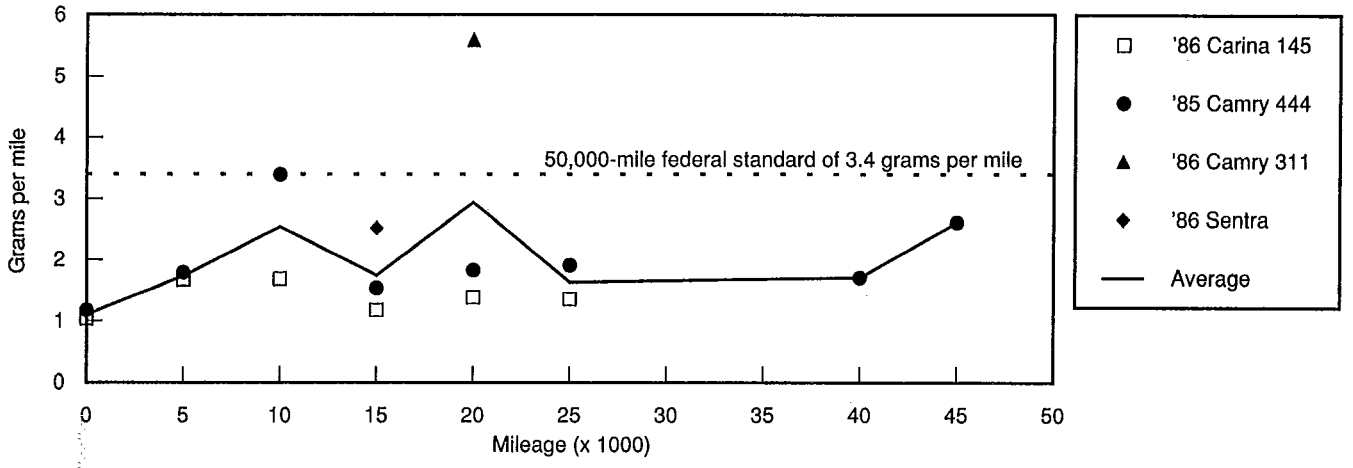
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalyst was changed on Rabbit 995 at 68,000 miles. The data in the figure are from the California Air Resources Board (1988, 1989).

Figure 33—CO Emissions: Two 1981 Fuel-Injected Volkswagen Rabbits (M85)



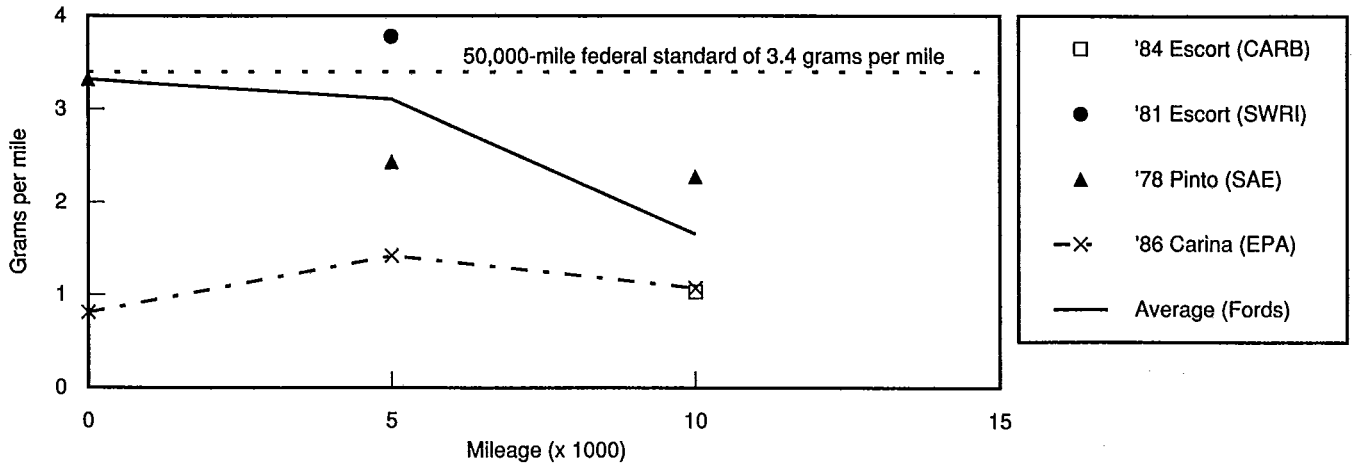
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89) and Piotrowski et al. (1987).

Figure 34—CO Emissions: Four Domestic Dedicated Vehicles (M85)



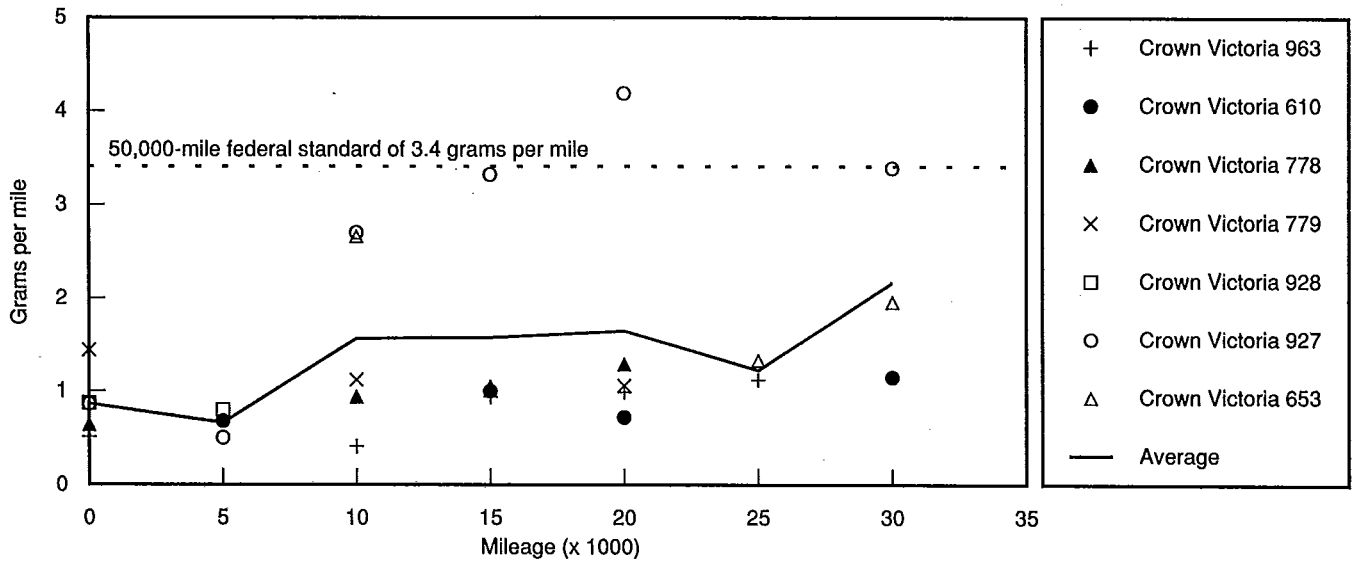
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from Blair (1988) and the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 35—CO Emissions: Four Dedicated Toyotas (M85)



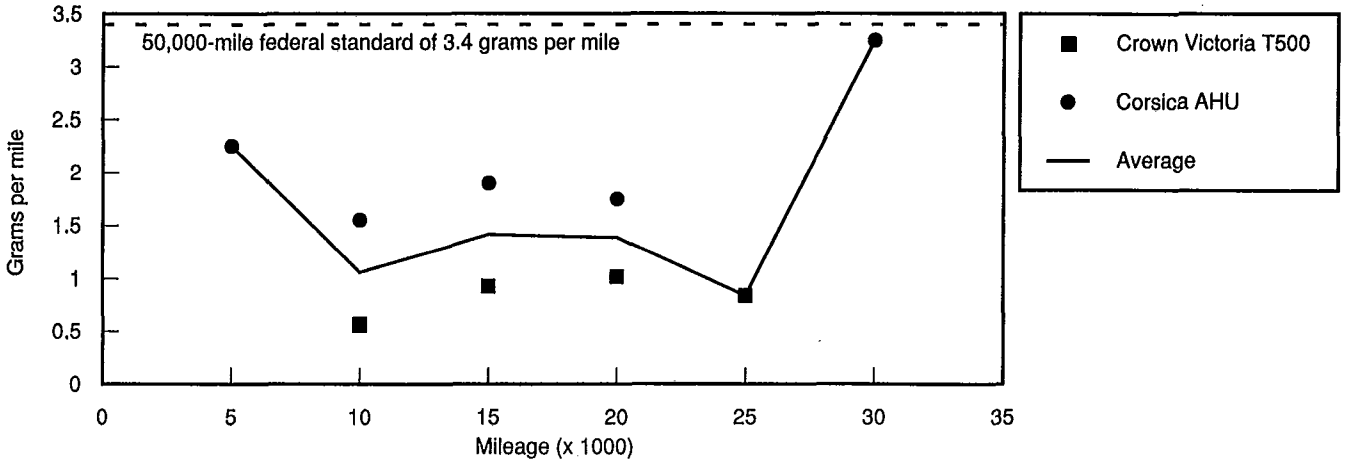
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1986), Edwards and Baisley (1981), Piotrowski (1987), Piotrowski et al. (1987), Piotrowski and Murrell (1987), and Smith (1985).

Figure 36—CO Emissions: Four Dedicated Vehicles (M100)



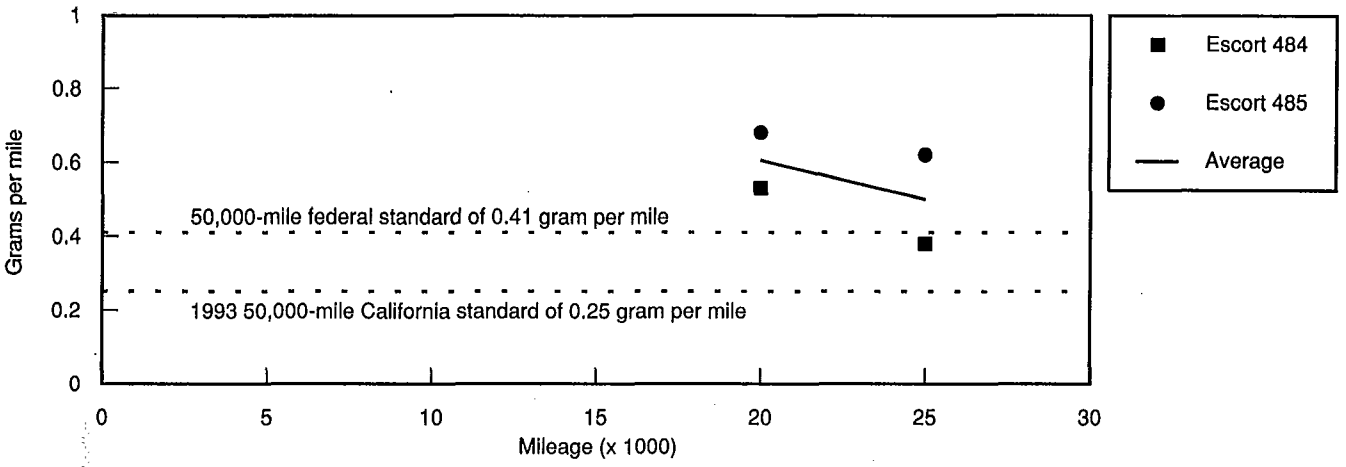
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 6/88–8/88; "Quarterly Summary," 12/88–2/89) and Horn and Hoekman (1989).

Figure 37—CO Emissions: Seven 1987 Ford Crown Victorias (M85 Flexible-Fuel Vehicles)



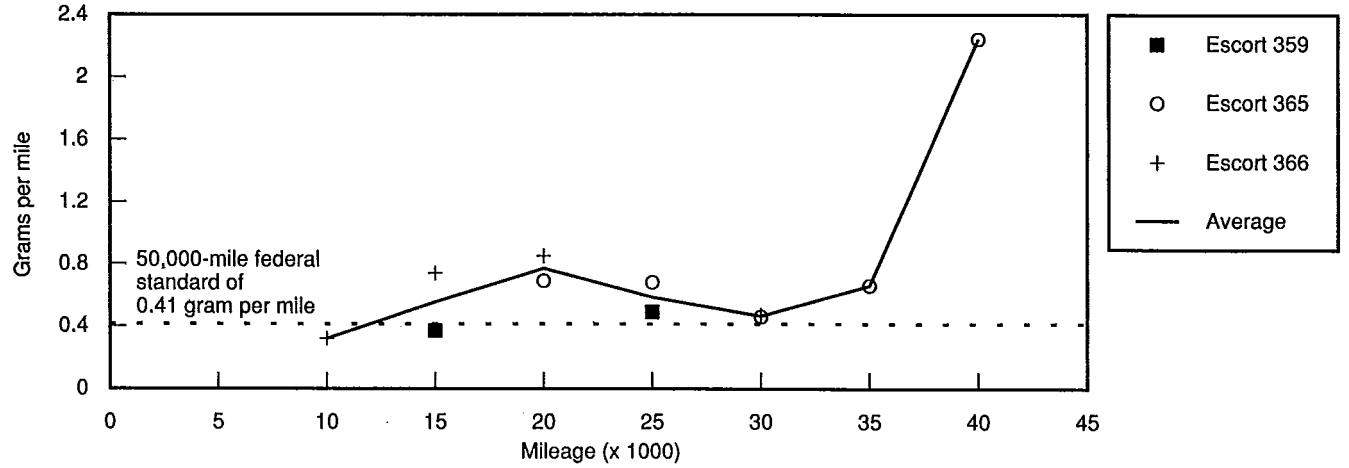
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988, 1989), Horn and Hoekman (1989), and Nichols et al. (1988).

Figure 38—CO Emissions: 1987 Ford Crown Victoria and 1988 Chevrolet Corsica (M85 Flexible-Fuel Vehicles)



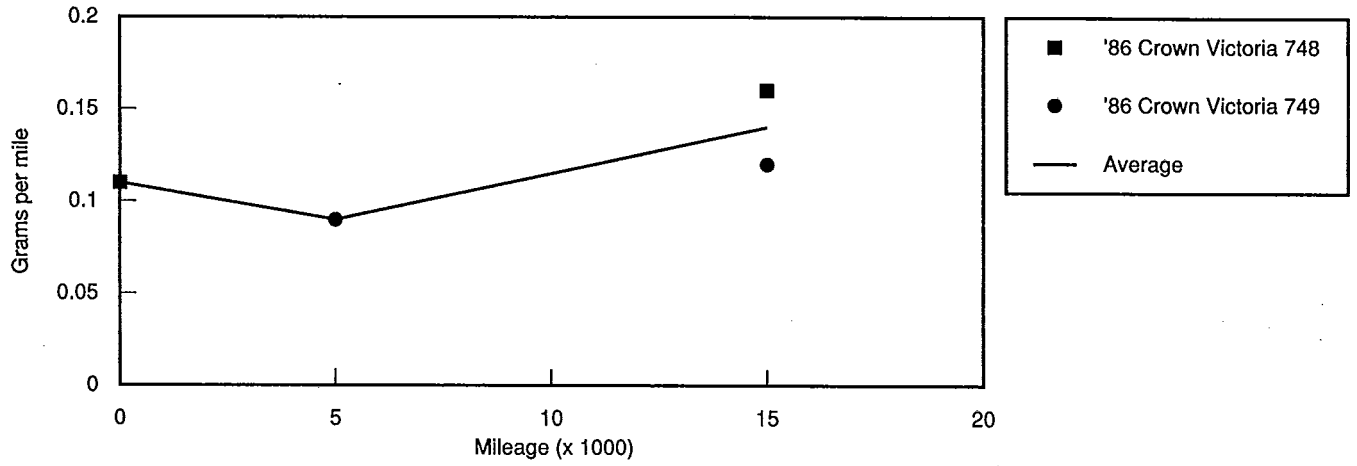
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 484 at 19,600 miles and on Escort 485 at 18,000 miles. The data in the figure are from the California Air Resources Board (1988; Quarterly Summary, 12/88–2/89).

Figure 39—OMHCE Emissions: Two 1983 Carbureted Ford Escorts (M85)



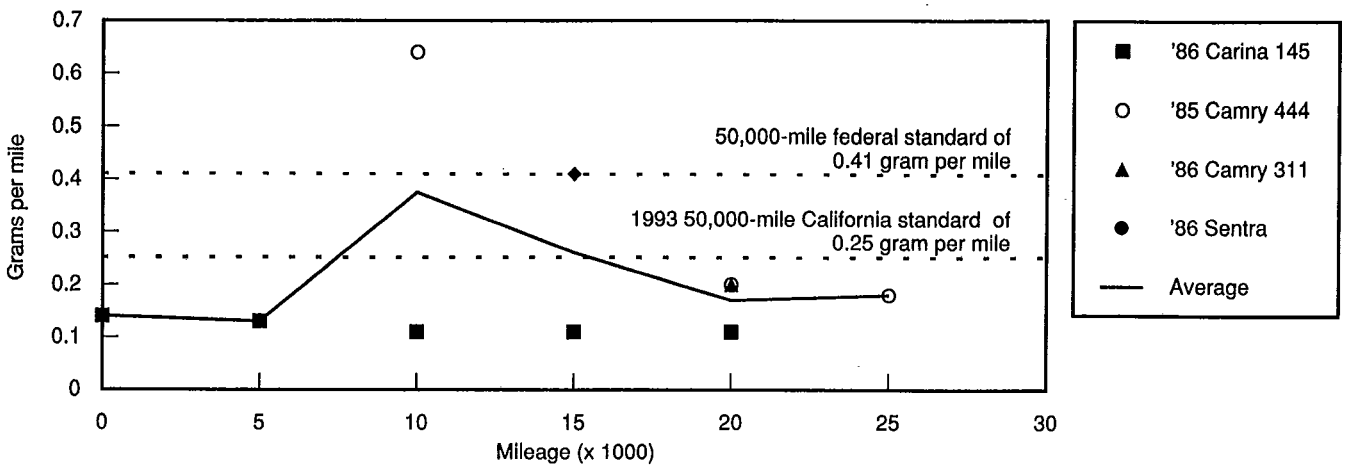
Note: Mileages are adjusted to the nearest 5000-mile interval. The catalysts were changed on Escort 359 at 27,000 miles, on Escort 365 at 27,600 miles, and on Escort 366 at 20,100 miles. (See Appendixes A and B for additional maintenance notations.) The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 40—OMHCE Emissions: Three 1983 Fuel-Injected Ford Escorts (M85)



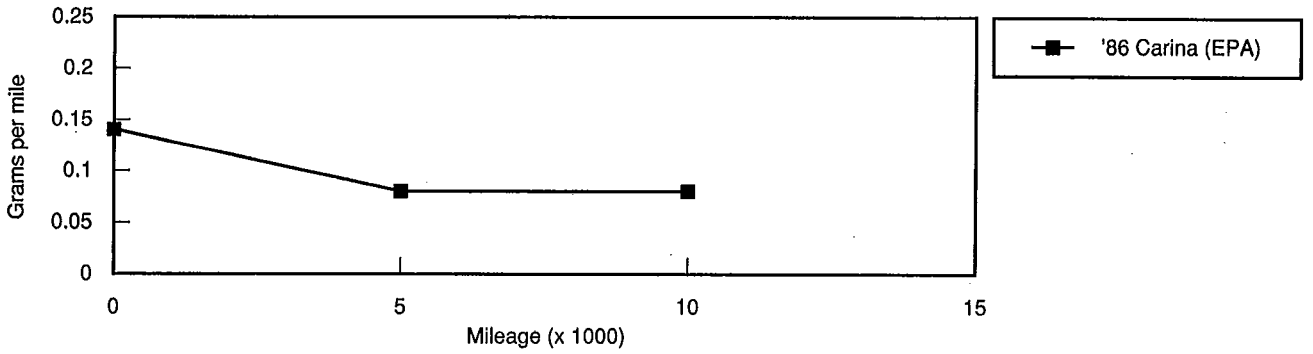
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; "Quarterly Summary," 12/88–2/89).

Figure 41—OMHCE Emissions: Two Domestic Dedicated Vehicles (M100)



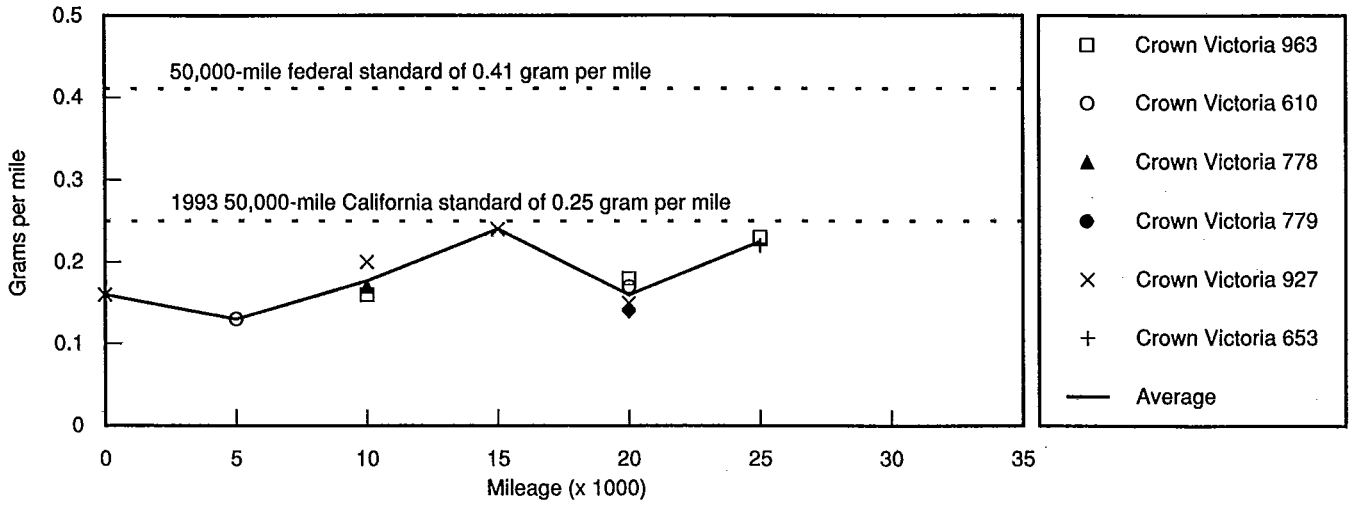
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from Blair (1988) and the California Air Resources Board (1988; 1989; "Quarterly Summary," 12/88–2/89).

Figure 42—OMHCE Emissions: Four Dedicated Toyotas (M85)



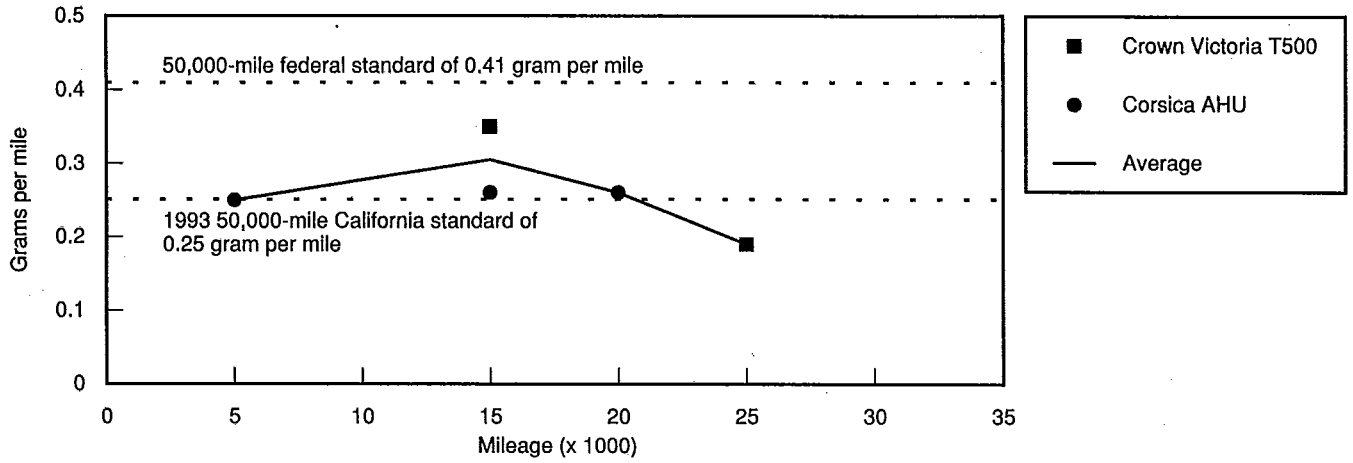
Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from Piotrowski (1987), Piotrowski (1989), and Piotrowski and Murrell (1987).

Figure 43—OMHCE Emissions: Dedicated Toyota Carina (M100)



Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; 1989; "Quarterly Summary," 6/88–8/88; "Quarterly Summary," 12/88–2/89) and Horn and Hoekman (1989).

Figure 44—OMHCE Emissions: Six 1987 Ford Crown Victorias (M85 Flexible-Fuel Vehicles)



Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988, 1989), Horn and Hoekman (1989), and Nichols et al. (1988).

Figure 45—OMHCE Emissions: 1987 Ford Crown Victoria and 1988 Chevrolet Corsica (M85 Flexible-Fuel Vehicles)

bon standard of 0.41 gram per mile. Only slightly less frequently, emissions were less than California's soon-to-be-implemented 50,000-mile standard of 0.25 gram per mile. In addition, there was little evidence of deterioration of emissions performance up to 25,000 miles, the maximum mileage at which measurements were recorded (see Figures 41–45). The performance of the newer vehicles was much better than that of the older Ford Escorts, which exceeded the federal standard at most mileages (see Figures 39 and 40). The advantage of the newer vehicles was more pronounced than when the aggregated data set was analyzed.

Emissions results were available for only one dedicated M100 vehicle, a 1986 Toyota Carina. Emissions performance was extremely good, but observations were recorded only to the 10,000-mile interval. As pointed out in the discussion of NO_x emissions, low OMHCE emissions were achieved at the cost of relatively poor NO_x emissions performance. Clearly, more vehicle testing—particularly for M100 vehicles at higher mileages—is needed to investigate the ability to control organic and NO_x emissions at the same time.

Analysis of Additional Methanol Emissions Data and Advanced Catalyst Research

A number of studies that presented additional information about methanol vehicle emissions were also reviewed. This information included exhaust and evaporative emissions data from more advanced M100 and M85 prototype vehicles and information on advanced catalyst research. This information was limited and anecdotal (and did not meet the criteria for constituting useful fleet data for our purposes). However, it is important because it represents the latest available information on methanol emissions and because EPA has used this information in estimating emissions performance for future methanol vehicles. The information indicates that lower emissions than those demonstrated in fleet tests to date are possible, but it leaves unanswered questions about the durability of emissions control. The results also indicate the difficulty of lowering organic and NO_x emissions simultaneously.

In preparing this technical report, very limited information on methanol emissions obtained under non-FTP conditions was also reviewed. The information was generated by four studies: Gabele (1990), Snow et al. (1989), Williams et al. (1990), and Gabele et al. (1985). Gabele and Snow et al. suggested that lowering the ambient temperature increased formaldehyde emissions. Snow et al. showed that CO and methanol emissions were reduced at 40°F when an M85 fuel blended with high-volatility gasoline was used. Williams et al. found that the composition of the gasoline used to make up M85 fuel could significantly affect the amount and composition of exhaust and evaporative emissions. Finally, Snow et al. found that extended engine warm-up reduced CO, methanol, and total hydrocarbon emissions; increased formaldehyde; and had little impact on NO_x.

ANALYSIS OF PROTOTYPE VEHICLE TECHNOLOGY

Dedicated M100 Prototypes

Three studies conducted FTP exhaust emissions tests on three prototype M100 vehicles: Williams et al. (1990), Hellman (1989), and Piotrowski and Murrell (1987). The vehicles included a prototype GM vehicle with a production three-way catalytic converter with platinum, palladium, and rhodium noble metal loading and a 1988 Nissan Sentra and 1986 Toyota Carina, both with lean-burn combustion design for improved fuel economy and a catalytic converter close-coupled to the exhaust manifolds. The Carina was also tested with a dual catalytic converter and, at a different time, with a resistively heated catalyst in a dual-converter system.

As shown in Table 5, the vehicles tested below the federal standard levels for regulated pollutants at low mileage, but none were lower than California's NO_x standard of 0.4 gram per mile, and only the Carina was below the California formaldehyde standard of 15 milligrams per mile. With the dual catalytic converter, the Carina showed potential for reducing aldehydes to 5 milligrams per mile at low mileage, but at the expense of increasing NO_x above the federal standard. With the resistively heated catalyst in a dual-converter system, the Carina emitted very low aldehydes and NO_x at low mileage, relative to a single-converter system. However, EPA noted that condensation in the sampling system and/or carryover from previous tests may have contributed to the very low formaldehyde levels reported.

Dedicated M85 Prototypes

Four studies provided FTP exhaust emissions data for four dedicated M85 vehicles: Katoh et al. (1986), Blair (1988), Yasuda et al. (1989), and Piotrowski and Murrell (1987). The vehicles were as follows:

Table 5—FTP Exhaust Emissions (Grams per Mile) From Prototype M100 Vehicles

Pollutant	GM Prototype (2.5 liter)	'88 Nissan Sentra (1.8 liter, MPFI)	'86 Toyota Carina (1.6 liter, PFI)
THC	0.026	0.01	0.09
CO	2.48	0.43	0.75
NO_x	0.70	0.57	0.65
HCHO	0.042	0.031	0.009
CH_3OH	0.569	0.38	0.31
OMHCE	0.27	0.19	0.15

Note: The data in this table are taken from Hellman (1989), Piotrowski and Murrell (1987), and Williams and Lipari (1989). Mileages were not available for the vehicles listed.

a. A 1986 Nissan Sentra equipped with a turbocharged 1.3-liter engine, closed-loop air/fuel ratio control with electronic fuel injection, and an oxidation catalyst.
b. Two 1986 Toyota Carinas, the same as the M100 Carina discussed above, except that the electronic control unit was replaced with one calibrated for M85 operation. (In addition, the Carina tested by EPA employed an 11.7:1 compression ratio, whereas the one evaluated by Toyota employed a 10.6:1 compression ratio.)
c. A 1987 Toyota Corolla that incorporated the Toyota Lean Combustion System—Methanol (TLCSM) used in the 1986 Carina, with several changes designed to meet the California NO_x standard of 0.4 gram per mile and to further reduce aldehyde emissions. These changes included the incorporation of an EGR system and the addition of a second underfloor converter along with the original manifold-type converter.

As shown in Table 6, the 1986 Sentra tested above the California organic emissions standard of 0.41 gram per mile and produced relatively high NO_x emissions (0.57 gram per mile) on FTP tests. Aldehyde emissions were about 25 milligrams per mile, and CO emissions, though below the standard, were also relatively high (3.02 grams per mile). These data should, however, be viewed with caution. Nissan had replaced the catalyst shortly before EPA tested the vehicle. The data may therefore reflect an unstabilized "green" catalyst.

Both the Carinas and the Corolla—the first- and second-generation lean-burn prototypes, respectively—were below the federal exhaust emissions standards for CO, NO_x, and organics at low mileages. However, the ability to achieve the NO_x standard of 0.4 gram per mile using lean burn remains an open question. A comparison of the Carinas tested by EPA and Toyota indicates the difficulty of controlling all emissions simultaneously. Toyota attempted to correct this problem in designing the second-generation methanol lean-burn system used in the 1987 Corolla. The addition of EGR on the 1987 Corolla, however, reduced NO_x only marginally relative to the first-generation lean-burn Carina tested by Toyota and produced a marked deterioration in vehicle driveability.

Katoh et al. (1986) reported that a second underfloor catalytic converter produced a substantial reduction in formaldehyde emissions on the Carina. However, these data were also based on a "green" catalyst. According to Toyota, formaldehyde emissions measured on the first-generation Carina rose to about 75 milligrams per mile after 40,000 miles of operation. The company noted that the durability of formaldehyde emission control with a second-generation lean-combustion system remains unclear (Yasuda et al., 1989).

Table 6—FTP Exhaust Emissions (Grams per Mile) From Prototype Dedicated M85 Vehicles

Pollutant	1986 Nissan Sentra (1.3 liter, EFI)	1986 Toyota Carina I	1986 Toyota Carina	1987 Toyota Corolla
THC	0.08	0.21	0.11	NR
CO	3.02	0.56	0.98	1.3
NO_x	0.57	0.39	0.72	0.31
HCHO	0.025	0.003	0.007	0.098
CH_3OH	0.76	NR	0.26	NR
OMHCE	0.42	NR	0.14	0.15

Note: NR = not reported. The data in this table were taken from Blair (1988), Katoh et al. (1986), Piotrowski and Murrell (1987), and Yasuda et al. (1989).

ANALYSIS OF ADVANCED CATALYST RESEARCH

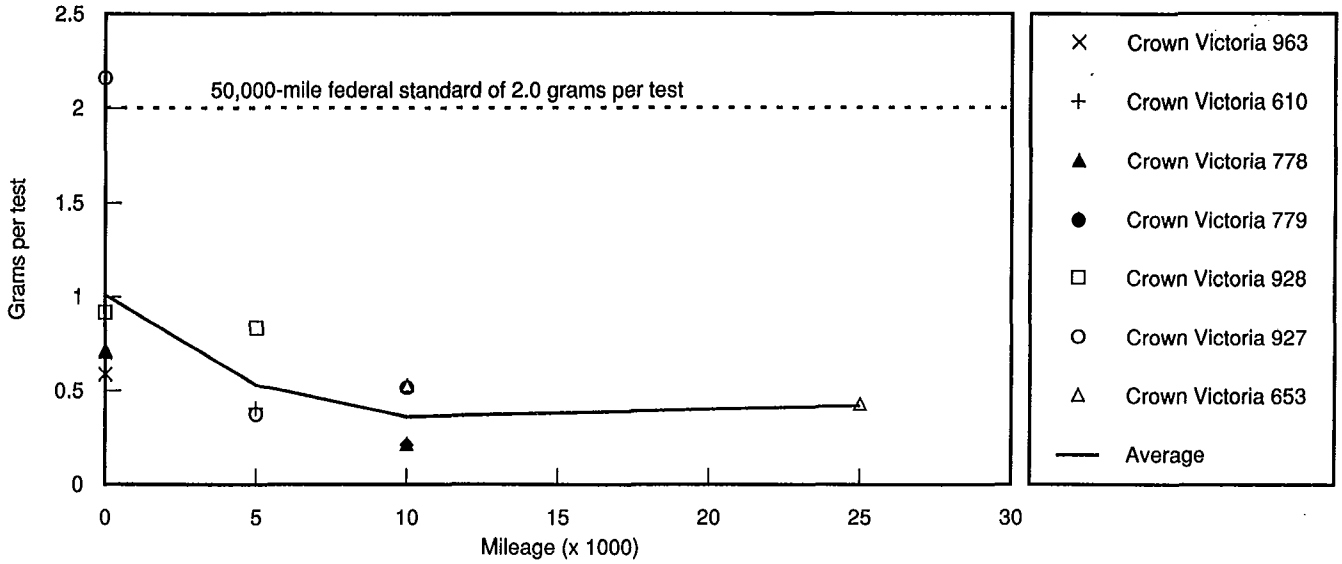
Over the past several years, EPA/Ann Arbor has tested alternative catalysts for formaldehyde and NO_x emission control on low-mileage M100 vehicles. Emissions were measured from a 1981 VW Rabbit and a 1986 Toyota Carina (modified for operation on M100 in a lean-burn mode). The results have shown a wide range in CO and hydrocarbon conversion efficiencies for alternative catalyst noble and base metal loadings. Formaldehyde conversion efficiencies have also been demonstrated to be generally high (85–95 percent).

EPA tests have also shown that catalytic converters located next to the exhaust manifold may be more effective in controlling formaldehyde emissions than are underfloor converters, because of the closer proximity to the engine (Piotrowski, 1988). Again, however, the key issues are NO_x control and emission control durability. For example, excessive deterioration as a result of exposure to high temperatures that results from close coupling of converters to the exhaust manifold has been a problem. EPA tests on a Toyota M100 Carina have shown that some catalyst formulations may actually increase NO_x relative to baseline conditions (Piotrowski, 1988).

Evaporative Emissions Trends

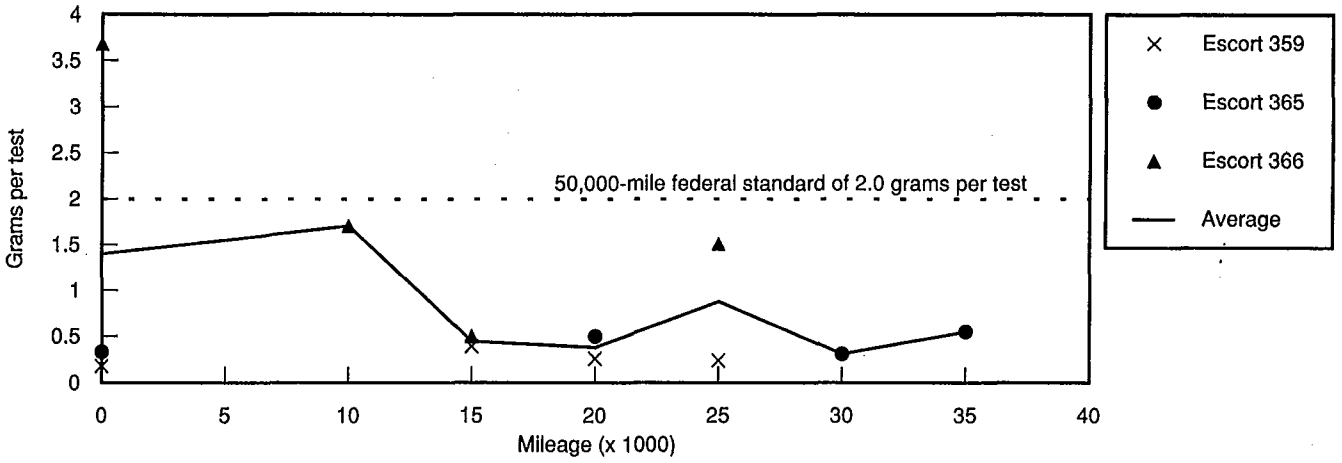
The available data for evaporative emissions (see Appendix B) are sparse. However, for the data available, methanol-fueled vehicles generally met the 50,000-mile federal standard for total evaporative emissions of 2.0 grams per test. Figure 46 shows that the total organic evaporative emissions from seven 1987 flexible-fuel Crown Victorias were, at most mileages, below the federal standard and remained relatively constant throughout the first 25,000 miles of vehicle operation. (One FFV—Crown Victoria 927—exceeded the standard at zero mileage because of improper testing.) Similar results are illustrated in Figures 47 and 48 for three 1983 fuel-injected Ford Escorts and two dedicated M85 Toyotas.

Instances where the standard was exceeded probably indicate vehicle component failures rather than long-term dete-



Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; "Quarterly Summary," 6/88–8/89; "Quarterly Summary," 12/88–2/89).

Figure 46—Total Organic Evaporative Emissions: Seven 1987 Ford Crown Victorias (M85 Flexible-Fuel Vehicles)

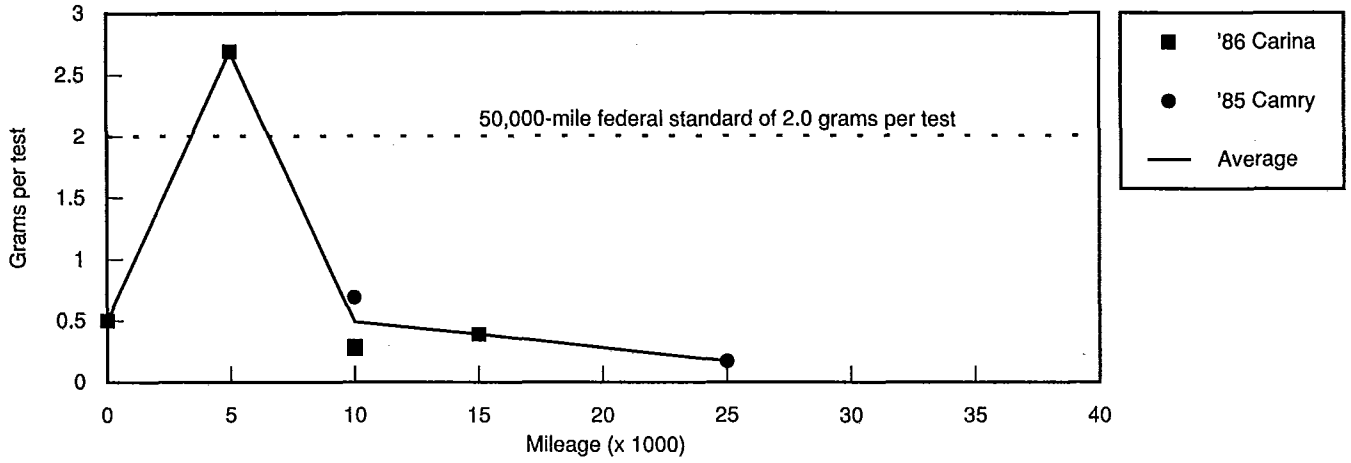


Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; "Quarterly Summary," 12/88–2/89).

Figure 47—Total Organic Evaporative Emissions: Three 1983 Fuel-Injected Ford Escorts (M85)

rioration in evaporative emission control. For example, in Figure 48, the 1986 Toyota Carina failed the standard at 5000 miles because of a leak in the test cap at the fuel tank filler neck.

Evaporative emissions from methanol vehicles were thought to be less than those from gasoline vehicles because of methanol's lower vapor pressure. Recently, however, Austin et al. (1989) reported increased evaporative emissions in some tests of methanol vehicles that, in their opinion, resulted from degraded performance of charcoal canisters with methanol fuel. In addition, if additives are used to enhance the volatility of methanol to assist cold starting, then evaporative emissions could increase. Finally, switching back and forth between gasoline and methanol in flexible-fuel vehicles would commingle the fuels in the tank, resulting in a mixture with a higher volatility (and hence potentially higher evaporative emissions) than that of either fuel alone.



Note: Mileages are adjusted to the nearest 5000-mile interval. The data in the figure are from the California Air Resources Board (1988; "Quarterly Summary," 12/88–2/89).

Figure 48—Total Organic Evaporative Emissions: Two Dedicated Toyotas (M85)

SECTION 5—CONCLUSIONS

Much more is known about M85 vehicles than about M100 vehicles. There are many more M85 vehicles, they have been in service longer and have recorded much higher mileages, they have been used in everyday service in fleets as opposed to being experimental test vehicles, and many more data are available on their emissions.

Although the M85 emissions data are less than ideal given the absence of standardized emission sampling and measurement procedures, they are sufficient to show improving exhaust emissions in late-model-year vehicles. Still, more data at higher mileages, more data on OMHCE emissions, and a better understanding of NO_x and organic emissions tradeoffs are clearly desirable. Much less is known about the emissions of M100 vehicles, and most of what is known relates to vehicles that incorporate older vehicle and emission control technology. Very few recent-technology M100 vehicles have actually been tested. None has accumulated substantial mileage in test fleets. Until more M100 vehicles are designed, built, operated at higher mileages, and thoroughly evaluated, they must be considered unknown quantities.

An evaluation of exhaust emissions data presented both distributionally and graphically by technology, vintage, and fuel classes supports the conclusions given below.

M85 Vehicles

FFV and dedicated M85 vehicles generally produced organic and CO exhaust emissions that were below the current 50,000-mile federal standards. However, no data were available for odometer readings beyond 40,000 miles (and for most of the vehicles, the highest mileage at which emissions were measured was much lower). This leaves in question whether such performance will be sustained so that compliance with the 50,000-mile standards is achieved.

FFVs and dedicated vehicles also generally tested below the existing federal standard for NO_x exhaust emissions but usually exceeded the more stringent California standard. The effectiveness of NO_x control is clearly a problem. In addition, most of the time both the dedicated and flexible-fuel M85 vehicles were unable to meet California's 50,000-mile tailpipe formaldehyde standard. The few vehicles that did meet the California formaldehyde standard often tested above the NO_x standard.

At most mileages, dedicated and flexible-fuel M85 vehicles had emissions that were below the 50,000-mile federal standard for total organic evaporative emissions.

M100 Vehicles

Exhaust organic emissions from one dedicated M100 vehicle were quite low, but testing was only done to 10,000 miles. M100 CO emissions were generally below the federal standard, but again, testing was only performed at low mileages. M100 NO_x emissions were generally lower than the federal standard but were higher than the 50,000-mile California standard. However, the most advanced vehicle tested (the 1986 Toyota Carina) exceeded even the current federal NO_x standard at the 10,000-mile interval, creating doubt about the practicality of the lean-burn approach it employed. In addition, like the M85 vehicles, all of the M100 vehicles except the Toyota Carina exceeded the 50,000-mile California formaldehyde standard at low mileages. An im-

portant question remains about whether advanced M100 vehicles of this kind can simultaneously achieve low emissions across all of the principal emission groups.

The most recent research on dedicated M85 and M100 vehicles indicates that methanol vehicles have some potential for improved emissions performance. However, this research, which is quite limited, has yet to answer questions about the durability of emissions control, the ability to meet the more stringent California standards, and the simultaneous control of all emissions.

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APPENDIX A—EXHAUST EMISSIONS DATA

Table A-1—'81 Ford Escort/License No. 276/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	95	5178	4.77	0.41	0.008	DNPH	0.3	GC	0.06	0.08	GC	—	
2	TWC	EGR	No air	95	5229	27.99	0.37	0.015	DNPH	0.78	GC	0.05	0.11	GC	—	
3	TWC	NEGR	Air	95	5289	4.43	1.13	0.031	DNPH	0.15	GC	0.07	0.1	GC	—	
4	TWC	NEGR	No air	95	5335	23.5	0.74	0.0826	DNPH	0.83	GC	0.13	0.18	GC	—	
5	NCAT	EGR	Air	95	14440	45.4	0.18	NA	—	0.42	GC	0.08	NA	—	—	Catalyst inactive
6	NCAT	EGR	Air	95	14521	24.3	0.1	0.011	DNPH	0.6	GC	0.06	0.23	GC	—	Catalyst replaced, disconnected vacuum hose
7	TWC	EGR	Air	95	14591	3.41	0.16	0	DNPH	0.29	GC	0.05	0.06	GC	—	
8	TWC	EGR	Air	95	14614	2.63	0.18	0.017	DNPH	0.24	GC	0.04	0.06	GC	—	
9	NCAT	EGR	Air	95	14637	28.42	0.45	NA	—	2.67	GC	0.04	0.16	GC	—	Catalyst removed
10	NCAT	EGR	Air	95	14655	28.11	0.53	0.07	DNPH	2.43	GC	0.03	0.17	GC	—	Catalyst removed
11	TWC	EGR	Air	95	25294	8.73	0.22	0.04	DNPH	NA	—	0.07	0.11	GC	—	Sunken float
12	TWC	EGR	Air	95	25315	8.12	0.2	NA	—	NA	—	0.07	0.1	GC	—	Sunken float
13	TWC	EGR	Air	95	25336	NA	NA	NA	—	NA	—	NA	NA	—	—	
14	TWC	EGR	Air	90	36978	5.46	0.48	0.196	DNPH	NA	—	0.06	0.14	GC	—	
15	TWC	EGR	Air	90	36990	5.79	0.43	NA	—	NA	—	0.06	NA	—	—	
16	TWC	EGR	Air	90	37032	6.58	0.45	0.072	DNPH	NA	—	0.07	0.21	GC	—	
17	TWC	EGR	Air	90	50024	14.31	0.25	NA	—	NA	—	0.11	NA	—	—	As-received test, carburetor rich, EGR malfunction
18	TWC	EGR	Air	90	50078	4.11	0.4	NA	—	0.59	GC	0.07	0.15	GC	—	
19	TWC	EGR	Air	90	50111	6.02	0.4	NA	—	NA	—	0.07	NA	—	—	

Source: Rows 1–19—California Air Resources Board (1986).

Table A-2—'81 Ford Escort/License No. 882/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	95	4233	6.21	0.24	0.012	DNPH	0.285	GC	0.06	0.08	GC	—	
2	TWC	EGR	Air	95	4257	7.04	0.24	0.013	DNPH	0.272	GC	0.06	0.09	GC	—	
3	NCAT	EGR	Air	95	4282	50.1	1.02	0.099	DNPH	3.462	GC	0.08	0.25	GC	—	
4	NCAT	EGR	Air	95	4305	52.1	0.99	0.114	DNPH	4.219	GC	0.07	0.45	GC	—	
5	TWC	EGR	Air	90	34860	8.31	0.41	NA	—	0.785	GC	0.08	0.22	GC	—	
6	TWC	EGR	Air	90	34888	5.8	1.29	NA	—	NA	—	0.08	NA	—	—	
7	TWC	EGR	Air	90	45369	6	0.39	0.15	DNPH	NA	—	0.07	NA	—	—	
8	TWC	EGR	Air	90	45399	7.34	0.37	0.12	DNPH	0.68	GC	0.08	0.14	GC	—	
9	TWC	EGR	Air	85	54058	7.99	0.39	0.13	DNPH	0.77	GC	0.09	0.49	GC	—	
10	TWC	EGR	Air	85	54088	7.24	0.44	0.14	DNPH	NA	—	0.09	NA	—	—	

Source: Rows 1–10—California Air Resources Board (1986).

Table A-3—'81 VW Rabbit/License No. 824/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	NEGR	No air	95	5269	1.33	0.21	0.047	DNPH	NA	—	—	—	—	—	
2	TWC	NEGR	No air	95	5290	1.29	0.21	0.027	DNPH	0.28	GC	—	—	—	—	
3	NCAT	NEGR	No air	95	5311	12.62	1.05	0.073	DNPH	NA	—	—	—	—	—	
4	NCAT	NEGR	No air	95	5344	12.62	1.07	0.077	DNPH	1.25	GC	—	—	—	—	

Source: California Air Resources Board (1986).

Table A-4—'81 VW Rabbit/License No. 995/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	NEGR	No air	95	4507	0.95	0.79	0.025	DNPH	0.34	GC	0.011	0.041	GC	0.2	
2	NCAT	NEGR	No air	95	4539	7.53	2.15	0.117	DNPH	1.28	GC	0.018	0.118	GC	—	
3	NCAT	NEGR	No air	95	4564	7.65	2.09	0.097	DNPH	1.65	GC	0.017	0.087	GC	—	
4	TWC	NEGR	No air	90	13583	1.03	1.03	0.039	DNPH	NA	—	0.019	—	—	—	
5	TWC	NEGR	No air	90	22609	1.79	1.04	NA	—	NA	—	0.028	0.078	GC	—	
6	TWC	NEGR	No air	90	22644	1.59	1.46	NA	—	NA	—	0.026	—	—	—	
7	TWC	NEGR	No air	90	23287	0	0	NA	—	NA	—	—	—	—	—	
8	TWC	NEGR	No air	90	23314	1.84	1.5	NA	—	0.71	GC	0.023	0.153	GC	—	
9	TWC	NEGR	No air	90	23395	1.58	1.26	NA	—	NA	—	0.023	—	—	—	Replaced faulty coil, regapped spark plugs
10	TWC	NEGR	No air	90	24630	2.03	1.35	NA	—	NA	—	0.023	—	—	—	
11	TWC	NEGR	No air	90	24645	1.62	0.88	NA	—	NA	—	0.023	—	—	—	New oxygen sensor
12	TWC	NEGR	No air	85	24867	1.89	0.92	0.043	DNPH	NA	—	0.007	—	—	—	Replaced fuel and cold start injectors
13	TWC	NEGR	No air	85	24896	0	0	NA	—	NA	—	—	—	—	—	
14	TWC	NEGR	No air	85	39621	2.5	1.23	0.045	DNPH	NA	—	—	—	—	—	Tested as received; idle CO was 6%
15	TWC	NEGR	No air	85	39696	2.45	1.14	0.048	DNPH	0.79	GC	—	—	—	—	
16	TWC	NEGR	No air	85	39749	2.08	1.12	0.052	DNPH	NA	—	—	—	—	—	
17	TWC	NEGR	No air	85	45320	2.46	1.2	0.049	DNPH	0.74	GC	—	—	—	—	
18	TWC	NEGR	No air	85	45343	2.57	1.26	0.039	DNPH	NA	—	—	—	—	—	
19	TWC	NEGR	No air	85	46500	0	0	NA	—	NA	—	—	—	—	—	
20	TWC	NEGR	No air	85	56305	3.7	1.86	0.075	DNPH	0.78	GC	—	—	—	—	Tested as received, adjusted idle CO and rpm after test
21	TWC	NEGR	No air	85	56355	3.9	1.85	NA	—	NA	—	0.13	—	—	—	
22	TWC	NEGR	No air	85	59384	2.88	1.08	0.065	DNPH	0.63	GC	0.03	0.13	GC	0.44	
23	TWC	NEGR	No air	85	59463	2.91	1.08	0.051	DNPH	NA	—	0.04	—	—	—	Tested with new O_2 sensor, fuel injectors, spark plugs, fuel filter
24	TWC	NEGR	No air	85	66486	25.26	0.8	0.07	DNPH	1.38	GC	0.06	2.69	GC	3.32	Tested as received, fuel mixture control malfunctioning
25	TWC	NEGR	No air	85	68025	18.24	0.77	NA	—	NA	—	—	—	—	—	Tested before and after replacement of catalyst
26	TWC	NEGR	No air	85	68050	1.62	0.8	NA	—	NA	—	—	—	—	—	
27	TWC	NEGR	No air	85	68078	1.52	0.82	NA	—	NA	—	—	—	—	—	
28	TWC	NEGR	No air	85	68188	1.34	0.92	0.018	DNPH	NA	—	—	—	—	—	

Sources: Rows 1–24—California Air Resources Board (1988), Rows 25–28—California Air Resources Board (1989).

Table A-5—'81 VW Rabbit/License No. 989/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	NEGR	No air	95	4448	1.13	0.7	0.017	DNPH	0.3	GC	0.011	0.03	GC	0.17	
2	TWC	NEGR	No air	95	4490	1.16	0.63	0.009	DNPH	0.4	GC	0.01	0.03	GC	0.21	
3	NCAT	NEGR	No air	95	4694	7.02	2.17	NA	—	1.57	GC	0.014	—	—	—	
4	NCAT	NEGR	No air	95	4713	7.09	2.81	0.085	DNPH	NA	—	0.015	—	—	—	
5	TWC	NEGR	No air	90	21062	2.7	0.56	NA	—	1.5	GC	0.027	—	—	—	Timing set at wrong rpm
6	TWC	NEGR	No air	90	21597	2.62	1.1	NA	—	NA	—	0.024	—	—	—	
7	TWC	NEGR	No air	90	21618	2.76	1.14	NA	—	NA	—	0.021	—	—	—	
8	TWC	NEGR	No air	90	21640	2.79	1.06	NA	—	NA	—	0.023	—	—	—	
9	TWC	NEGR	No air	90	21661	2.75	1.04	NA	—	NA	—	0.019	—	—	—	
10	TWC	NEGR	No air	85	26237	2.78	1.36	0.014	DNPH	0.58	GC	0.007	—	—	—	New fuel and cold start injectors and other fuel system parts
11	TWC	NEGR	No air	85	26292	2.32	1.45	NA	—	0.48	GC	0.021	—	—	—	New oxygen sensor
12	TWC	NEGR	No air	85	31869	4.65	1.13	0.016	DNPH	0.38	GC	—	—	—	—	Vehicle refused to start, new spark plugs installed
13	TWC	NEGR	No air	85	35199	4.71	1.22	0.0034	DNPH	NA	—	0.03	—	—	—	
14	TWC	NEGR	No air	85	35235	3.9	1.2	NA	—	0.55	—	—	—	—	—	

Source: Rows 1–14—California Air Resources Board (1988).

Table A-6—'81 Ford Escort/License No. 920/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	85341	8.98	1.01	NA	—	1.3	GC	0.1	0.29	GC	—	
2	TWC	EGR	Air	90	85371	9.85	1.03	NA	—	NA	—	0.09	NA	—	—	
3	TWC	EGR	Air	90	85430	8.78	0.47	NA	—	NA	—	0.09	NA	—	—	After EGR repairs, vacuum line plugged
4	TWC	EGR	Air	90	115556	12.27	0.38	0.104	DNPH	1.34	GC	NA	NA	—	—	
5	TWC	EGR	Air	90	115590	12.7	0.37	NA	—	NA	—	0.08	NA	—	—	

Source: Rows 1–5—California Air Resources Board (1986).

Table A-7—'84 Ford Escort/License No. 154/Mix Method: Fuel Injection/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	100	8580	0.96	0.81	0.084	DNPH	0.64	GC	0.01	0.3	FID	—	FID uncorrected for MeOH, MeOH by GC includes weight of O_2
2	TWC	EGR	Air	100	8620	1.09	0.77	0.111	DNPH	0.88	GC	0.01	0.4	FID	—	FID uncorrected for MeOH, MeOH by GC includes weight of O_2

Source: Rows 1 and 2—California Air Resources Board (1986).

Table A-8—'83 Ford Escort/License No. 359/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	109	3.36	0.38	0.06	DNPH	NA	—	0.03	—	—	—	
2	TWC	EGR	Air	90	138	2.74	0.38	0.1	DNPH	0.73	GC	0.03	0.05	GC	0.41	
3	TWC	EGR	Air	90	167	0	0	NA	—	NA	—	—	—	—	—	
4	TWC	EGR	Air	90	208	3.88	0.37	0.07	DNPH	NA	—	0.03	—	—	—	
5	TWC	EGR	Air	90	230	4.44	0.29	0.08	DNPH	0.65	GC	0.03	0.06	GC	0.38	
6	TWC	EGR	Air	85	5469	3.13	0.34	0.1	DNPH	NA	—	0.03	—	—	—	
7	TWC	EGR	Air	85	5516	3.32	0.51	0.08	DNPH	NA	—	0.03	—	—	—	
8	TWC	EGR	Air	85	11789	5.14	0.48	0.08	DNPH	NA	—	—	—	—	—	
9	TWC	EGR	Air	85	11828	7.68	0.5	0.09	DNPH	0.86	GC	—	—	—	—	
10	TWC	EGR	Air	85	13180	19.2	0.31	0.05	DNPH	1.22	GC	0.04	—	—	—	Tests after fuel injectors cleaned
11	TWC	EGR	Air	85	13584	0	0	NA	—	0	GC	—	—	—	—	
12	TWC	EGR	Air	85	15960	3.53	0.36	0.03	DNPH	0.54	GC	—	0.21	GC	0.46	Tests after reprogrammed computer for leaner operation
13	TWC	EGR	Air	85	15987	3.21	0.34	0.08	DNPH	0	GC	0.05	—	—	—	
14	TWC	EGR	Air	85	16667	2.56	0.4	0.09	DNPH	0.34	GC	0.04	0.09	GC	0.28	
15	TWC	EGR	Air	85	19390	1.71	0.71	0.13	DNPH	0.53	GC	0.01	—	—	—	
16	TWC	EGR	Air	85	20375	1.68	0.74	NA	—	0.51	GC	0.02	0.15	GC	—	Tests with new fuel injectors
17	TWC	EGR	Air	85	20394	1.63	0.79	0.11	DNPH	0.48	GC	0.03	0.21	GC	0.47	
18	TWC	EGR	Air	85	25300	4.03	0.79	0.12	DNPH	0.69	GC	0.03	0.21	GC	0.56	Tests after new fuel injectors installed
19	TWC	EGR	Air	85	27050	3.08	0.24	0.07	DNPH	0.52	GC	0.02	0.15	GC	0.41	Tests after new converter, O_2 sensor, EGR valve installed
20	TWC	EGR	Air	85	30597	3.92	0.47	0.05	DNPH	NA	—	—	—	—	—	Tested after ignition module replaced and computer rebuilt

Sources: Rows 1–19—California Air Resources Board (1988), Row 20—California Air Resources Board (1989).

Table A-9—'83 Ford Escort/License No. 365/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	43	3.73	1.29	0.03	DNPH	0.9	GC	0.03	—	—	—	15°BTDC timing, ported vacuum signal to EGR (with restrictor)
2	TWC	EGR	Air	90	85	3.99	1.13	0.012	DNPH	0.76	GC	0.04	—	—	—	15°BTDC timing, ported vacuum signal to EGR (with restrictor)
3	TWC	EGR	Air	90	114	4.84	0.73	0.08	DNPH	NA	—	0.03	—	—	—	10°BTDC timing, ported vacuum signal to EGR (with restrictor)
4	TWC	EGR	Air	90	213	15.05	0.48	0.09	DNPH	1	GC	0.05	—	—	—	10°BTDC timing, manifolded vacuum signal to EGR (with restrictor)
5	TWC	EGR	Air	85	422	2.39	0.35	NA	—	1.49	GC	0.03	0.22	GC	—	10°BTDC timing, manifolded vacuum signal to EGR (without restrictor)
6	TWC	EGR	Air	85	742	17.4	0.34	NA	—	1.01	GC	0.05	0.28	GC	—	
7	TWC	EGR	Air	85	1443	1.24	0.43	NA	—	NA	—	—	—	—	—	Computer reprogrammed for leaner operation
8	TWC	EGR	Air	85	8329	1.85	0.54	0.08	DNPH	NA	—	—	—	—	—	
9	TWC	EGR	Air	85	8369	1.81	0.51	0.09	DNPH	0.37	GC	—	—	—	—	
10	TWC	EGR	Air	85	12265	NA	NA	NA	—	NA	—	—	—	—	—	
11	TWC	EGR	Air	85	14693	3.41	0.55	NA	—	0.71	GC	0.04	0.33	GC	—	
12	TWC	EGR	Air	85	21594	2.87	0.58	0.11	DNPH	0.63	GC	0.04	—	—	—	Replaced leaking EGR tube
13	TWC	EGR	Air	85	21621	2.64	0.53	0.11	DNPH	NA	—	0.04	0.26	GC	0.58	
14	TWC	EGR	Air	85	21789	4.03	0.79	0.14	DNPH	0.79	GC	0.04	—	—	—	Replaced fuel injectors
15	TWC	EGR	Air	85	21825	3.6	0.78	0.14	DNPH	NA	—	0.04	0.39	GC	0.8	
16	TWC	EGR	Air	85	24150	3.29	0.59	0.12	DNPH	0.74	GC	0.04	0.27	GC	0.65	Running rough, tested as received
17	TWC	EGR	Air	85	25490	5.6	0.9	0.14	DNPH	0.84	GC	0.03	0.27	GC	0.7	
18	TWC	EGR	Air	85	27554	3.26	0.5	0.11	DNPH	0.54	GC	0.02	0.18	GC	0.46	Tested with new converter, EGR valve, O_2 sensor
19	TWC	EGR	Air	85	34027	4.06	0.44	0.09	DNPH	0.83	GC	0.04	0.26	GC	0.66	Tested after spark plugs and air cleaner replaced, idle speed and timing adjusted
20	TWC	EGR	Air	85	39209	47.91	0.22	0.11	DNPH	2.79	GC	0.14	0.98	GC	2.24	Tested after oxygen sensor replaced
21	TWC	EGR	Air	85	39299	14.43	0.44	NA	—	NA	—	0.02	—	—	—	

Sources: Rows 1–18—California Air Resources Board (1988); Row 19—California Air Resources Board, "Quarterly Summary" (12/88–2/89); Rows 20 and 21—California Air Resources Board (1989).

Table A-10—'83 Ford Escort/License No. 366/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	76	3.07	0.48	0.08	DNPH	0.66	GC	0.02	0.04	GC	0.36	Tested as received, wrong ignition timing
2	TWC	EGR	Air	90	109	3.41	0.29	0.09	DNPH	0.74	GC	0.03	0.05	GC	0.41	
3	TWC	EGR	Air	90	137	NA	NA	NA	—	NA	—	—	—	—	—	
4	TWC	EGR	Air	90	139	3.17	0.3	0.12	DNPH	NA	—	0.03	—	—	—	
5	TWC	EGR	Air	85	262	3.97	0.35	0.09	DNPH	0.82	GC	0.01	—	—	—	
6	TWC	EGR	Air	85	291	3.97	0.33	0.06	DNPH	0.91	GC	0.01	—	—	—	
7	TWC	EGR	Air	85	7493	2.29	0.39	0.08	DNPH	NA	—	0.04	—	—	—	Tested as received, idle speed high
8	TWC	EGR	Air	85	7559	1.86	0.44	0.05	DNPH	0.4	GC	0.03	0.11	GC	0.31	Tested after idle speed adjusted
9	TWC	EGR	Air	85	9409	NA	NA	NA	—	NA	—	—	—	—	—	
10	TWC	EGR	Air	85	9416	1.6	0.52	NA	—	NA	—	—	—	—	—	Tested after timing belt and bent valves replaced
11	TWC	EGR	Air	85	11259	4.07	0.43	0.18	DNPH	0.35	GC	0.03	0.09	GC	0.32	Tested after broken distributor rotor replaced
12	TWC	EGR	Air	85	15341	NA	NA	NA	—	NA	—	—	—	—	—	
13	TWC	EGR	Air	85	14732	3.83	0.71	0.17	DNPH	0.79	GC	0.02	0.32	GC	0.74	
14	TWC	EGR	Air	85	19652	8.05	1.13	0.3	DNPH	1.59	GC	0.04	0.54	GC	1.37	
15	TWC	EGR	Air	85	20096	5.98	1.1	NA	—	NA	—	0.04	—	—	—	Tested with new pistons, rings, and fuel injectors
16	TWC	EGR	Air	85	20130	6.48	1.13	NA	—	NA	—	0.04	—	—	—	Tested with new oxygen sensor
17	TWC	EGR	Air	85	20149	2.05	0.16	NA	—	NA	—	0.03	—	—	—	Tested with new converter
18	TWC	EGR	Air	85	20168	2.02	0.16	0.06	DNPH	0.35	GC	0.03	0.14	GC	0.32	
19	TWC	EGR	Air	85	25088	4.83	0.59	NA	—	1.39	GC	0.05	0.26	GC	—	
20	TWC	EGR	Air	85	25113	4.87	0.55	0.048	DNPH	NA	—	0.04	—	—	—	
21	TWC	EGR	Air	85	29699	5.25	0.48	0.056	DNPH	0.69	GC	0.04	0.15	—	0.47	

Sources: Rows 1–20—California Air Resources Board (1988), Row 21—California Air Resources Board (1989).

Table A-11—'85 Toyota Camry/License No. 444/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	434	1.9	0.73	0.011	DNPH	NA	—	0.01	—	—	—	
2	TWC	EGR	Air	85	473	1.85	0.71	NA	—	0.3	GC	0.02	0.08	GC	—	
3	TWC	EGR	Air	85	3786	1.76	0.98	0.032	DNPH	0.24	GC	—	—	—	—	
4	TWC	EGR	Air	85	3812	1.84	0.94	0.019	DNPH	NA	—	—	—	—	—	
5	TWC	EGR	Air	85	4813	1.78	0.68	0.022	DNPH	0.25	GC	—	—	—	—	Replaced fuel injectors
6	TWC	EGR	Air	85	8508	3	1.62	0.02	DNPH	NA	—	—	—	—	—	
7	TWC	EGR	Air	85	8685	1.92	1.54	0.019	DNPH	0.27	GC	—	—	—	—	
8	TWC	EGR	Air	85	8953	1.13	0.7	0.016	DNPH	0.18	GC	—	—	—	—	Replaced fuel injectors
9	TWC	EGR	Air	85	8990	1.59	0.65	0.004	DNPH	NA	—	—	—	—	—	
10	TWC	EGR	Air	85	9016	1.32	0.67	0.015	DNPH	NA	—	—	—	—	—	
11	TWC	EGR	Air	85	10792	2.27	0.68	0.02	DNPH	0.24	GC	—	—	—	—	
12	TWC	EGR	Air	85	11431	3.22	1.39	0.02	DNPH	0.3	GC	0.02	—	—	—	Replaced fuel injectors
13	TWC	EGR	Air	85	11473	2.7	1.43	0.029	DNPH	0.3	GC	0.02	0.07	GC	0.22	
14	TWC	EGR	Air	85	11506	6.29	0.27	0.025	DNPH	0.3	GC	0.03	0.23	GC	0.38	
15	NCAT	EGR	Air	85	11575	6.93	2.68	NA	—	NA	—	NA	NA	—	NA	
16	NCAT	EGR	Air	85	11608	7.22	2.65	0.194	DNPH	2.1	GC	0.02	0.69	GC	1.76	
17	TWC	NEGR	Air	85	11805	3.17	1.2	NA	—	NA	—	0.02	NA	—	NA	
18	TWC	NEGR	Air	85	11844	3.34	1.25	0.02	DNPH	0.24	GC	0.02	0.07	GC	0.19	
19	TWC	EGR	Air	85	15111	1.56	2.02	0.017	DNPH	0.19	GC	—	—	—	—	
20	TWC	EGR	Air	85	15561	1.37	0.39	NA	—	NA	—	0.02	—	—	—	Replaced fuel injector—full stoichiometric operation
21	TWC	EGR	Air	85	15597	1.68	0.38	NA	—	0.25	GC	0.02	—	—	—	Replaced fuel pump
22	TWC	EGR	Air	85	21544	1.67	0.84	NA	—	NA	—	0.01	0.08	GC	—	
23	TWC	EGR	Air	85	21579	1.98	0.69	0.027	DNPH	0.24	GC	0.02	—	—	0.2	
24	TWC	EGR	Air	85	26270	1.91	1.16	0.025	DNPH	0.18	GC	0.02	0.09	GC	0.18	
25	TWC	EGR	Air	85	37772	1.86	0.99	NA	—	0.25	GC	0.02	0.06	GC	—	
26	TWC	EGR	Air	85	37799	1.56	0.96	0.019	DNPH	0.26	GC	0.02	0.06	GC	—	
27	TWC	EGR	Air	85	43309	2.61	1.62	0.022	DNPH	NA	—	0.03	0.07	GC	—	

Sources: Rows 1–24—California Air Resources Board (1988), Rows 25–27—California Air Resources Board (1989).

Table A-12—'86 Toyota Carina/License No. 145/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	OC	NEGR	No air	85	944	0.62	1.05	0.014	DNPH	0.12	GC	0.02	0.07	GC	0.13	
2	OC	NEGR	No air	85	990	0.78	0.94	NA	—	NA	—	0.016	—	—	—	
3	OC	NEGR	No air	85	1006	0	0	NA	—	NA	—	—	—	—	—	
4	OC	NEGR	No air	85	1272	1.55	0.75	0.009	DNPH	0.12	GC	0.025	0.09	GC	0.15	Tested at 2500 lbs. I.W., several driver errors
5	OC	NEGR	No air	85	1326	1.19	0.53	NA	—	NA	—	0.022	—	—	—	Tested at 2500 lbs. I.W.
6	OC	NEGR	No air	85	3544	1.68	0.94	0.01	DNPH	0.12	GC	0.021	0.07	GC	0.13	Leak in test cap at filler neck
7	OC	NEGR	No air	85	8648	1.66	0.52	0.013	DNPH	0.12	GC	0.021	0.07	GC	0.13	Tested after fuel injector replaced and tested at 2250 lbs. I.W.
8	OC	NEGR	No air	85	8799	1.72	0.59	0.011	DNPH	0.06	GC	0.021	0.06	GC	0.09	Tested at 2500 lbs. I.W.
9	OC	NEGR	No air	85	13012	1.18	0.96	0.017	DNPH	0.12	GC	0.016	0.05	GC	0.11	Tested at 2500 lbs. I.W.
10	OC	NEGR	No air	85	20785	1.39	1.06	0.019	DNPH	0.13	GC	0.015	0.04	GC	0.11	Tested at 2500 lbs. I.W.
11	OC	NEGR	No air	85	24589	1.36	1.75	0.036	DNPH	NA	—	0.02	—	—	—	No. 3 fuel injector not working during test
12	OC	NEGR	No air	85	24713	1.36	0.68	0.021	DNPH	NA	—	—	NA	—	—	

Sources: Rows 1–8—California Air Resources Board (1988); Rows 9–11—California Air Resources Board, "Quarterly Summary" (12/88–2/89); Row 12—California Air Resources Board (1989).

Table A-13—'87 Ford Crown Victoria/License No. 927/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	177	0.66	0.54	0.01	DNPH	0.12	GC	0.06	0.1	GC	0.16	Suspect leak in test connection
2	TWC	EGR	Air	50	195	0.88	0.66	0.011	DNPH	0.25	GC	0.1	0.21	GC	0.32	
3	TWC	EGR	Air	85	305	1.05	0.55	NA	—	NA	—	0.03	0.06	GC	—	
4	TWC	EGR	Air	85	5826	0.53	0.67	0.022	DNPH	NA	—	0.03	0.05	GC	—	
5	TWC	EGR	Air	85	5852	0.46	0.61	0.019	DNPH	NA	—	0.02	NA	—	—	
6	TWC	EGR	Air	0	5886	0.51	0.76	0.007	DNPH	NA	—	0.08	NA	—	—	
7	TWC	EGR	Air	0	7985	8.16	0.66	0.003	DNPH	NA	—	0.08	NA	—	—	Tested after new fuel injectors installed
8	TWC	EGR	Air	85	8025	2.7	0.92	0.023	DNPH	0.26	GC	0.03	0.08	GC	0.2	
9	TWC	EGR	Air	0	8104	6.4	0.98	0.005	DNPH	0	GC	0.07	NA	—	—	
10	TWC	EGR	Air	85	13668	3.32	0.93	0.029	DNPH	0.19	GC	0.03	0.14	GC	0.24	
11	TWC	EGR	Air	25	15111	5.99	0.69	0.003	DNPH	0.04	GC	0.07	NA	—	—	
12	TWC	EGR	Air	85	19813	5.13	0.9	0.032	DNPH	NA	GC	0.04	NA	—	—	
13	TWC	EGR	Air	85	19878	3.93	0.93	0.026	DNPH	0.26	GC	0.04	0.12	GC	0.24	
14	TWC	EGR	Air	50	19910	6.55	0.72	0.015	DNPH	0.2	GC	0.07	0.33	GC	0.42	
15	TWC	EGR	Air	0	20046	6.6	0.67	0.006	DNPH	NA	GC	0.07	0.58	GC	0.58	
16	TWC	EGR	Air	85	20199	8.73	0.82	0.028	DNPH	NA	GC	0.07	NA	—	—	Between 20046 and 20199 miles vehicle operated on E85/E95 fuels
17	TWC	EGR	Air	85	20358	7.06	0.89	0.027	DNPH	0.18	GC	0.05	NA	—	—	MeOH and THC measured but lab analysis not completed
18	TWC	EGR	Air	100	20377	8.83	0.83	0.034	DNPH	1.37	GC	0.03	NA	—	—	MeOH and THC measured but lab analysis not completed
19	TWC	EGR	Air	85	20469	2.11	0.47	NA	DNPH	NA	GC	0.04	NA	—	—	Tested after replacing vacum control tubing to solenoid valve
20	TWC	EGR	Air	100	21941	1.4	0.44	0.032	DNPH	0.7	GC	0.02	0.03	—	0.33	
21	TWC	EGR	Air	100	21959	1.35	0.46	NA	DNPH	NA	GC	0.02	0.33	—	—	
22	TWC	EGR	Air	0	22002	3.56	0.77	NA	DNPH	NA	GC	0.16	NA	—	—	
23	TWC	EGR	Air	85	22045	1.01	0.45	0.022	DNPH	0.12	GC	0.04	0.09	—	0.15	
24	TWC	EGR	Air	85	22069	1.34	0.46	NA	DNPH	—	—	0.05	NA	—	—	
25	TWC	EGR	Air	85	32446	3.39	0.43	0.036	DNPH	NA	—	0.1	0.31	—	—	
26	TWC	EGR	Air	25	32480	3.09	0.51	0.012	DNPH	NA	—	0.15	1.09	—	—	

Sources: Rows 1–11—California Air Resources Board (1988); Rows 12–19—California Air Resources Board, "Quarterly Summary" (6/88–8/88); Rows 20–26—California Air Resources Board (1989).

Table A-14—'87 Ford Crown Victoria/License No. 928/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	244	0.87	0.59	NA	—	NA	—	—	—	—	—	
2	TWC	EGR	Air	50	262	0.74	0.79	NA	—	NA	—	—	—	—	—	
3	TWC	EGR	Air	85	5334	1.08	0.74	0.015	DNPH	0.25	GC	—	—	—	—	
4	TWC	EGR	Air	85	5375	0.72	0.66	0.02	DNPH	NA	—	—	—	—	—	
5	TWC	EGR	Air	0	6279	2.41	1.28	0.004	DNPH	NA	—	—	—	—	—	HCHO does not include 0.013 gram per mile acrolein
6	TWC	EGR	Air	85	6690	0.61	0.65	0.015	DNPH	0.06	GC	—	—	—	—	Tested after new fuel injectors installed
7	TWC	EGR	Air	0	6742	0.76	0.79	0.005	DNPH	NA	—	—	—	—	—	

Source: Rows 1–7—California Air Resources Board (1988).

Table A-15—'87 Ford Crown Victoria/License No. 779/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	187	1.44	0.7	0.015	DNPH	NA	—	0.06	NA	—	NA	
2	TWC	EGR	Air	50	205	0.98	0.89	0.016	DNPH	NA	—	0.08	NA	—	NA	
3	TWC	EGR	Air	85	7666	1.11	0.57	0.025	DNPH	0.12	GC	0.04	0.08	GC	0.14	New fuel injector, spark plugs, and fuel pressure regulator at 3854 miles
4	TWC	EGR	Air	0	7696	1.46	0.65	0.005	DNPH	NA	—	0.09	NA	—	NA	
5	TWC	EGR	Air	0	10862	1.35	0.66	0.008	DNPH	NA	—	0.08	NA	—	NA	MeOH and THC measured but lab analysis not completed
6	TWC	EGR	Air	85	10888	1.01	0.61	0.019	DNPH	NA	—	0.04	NA	—	NA	MeOH and THC measured but lab analysis not completed
7	TWC	EGR	Air	85	10907	1.21	0.64	NA	—	NA	—	0.03	NA	—	NA	MeOH and THC measured but lab analysis not completed
8	TWC	EGR	Air	85	10925	1.05	0.61	NA	—	NA	—	0.04	NA	—	NA	MeOH and THC measured but lab analysis not completed
9	TWC	EGR	Air	100	10951	1.54	0.53	0.038	DNPH	NA	—	0.02	NA	—	NA	MeOH and THC measured but lab analysis not completed
10	TWC	EGR	Air	100	10962	1.75	0.61	NA	—	NA	—	0.01	NA	—	NA	MeOH and THC measured but lab analysis not completed
11	TWC	EGR	Air	85	20497	1.06	0.58	0.016	DNPH	0.12	GC	0.05	0.08	—	0.14	

Sources: Rows 1–4—California Air Resources Board (1988); Rows 5–10—California Air Resources Board, "Quarterly Summary" (6/88–8/88); California Air Resources Board (1989).

Table A-16—'87 Ford Crown Victoria/License No. 778/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	200	0.64	0.75	NA	—	0.14	GC	0.04	0.07	GC	—	
2	TWC	EGR	Air	50	218	0.33	0.92	NA	—	NA	—	0.05	0.09	GC	—	
3	TWC	EGR	Air	85	8584	0.94	0.68	0.036	DNPH	0.17	GC	0.04	0.08	GC	0.17	New fuel injectors, spark plugs, and fuel pressure regulator at 3318 miles
4	TWC	EGR	Air	0	8616	0.85	0.8	0.007	DNPH	NA	—	0.08	—	—	—	
5	TWC	EGR	Air	85	22155	1.29	0.75	0.022	DNPH	NA	—	0.04	0.08	GC	—	
6	TWC	EGR	Air	25	22190	0.99	0.72	0.01	DNPH	NA	—	0.09	0.35	GC	—	

Sources: Rows 1–4—California Air Resources Board (1988), Rows 5 and 6—California Air Resources Board (1989).

Table A-17—'87 Ford Crown Victoria/License No. 963/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	242	0.51	0.5	0.008	DNPH	NA	—	0.04	0.07	GC	—	
2	TWC	EGR	Air	50	261	0.37	0.67	0.008	DNPH	NA	—	0.07	0.17	GC	—	
3	TWC	EGR	Air	85	8323	0.42	0.88	0.017	DNPH	0.05	GC	0.04	0.09	GC	—	
4	TWC	EGR	Air	85	8357	0.4	0.83	0.017	DNPH	0.12	GC	0.04	0.1	GC	0.16	
5	TWC	EGR	Air	50	8391	0.32	1	0.018	DNPH	NA	—	0.06	0.15	GC	—	
6	TWC	EGR	Air	50	8786	0.37	0.84	0.017	DNPH	NA	—	0.05	—	—	—	
7	TWC	EGR	Air	0	10576	0.56	0.92	NA	—	—	—	0.09	—	—	—	
8	TWC	EGR	Air	85	14983	1.41	0.54	0.037	DNPH	0.13	GC	0.05	0.15	GC	0.22	
9	TWC	EGR	Air	25	15019	1.12	0.67	0.016	DNPH	0.03	GC	0.07	0.23	GC	0.25	
10	TWC	EGR	Air	0	15042	1.4	0.75	0.01	DNPH	—	—	0.09	—	—	—	
11	TWC	EGR	Air	0	15076	0.72	0.71	0.005	DNPH	—	—	0.08	—	—	—	
12	TWC	EGR	Air	85	15139	1.05	0.62	0.028	DNPH	0.12	GC	NA	0.16	FID	—	
13	TWC	EGR	Air	85	15157	0.83	0.58	0.029	DNPH	0.13	GC	NA	0.16	FID	—	
14	TWC	EGR	Air	0	15183	0.67	0.73	0.009	DNPH	—	—	—	0.34	FID	—	
15	TWC	EGR	Air	0	15201	0.65	0.72	0.009	DNPH	—	—	—	0.36	FID	—	
16	TWC	EGR	Air	0	21087	0.73	0.94	0.008	DNPH	—	—	—	0.34	FID	0.35	
17	TWC	EGR	Air	0	21127	0.65	0.95	0.007	DNPH	—	—	—	0.28	FID	0.29	
18	TWC	EGR	Air	0	21148	0.95	0.86	0.008	DNPH	—	—	—	0.4	FID	0.4	
19	TWC	EGR	Air	85	21174	1.03	0.67	0.038	DNPH	0.157	GC	NA	0.16	FID	0.18	
20	TWC	EGR	Air	85	21215	0.95	0.62	0.038	DNPH	0.138	GC	NA	0.16	FID	0.17	
21	TWC	EGR	Air	85	26466	1	0.66	0.042	DNPH	0.204	GC	NA	0.21	FID	0.23	
22	TWC	EGR	Air	85	26506	1.24	0.58	0.038	DNPH	0.209	GC	NA	0.2	FID	0.22	
23	NCAT	EGR	Air	85	26525	20.35	1.43	0.571	DNPH	4.6	GC	NA	3.31	FID	3.74	
24	NCAT	EGR	Air	85	26563	19.51	1.39	0.6	DNPH	3.98	GC	NA	3.28	FID	3.65	
25	NCAT	EGR	Air	0	26588	21.71	1.9	0.174	DNPH	—	—	—	5.44	FID	5.59	
26	NCAT	EGR	Air	0	26625	20.31	1.91	0.169	DNPH	—	—	—	5.24	FID	5.38	
27	TWC	EGR	Air	0	26644	0.78	0.94	0.008	DNPH	—	—	—	0.34	FID	0.35	
28	TWC	EGR	Air	0	26682	1.02	0.98	0.008	DNPH	—	—	—	0.39	FID	0.4	

Sources: Rows 1–11—California Air Resources Board (1988), Rows 12–28—Horn and Hoekman (1989).

Table A-18—'83 Ford Escort/License No. 319/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	4553	4.12	0.55	NA	—	0.5	GC	NA	—	—	—	
2	TWC	EGR	Air	86	9938	3.46	0.43	NA	—	0.32	GC	0.09	—	—	—	
3	TWC	EGR	Air	86	9967	5.03	0.44	0.06	DNPH	NA	—	0.14	—	—	—	
4	TWC	EGR	Air	85	16739	5.41	0.43	0.087	DNPH	0.681	GC	0.03	—	—	—	

Source: Rows 1–4—California Air Resources Board (1986).

Table A-19—'83 Ford Escort/License No. 893/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	20245	3.58	0.64	0.062	DNPH	NA	—	NA	—	—	—	
2	TWC	EGR	Air	90	20267	3.65	0.62	0.072	DNPH	0.62	GC	0.62	—	—	—	
3	TWC	EGR	Air	85	31790	6.96	0.67	0.08	DNPH	0.611	GC	0.61	0.52	GC	—	
4	TWC	EGR	Air	85	31835	6.24	0.72	0.09	DNPH	NA	—	NA	—	—	—	

Source: Rows 1–4—California Air Resources Board (1986).

Table A-20—'83 Ford Escort/License No. 570/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	4992	3.34	0.55	0.026	DNPH	NA	—	0.1	NA	—	—	
2	TWC	EGR	Air	90	5030	2.64	0.57	0.024	DNPH	0.51	GC	0.09	0.11	GC	—	

Source: Rows 1 and 2—California Air Resources Board (1986).

Table A-21—'83 Ford Escort/License No. 571/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	5437	2.56	0.52	0.034	DNPH	NA	—	0.06	NA	—	—	
2	TWC	EGR	Air	90	5531	2.28	0.54	0.035	DNPH	0.459	GC	0.06	0.08	GC	—	

Source: Rows 1 and 2—California Air Resources Board (1986).

Table A-22—'83 Ford Escort/License No. 778/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	6044	2.63	0.8	NA	—	NA	—	0.03	NA	—	—	
2	TWC	EGR	Air	90	6062	3.07	0.92	0.082	DNPH	0.37	GC	0.04	NA	—	—	
3	TWC	EGR	Air	85	7426	3.14	0.82	0	DNPH	0.51	GC	0.04	NA	—	—	
4	TWC	EGR	Air	85	7439	3.08	0.75	NA	—	NA	—	0.01	NA	—	—	

Source: Rows 1–4—California Air Resources Board (1986).

Table A-23—'82 GM Citation/License No. 112/Mix Method: Fuel Injection/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	30652	3.76	0.63	0.039	DNPH	0.2	GC	0.02	NA	—	—	Mid-range GC not available so THC by GC not calculated
2	TWC	EGR	Air	85	41547	6.6	0.87	NA	—	0.55	GC	0.03	NA	—	—	
3	TWC	EGR	Air	85	41566	11.5	0.8	NA	—	0.38	GC	0.01	NA	—	—	
4	TWC	EGR	Air	85	41593	13.9	0.68	NA	—	0.351	GC	0.01	NA	—	—	
5	TWC	EGR	Air	85	41605	11	0.83	NA	—	0.26	GC	0.03	NA	—	—	

Source: Rows 1–5—California Air Resources Board (1986).

Table A-24—'87 Ford Crown Victoria/License No. 653/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	388	0.65	0.51	NA	—	0.19	GC	0.04	0.1	GC	NA	
2	TWC	EGR	Air	50	406	0.64	0.72	NA	—	NA	—	0.06	0.11	GC	NA	
3	TWC	EGR	Air	85	7630	3.64	0.52	0.03	DNPH	0.36	GC	0.13	0.24	GC	0.45	
4	TWC	EGR	Air	0	7663	1.18	0.7	0.004	DNPH	NA	—	0.11	NA	—	NA	
5	TWC	EGR	Air	85	10006	2.278	0.388	0.04248	DNPH	0.362	GC	—	0.311	FID	NA	
6	TWC	EGR	Air	85	10026	2.057	0.47	0.03827	DNPH	0.421	GC	—	0.311	FID	NA	
7	TWC	EGR	Air	0	10046	1.098	0.59	0.00996	DNPH	NA	—	—	0.409	FID	NA	
8	TWC	EGR	Air	0	10066	1.101	0.644	—	DNPH	NA	—	—	0.409	FID	NA	
9	TWC	EGR	Air	85	14126	0.947	0.696	0.02767	DNPH	0.03198	GC	—	0.154	FID	NA	
10	TWC	EGR	Air	85	14144	1.135	0.73	0.03119	DNPH	0.07887	GC	—	0.174	FID	NA	
11	TWC	EGR	Air	0	14169	0.599	0.903	0.01146	DNPH	NA	—	—	0.304	FID	NA	
12	TWC	EGR	Air	0	14187	0.788	0.948	0.01154	DNPH	NA	—	—	0.301	FID	NA	
13	TWC	EGR	Air	85	23186	1.39	0.63	0.04	DNPH	0.19	GC	0.06	0.11	GC	0.21	New computer chip, spark plugs, and optical sensor on 9/88
14	TWC	EGR	Air	85	23205	1.68	0.63	NA	DNPH	NA	—	0.06	NA	—	NA	
15	TWC	EGR	Air	25	26049	0.802	0.943	0.01887	DNPH	0.04518	GC	—	0.361	FID	0.37	
16	TWC	EGR	Air	25	26087	0.806	0.844	0.01807	DNPH	0.04151	GC	—	0.327	FID	0.34	
17	TWC	EGR	Air	50	26112	0.945	0.817	0.02607	DNPH	0.08602	GC	—	0.293	FID	0.30	
18	TWC	EGR	Air	50	26150	0.956	0.768	0.02603	DNPH	0.0813	GC	—	0.299	FID	0.31	
19	TWC	EGR	Air	85	26175	0.91	0.697	0.04174	DNPH	0.11288	GC	—	0.155	FID	0.17	
20	TWC	EGR	Air	85	26218	1.3	0.715	0.04671	DNPH	0.21776	GC	—	0.218	FID	0.24	
21	TWC	EGR	Air	85	26255	1.379	0.706	0.05492	DNPH	0.21301	GC	—	0.22	FID	0.25	
22	TWC	EGR	Air	0	26281	0.85	0.876	0.0125	DNPH	NA	—	—	0.418	FID	0.43	
23	TWC	EGR	Air	0	26299	0.795	0.845	0.01214	DNPH	NA	—	—	0.382	FID	0.39	
24	TWC	EGR	Air	85	30321	2.4	0.78	0.044	DNPH	NA	—	0.07	NA	GC	—	
25	TWC	EGR	Air	85	30355	1.52	0.72	0.045	DNPH	NA	—	0.07	NA	GC	—	
26	TWC	EGR	Air	25	30395	1.79	0.93	0.014	DNPH	NA	—	0.11	0.4	GC	—	
27	TWC	EGR	Air	0	30428	1.65	1.03	0.015	DNPH	NA	—	0.13	NA	GC	—	

Sources: Rows 1–4—California Air Resources Board (1988); Rows 5–12 and 15–23—Horn and Hoekman (1989); Rows 13 and 14—California Air Resources Board, "Quarterly Summary" (12/88–2/89); Rows 24–27—California Air Resources Board (1989).

Table A-25—'83 Ford Escort/License No. 484/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	17672	35.33	0.64	NA	—	4.83	GC	0.17	1.88	GC	NA	
2	TWC	EGR	Air	85	17705	36.23	0.69	0.12	DNPH	NA	—	NA	NA	—	NA	
3	TWC	EGR	Air	85	17754	4.43	0.76	0.07	DNPH	0.63	GC	0.09	0.3	GC	0.61	Tested after carburetor repairs
4	TWC	EGR	Air	85	19594	3.21	0.55	0.027	DNPH	0.43	GC	0.1	0.24	GC	0.44	Tested with new converter and carburetor float
5	TWC	EGR	Air	85	24379	3.76	0.66	0.032	DNPH	0.36	GC	0.1	0.21	GC	0.38	
6	TWC	EGR	Air	85	31377	4.62	0.41	0.036	DNPH	NA	—	0.1	NA	—	NA	

Sources: Rows 1–5—California Air Resources Board (1988); Row 6—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table A-26—'83 Ford Escort/License No. 485/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	13480	4.36	0.88	NA	—	0.73	GC	0.13	NA	—	NA	
2	TWC	EGR	Air	85	13529	4.77	0.85	NA	—	0.55	GC	0.13	NA	—	NA	
3	TWC	EGR	Air	85	17984	4.18	0.27	0.043	DNPH	0.57	GC	0.16	0.41	GC	0.68	Tested with new converter and carburetor float
4	TWC	EGR	Air	85	22773	6.05	0.29	0.073	DNPH	0.57	GC	0.21	0.34	GC	0.62	
5	TWC	EGR	Air	85	28378	8.46	0.68	0.1	DNPH	NA	—	0.09	NA	—	NA	

Sources: Rows 1–4—California Air Resources Board (1988); Row 5—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table A-27—'87 Ford Crown Victoria/License No. 610/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	5984	0.85	0.67	0.026	DNPH	0.12	GC	0.04	0.07	GC	0.13	
2	TWC	EGR	Air	85	6017	0.51	0.81	0.006	DNPH	NA	—	0.08	NA	—	—	
3	TWC	EGR	Air	0	15263	3.286	0.696	0.00633	DNPH	NA	—	—	0.367	FID	NA	
4	TWC	EGR	Air	0	15281	3.236	0.644	0.0093	DNPH	NA	—	—	0.383	FID	NA	
5	TWC	EGR	Air	85	15307	0.924	0.67	0.03165	DNPH	0.19698	—	—	0.168	FID	NA	
6	TWC	EGR	Air	85	15326	1.065	0.653	0.03508	DNPH	NA	—	—	0.171	FID	NA	
7	TWC	EGR	Air	0	15357	1.18	0.77	0.00716	DNPH	NA	—	—	0.307	FID	0.31	
8	TWC	EGR	Air	0	15377	2.069	0.718	0.00734	DNPH	NA	—	—	0.334	FID	0.34	
9	TWC	EGR	Air	0	15395	2.307	0.689	0.01029	DNPH	NA	—	—	0.365	FID	0.37	
10	TWC	EGR	Air	0	15413	3.242	0.664	0.00641	DNPH	NA	—	—	0.373	FID	0.38	
11	TWC	EGR	Air	0	21428	4.564	0.757	0.00869	DNPH	NA	—	—	0.615	FID	0.63	
12	TWC	EGR	Air	0	21467	4.364	0.777	0.00704	DNPH	NA	—	—	0.624	FID	0.64	
13	TWC	EGR	Air	85	21492	0.597	0.761	0.02733	DNPH	0.0918	—	—	0.14	FID	0.15	
14	TWC	EGR	Air	85	21531	0.733	0.786	0.03462	DNPH	0.13496	—	—	0.166	FID	0.18	
15	TWC	EGR	Air	85	21549	0.818	0.809	0.03716	DNPH	0.13786	—	—	0.175	FID	0.19	
16	TWC	EGR	Air	85	21568	0.737	0.823	0.04087	DNPH	0.12967	—	—	0.144	FID	0.16	
17	TWC	EGR	Air	85	29178	1.15	0.71	0.03	DNPH	NA	—	0.03	0.1	GC	NA	
18	TWC	EGR	Air	25	29211	1.39	0.83	0.017	DNPH	NA	—	0.08	0.45	GC	NA	
19	TWC	EGR	Air	0	29249	1.08	0.89	0.006	DNPH	NA	—	0.08	NA	GC	NA	

Sources: Rows 1 and 2—California Air Resources Board (1988); Rows 3–16—Horn and Hoekman (1989); Rows 17–19—California Air Resources Board (1989).

Table A-28—'88 GM Corsica/License No. AHU/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	3956	2.62	0.47	0.038	DNPH	0.25	GC	0.02	0.13	GC	0.26	
2	TWC	EGR	Air	85	3990	2.97	0.47	0.036	DNPH	NA	—	0.02	NA	—	NA	
3	TWC	EGR	Air	50	4044	3.17	0.44	0.031	DNPH	NA	—	0.04	NA	—	NA	
4	TWC	EGR	Air	50	4075	3.25	0.4	0.017	DNPH	NA	—	0.04	NA	—	NA	
5	TWC	EGR	Air	50	4133	2.93	0.44	0.031	DNPH	0.18	GC	0.04	0.17	GC	0.26	
6	TWC	EGR	Air	50	4191	1.31	0.41	0.031	DNPH	0.12	GC	0.02	0.12	GC	0.19	
7	TWC	EGR	Air	50	4225	1.41	0.41	0.026	DNPH	NA	—	0.03	NA	—	NA	
8	TWC	EGR	Air	85	4509	1.17	0.46	0.036	DNPH	0.25	GC	0.02	0.11	GC	0.23	
9	TWC	EGR	Air	100	4548	1.23	0.45	0.053	DNPH	0.49	GC	0	0.03	GC	0.27	
10	TWC	EGR	Air	0	4624	1.64	0.13	NA	—	NA	—	0.02	NA	—	NA	
11	TWC	EGR	Air	25	4666	1.3	0.2	0.013	DNPH	0.02	GC	0.02	0.24	GC	0.25	
12	TWC	EGR	Air	0	10194	2.1	0.2	0.0121	DNPH	NA	—	—	0.35	FID	NA	
13	TWC	EGR	Air	0	10230	2.3	0.21	0.0094	DNPH	NA	—	—	0.35	FID	NA	
14	TWC	EGR	Air	85	10257	1.47	0.5	0.0326	DNPH	0.158	GC	—	0.24	FID	NA	
15	TWC	EGR	Air	85	10275	1.63	0.54	0.0321	DNPH	NA	—	—	0.23	FID	NA	
16	TWC	EGR	Air	0	14662	2.543	0.207	0.00782	DNPH	NA	—	—	0.379	FID	0.38	
17	TWC	EGR	Air	0	14700	2.544	0.174	0.00757	DNPH	NA	—	—	0.376	FID	0.38	
18	TWC	EGR	Air	85	14801	1.698	0.324	0.03693	DNPH	0.28091	GC	—	0.206	FID	0.23	
19	TWC	EGR	Air	85	14988	2.091	0.364	0.03548	DNPH	0.37907	GC	—	0.254	FID	0.28	
20	TWC	EGR	Air	0	20684	2.314	0.225	0.00779	DNPH	NA	—	—	0.565	FID	0.57	
21	TWC	EGR	Air	0	20722	1.942	0.235	0.00911	DNPH	NA	—	—	0.375	FID	0.38	
22	TWC	EGR	Air	0	20740	3.056	0.24	0.00763	DNPH	NA	—	—	0.41	FID	0.41	
23	TWC	EGR	Air	85	20766	1.488	0.499	0.03197	DNPH	0.28091	GC	—	0.206	FID	0.23	
24	TWC	EGR	Air	85	20805	1.886	0.525	0.02822	DNPH	0.37907	GC	—	0.256	FID	0.28	
25	TWC	EGR	Air	85	20822	1.861	0.502	0.03088	DNPH	NA	—	—	0.25	FID	0.28	
26	TWC	EGR	Air	85	31468	2.77	0.42	NA	DNPH	NA	—	0.04	NA	—	NA	
27	TWC	EGR	Air	85	31588	1.93	0.61	NA	DNPH	NA	—	0.03	NA	—	NA	
28	TWC	EGR	Air	85	31617	5.23	0.45	NA	DNPH	NA	—	0.08	NA	—	NA	
29	TWC	EGR	Air	85	31680	2.68	0.41	NA	DNPH	NA	—	0.03	NA	—	NA	
30	TWC	EGR	Air	85	31725	3.64	0.34	NA	DNPH	NA	—	0.05	NA	—	NA	
31	TWC	EGR	Air	0	31743	4.00	0.35	NA	DNPH	NA	—	0.07	NA	—	NA	

Sources: Rows 1–11—California Air Resources Board (1988); Rows 12–25—Horn and Hoekman (1989); Rows 26–31—California Air Resources Board (1989).

Table A-29—'87 Ford Crown Victoria/License No. 748/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	2391	0.7	0.34	0.022	DNPH	0.06	GC	0.04	0.07	GC	0.11	Unocal dedicated M85 vehicle
2	TWC	EGR	Air	85	15930	0.4	0.36	0.03	DNPH	0.12	GC	0.04	0.09	GC	0.16	Unocal dedicated M85 vehicle

Sources: Row 1—California Air Resources Board (1988); Row 2—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table A-30—'87 Ford Crown Victoria/License No. 749/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	2511	0.9	0.37	0.017	DNPH	0.04	GC	0.04	0.06	GC	0.09	UNOCAL dedicated M85 vehicle
2	TWC	EGR	Air	85	15420	0.4	0.32	0.028	DNPH	0.06	GC	0.06	0.08	GC	0.12	UNOCAL dedicated M85 vehicle

Source:Rows 1 and 2—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table A-31—'86 Toyota Camry/License No. 311/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	NCAT	EGR	Air	85	22438	9.09	1.95	0.132	DNPH	NA	—	0.02	NA	—	NA	SWRI dedicated M85 vehicle
2	TWC	EGR	Air	85	22474	2.11	0.46	0.021	DNPH	0.25	GC	0.02	0.08	GC	0.2	SWRI dedicated M85 vehicle

Source: Rows 1 and 2—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table A-32—'88 GM Corsica/License No. WPS/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	3967	2.87	0.39	0.023	DNPH	NA	—	0.03	NA	—	NA	CSUN MeOH Marathon vehicle
2	TWC	EGR	Air	85	4256	1.69	0.97	0.021	DNPH	NA	—	0.04	NA	—	—	

Sources: Row 1—California Air Resources Board, "Quarterly Summary" (12/88–2/89); Row 2—California Air Resources Board (1989).

Table A-33—'88 GM Corsica/License No. 945/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	25	1697	1.51	0.31	0.003	DNPH	NA	—	0.06	0.12	—	0.15	
2	TWC	EGR	Air	85	1754	2.07	0.16	0.02	DNPH	NA	—	0.002	0.09	—	—	
3	TWC	EGR	Air	0	1794	2.57	0.27	0.003	DNPH	NA	—	0.008	0.23	—	—	

Source: Rows 1–3—California Air Resources Board (1989).

Table A-34—'88 GM Corsica/License No. 944/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	25	6024	1.97	0.24	NA	DNPH	NA	—	0.03	NA	—	—	

Source: Row 1—California Air Resources Board (1989).

Table A-35—GM Prototype VFV/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	UNK	UNK	0	NA	1.62	0.51	0.007	DNPH	0.001	GC	0.036	0.229	GC	0.233	
2	TWC	UNK	UNK	15	NA	1.34	0.5	0.011	DNPH	0.038	GC	0.016	0.21	GC	0.232	
3	TWC	UNK	UNK	50	NA	1.89	0.3	0.017	DNPH	0.106	GC	0.02	0.172	GC	0.226	
4	TWC	UNK	UNK	85	NA	0.88	0.68	0.037	DNPH	0.215	GC	0.014	0.051	GC	0.161	
5	TWC	UNK	UNK	85	NA	1.2	0.6	0.048	DNPH	0.202	GC	0.012	0.059	GC	0.169	
6	TWC	UNK	UNK	100	NA	1.91	0.56	0.04	DNPH	0.761	GC	0.002	0.009	GC	0.358	

Source: Rows 1–6—Williams et al. (1990).

Table A-36—Prototype Operated by SOHIO

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	UNK	UNK	UNK	90	NA	2.75	0.66	0.05	DNPH	0.559	GC	0.046	0.097	GC	0.362	

Source: Row 1—Williams et al. (1990).

Table A-37—GM Prototype M100/Mix Method: Fuel Injection

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	UNK	UNK	UNK	100	NA	2.48	0.7	0.042	DNPH	0.562	GC	0.008	0.026	GC	0.292	

Source: Row 1—Williams et al. (1990).

Table A-38—'83 Ford Escort/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	NA	7	0.65	0.12	DNPH	0.96	GC-I	0.16	0.49	FID	—	Refueling (0.05 MeOH/0.15 NMHC)

Source: Row 1—Stump and Braddock (1989).

Table A-39—'83 Ford Escort/Mix Method: Carburetion

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	NA	6.72	0.72	0.0811	DNPH	0.836	GC-I	—	—	—	—	
2	TWC	EGR	Air	90	NA	8.5	0.75	0.0669	DNPH	1.001	GC-I	—	—	—	—	
3	TWC	EGR	Air	90	NA	7.29	0.65	NA	DNPH	0.739	GC-I	—	—	—	—	
4	TWC	EGR	Air	90	NA	0	0	NA	DNPH	NA	GC-I	—	—	—	—	
5	TWC	EGR	Air	90	NA	4.46	1.12	NA	DNPH	0.827	GC-I	—	—	—	—	
6	TWC	EGR	Air	90	NA	5.61	1.09	NA	DNPH	0.98	GC-I	—	—	—	—	
7	TWC	EGR	Air	90	NA	7.26	1.21	NA	DNPH	NA	GC-I	—	—	—	—	
8	TWC	EGR	Air	90	NA	4.64	1.1	NA	DNPH	NA	GC-I	—	—	—	—	
9	TWC	EGR	Air	90	NA	4.96	0.98	0.0391	DNPH	0.812	GC-I	—	—	—	—	
10	TWC	EGR	Air	90	NA	6.56	1	0.0357	DNPH	NA	GC-I	—	—	—	—	
11	TWC	EGR	Air	90	NA	6.98	0.99	0.0387	DNPH	1.054	GC-I	—	—	—	—	
12	TWC	EGR	Air	90	NA	5.12	1.12	0.0383	DNPH	0.581	GC-I	—	—	—	—	
13	TWC	EGR	Air	90	NA	4.87	0.97	0.037	DNPH	0.494	GC-I	—	—	—	—	
14	TWC	EGR	Air	90	NA	5.15	0.94	0.0303	DNPH	0.712	GC-I	—	—	—	—	
15	TWC	EGR	Air	90	NA	6.42	0.96	0.0385	DNPH	0.78	GC-I	—	—	—	—	
16	TWC	EGR	Air	90	NA	5.28	0.83	0.0414	DNPH	0.798	GC-I	—	—	—	—	
17	TWC	EGR	Air	90	NA	7.61	0.85	NA	DNPH	0.712	GC-I	—	—	—	—	
18	TWC	EGR	Air	90	NA	6.08	0.91	NA	DNPH	0.908	GC-I	—	—	—	—	
19	TWC	EGR	Air	90	NA	6.87	1	NA	DNPH	1.144	GC-I	—	—	—	—	
20	TWC	EGR	Air	90	NA	5.35	1.02	NA	DNPH	0.721	GC-I	—	—	—	—	
21	TWC	EGR	Air	90	NA	4.47	1.04	NA	DNPH	0.706	GC-I	—	—	—	—	
22	TWC	EGR	Air	100	NA	2.04	0.7	0.053	DNPH	NA	—	—	—	—	—	
23	TWC	EGR	Air	100	NA	1.98	0.67	0.055	DNPH	NA	—	—	—	—	—	
24	TWC	EGR	Air	90	NA	2.29	0.64	0.027	DNPH	NA	—	—	—	—	—	
25	TWC	EGR	Air	90	NA	2.49	0.64	0.023	DNPH	NA	—	—	—	—	—	
26	TWC	EGR	Air	90	NA	2.31	0.64	0.026	DNPH	NA	—	—	—	—	—	
27	TWC	EGR	Air	90	NA	4.91	1.17	0.041	DNPH	NA	—	—	—	—	—	

Sources: Rows 1–21—Gabele et al. (1985), Rows 22–27—Smuda (1984a).

Table A-40—'81 GM Citation/License No. 221/Mix Method: Carburetion/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	88	28597	3.2	0.79	0.02	DNPH	0.26	GC	—	—	—	NA	
2	TWC	EGR	Air	88	28655	7.69	0.74	0.04	DNPH	0.44	GC	—	—	—	NA	

Source: Rows 1 and 2—California Air Resources Board (1984).

Table A-41—'81 GM Phoenix/License No. 616/Mix Method: Carburetion/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	88	2325	2.47	0.42	0.013	DNPH	0.12	GC	—	—	—	NA	
2	TWC	EGR	Air	88	NA	58.99	0.07	0.017	DNPH	0.62	GC	—	—	—	NA	

Source: Rows 1 and 2—California Air Resources Board (1984).

Table A-42—'81 Ford Escort/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWOC	EGR	Air	100	6006	7.26	0.37	0.043	DNPH	0.461	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
2	TWOC	EGR	Air	100	6045	5.63	0.42	0.024	DNPH	0.311	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
3	TWOC	EGR	Air	100	6072	5.21	0.4	0.031	DNPH	0.447	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
4	TWOC	EGR	Air	100	6317	1.56	0.4	0.003	DNPH	0.149	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
5	TWOC	EGR	Air	100	6343	1.46	0.31	0.003	DNPH	0.093	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
6	TWOC	EGR	Air	100	6387	1.53	0.34	0.003	DNPH	0.213	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
7	NCAT	EGR	Air	100	6770	37.04	0.66	0.358	DNPH	10.544	GC-I	—	—	—	NA	THC by FID without MeOH adjustment
8	NCAT	EGR	Air	100	6804	44.49	0.56	0.354	DNPH	12.388	GC-I	—	—	—	NA	THC by FID without MeOH adjustment

Source: Rows 1–8—Smith (1985).

Table A-43—'81 VW Rabbit/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	NEGR	No air	100	1770	3.25	1.72	0.046	DNPH	0.689	GC-I	—	—	—	NA	
2	TWC	NEGR	No air	100	1804	3.65	1.71	0.053	DNPH	0.962	GC-I	—	—	—	NA	
3	TWC	NEGR	No air	100	1829	3.91	1.83	0.046	DNPH	1.114	GC-I	—	—	—	NA	
4	—	NEGR	No air	100	1432	0.95	0.66	0.011	DNPH	0.515	GC-I	—	—	—	NA	
5	—	NEGR	No air	100	1457	0.87	0.64	NA	DNPH	0.448	GC-I	—	—	—	NA	
6	—	NEGR	No air	100	1489	0.85	0.72	0.01	DNPH	0.353	GC-I	—	—	—	NA	
7	TWC	NEGR	No air	100	2334	2.74	1.45	0.037	DNPH	0.519	GC-I	—	—	—	NA	
8	TWC	NEGR	No air	100	2360	2.74	1.58	0.029	DNPH	0.563	GC-I	—	—	—	NA	

Source: Rows 1–8—Smith (1985).

Table A-44—'81 Nissan 200SX/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	OC	NEGR	—	100	NA	0.91	0.56	0.256	DNPH	NA	—	—	—	—	NA	
2	OC	NEGR	—	100	NA	0.91	0.54	0.267	DNPH	NA	—	—	—	—	NA	
3	OC	NEGR	—	100	NA	0.97	0.95	0.112	DNPH	NA	—	—	—	—	NA	
4	OC	NEGR	—	100	NA	0.73	0.95	0.111	DNPH	NA	—	—	—	—	NA	
5	OC	NEGR	—	100	NA	1.68	1.18	0.082	DNPH	NA	—	—	—	—	NA	
6	OC	NEGR	—	100	NA	1.89	1.17	0.082	DNPH	NA	—	—	—	—	NA	
7	OC	NEGR	—	100	NA	6.36	1.23	0.062	DNPH	NA	—	—	—	—	NA	
8	TWC	NEGR	—	100	NA	1.41	1.01	NA	DNPH	NA	—	—	—	—	NA	
9	OC	NEGR	Air	100	1494	0.66	1.3	NA	DNPH	NA	—	—	—	—	NA	
10	OC	NEGR	Air	100	1542	0.81	1.26	NA	DNPH	NA	—	—	—	—	NA	
11	OC	EGR	Air	100	1641	0.55	0.47	NA	DNPH	NA	—	—	—	—	NA	
12	OC	EGR	Air	100	1593	0.54	0.43	NA	DNPH	NA	—	—	—	—	NA	

Source: Rows 1–12—Smuda (1984b).

Table A-45—'78 Ford Pinto (3-Car Average)/Mix Method: Carburetion/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	100	1250	2.95	0.76	0.02	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
2	TWC	EGR	Air	100	2050	3.69	0.64	0.025	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
3	TWC	EGR	Air	100	3050	2.72	0.73	NA	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
4	TWC	EGR	Air	100	4825	2.13	0.63	0.044	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
5	TWC	EGR	Air	100	7900	2.46	0.72	NA	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
6	TWC	EGR	Air	100	9200	2.04	0.61	0.04	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO
7	TWC	EGR	Air	100	10000	2.31	0.67	0.03	MBTH	NA	—	—	—	—	NA	Total aldehydes reported as HCHO

Source: Rows 1–7—Edwards and Baisley (1981).

Table A-46—'83 Ford Escort/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	55	3.41	0.23	0.019	DNPH	0.4	GC-I	—	—	—	NA	
2	TWC	EGR	Air	90	204	3.48	0.28	0.02	DNPH	0.36	GC-I	—	—	—	NA	
3	TWC	EGR	Air	90	365	3.46	0.29	0.021	DNPH	0.34	GC-I	—	—	—	NA	
4	TWC	EGR	Air	90	554	3.47	0.29	0.033	DNPH	0.728	GC-I	—	—	—	NA	
5	TWC	EGR	Air	100	709	2.87	0.32	0.029	DNPH	0.75	GC-I	—	—	—	NA	
6	TWC	EGR	Air	100	946	2.7	0.31	0.034	DNPH	1.12	GC-I	—	—	—	NA	
7	NCAT	EGR	Air	90	298	30.71	0.39	0.242	DNPH	3.95	GC-I	—	—	—	NA	
8	NCAT	EGR	Air	90	598	30.93	0.4	0.203	DNPH	6.16	GC-I	—	—	—	NA	
9	NCAT	EGR	Air	100	799	21.98	0.45	0.255	DNPH	11.02	GC-I	—	—	—	NA	
10	NCAT	EGR	Air	100	850	31.65	0.47	0.501	DNPH	18.76	GC-I	—	—	—	NA	

Source: Rows 1–10—Smith (1984).

Table A-47—'83 Ford Escort/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	90	180	2.94	0.46	NA	—	NA	—	—	0.23	UNK	NA	
2	TWC	EGR	Air	90	281	3.25	0.52	NA	—	NA	—	—	0.32	UNK	NA	
3	TWC	EGR	Air	100	370	2.95	0.52	NA	—	NA	—	—	0.24	UNK	NA	
4	TWC	EGR	Air	100	1161	2.16	0.25	NA	—	NA	—	—	1.07	UNK	NA	
5	TWC	EGR	Air	100	2255	2.83	0.61	NA	—	NA	—	—	0.76	UNK	NA	
6	TWC	EGR	Air	90	2474	3.19	0.66	NA	—	NA	—	—	0.75	UNK	NA	
7	TWC	EGR	Air	90	3129	3.56	0.36	NA	—	NA	—	—	0.39	UNK	NA	
8	TWC	EGR	Air	90	5234	3.06	0.66	NA	—	NA	—	—	0.49	UNK	NA	
9	TWC	EGR	Air	90	13188	6.37	0.52	NA	—	NA	—	—	0.94	UNK	NA	
10	TWC	EGR	Air	90	13220	5.41	0.77	NA	—	NA	—	—	0.81	UNK	NA	
11	TWC	EGR	Air	100	13260	4.65	0.61	NA	—	NA	—	—	0.84	UNK	NA	
12	TWC	EGR	Air	100	13299	5.15	0.93	NA	—	NA	—	—	0.9	UNK	NA	

Source: Rows 1–12—Mobil Research and Development Corporation (1987).

Table A-48—'87 Nissan Sentra/Mix Method: Fuel Injection

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	—	—	—	100	NA	0.43	0.57	0.031	UNK	0.38	UNK	—	0.01	UNK	NA	Dedicated M85 vehicle

Source: Row 1—Hellman (1989).

Table A-49—'86 Ford Crown Victoria/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	2500	0.28	0.82	NA	—	NA	—	—	0.19	UNK	NA	Tested at NYC
2	TWC	EGR	Air	85	3400	0.3	0.66	0.029	DNPH	NA	—	—	0.039	UNK	NA	Tested at MVEL, HC method unknown
3	TWC	EGR	Air	85	3438	0.54	0.63	0.036	DNPH	NA	—	—	0.05	UNK	NA	Tested at MVEL, HC method unknown
4	TWC	EGR	Air	85	3474	0.29	0.7	0.029	DNPH	NA	—	—	0.046	UNK	NA	Tested at MVEL, HC method unknown
5	TWC	EGR	Air	85	3532	0.24	0.67	0.045	DNPH	NA	—	—	0.045	UNK	NA	Tested at MVEL, HC method unknown
6	TWC	EGR	Air	85	3569	0.23	0.71	0.032	DNPH	NA	—	—	0.046	UNK	NA	Tested at MVEL, HC method unknown
7	TWC	EGR	Air	85	3589	0.34	0.72	0.026	DNPH	NA	—	—	0.05	UNK	NA	Tested at MVEL, HC method unknown
8	TWC	EGR	Air	85	3607	0.41	0.68	0.03	DNPH	NA	—	—	0.071	UNK	NA	Tested at MVEL, HC method unknown
9	TWC	EGR	Air	85	3625	0.28	0.71	0.027	DNPH	NA	—	—	0.042	UNK	NA	Tested at MVEL, HC method unknown
10	TWC	EGR	Air	85	3645	0.29	0.68	0.026	DNPH	NA	—	—	0.044	UNK	NA	Tested at MVEL, HC method unknown
11	TWC	EGR	Air	85	—	0.22	0.69	NA	—	NA	—	—	0.24	UNK	NA	Tested at MVEL, HC method unknown
12	TWC	EGR	Air	85	—	0.29	0.68	NA	—	NA	—	—	0.2	UNK	NA	Tested at ECS, HC method unknown

Source: Rows 1–12—Piotrowski, Heavenrich, Bruetsch, and Cheng (1987).

Table A-50—'86 Nissan Sentra/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	—	—	85	16739	2.52	0.54	0.025	DNPH	0.73	FID	—	0.08	FID	0.41	Dedicated M85 vehicle
2	TWC	—	—	85	NA	2.43	0.56	0.026	DNPH	0.68	FID	—	0.07	FID	0.38	Dedicated M85 vehicle
3	TWC	—	—	85	NA	2.59	0.56	0.024	DNPH	0.6	FID	—	0.07	FID	0.34	Dedicated M85 vehicle
4	TWC	—	—	85	NA	3.58	0.59	0.03	DNPH	0.81	FID	—	0.09	FID	0.45	Dedicated M85 vehicle
5	TWC	—	—	85	NA	3.33	0.59	0.024	DNPH	0.81	FID	—	0.09	FID	0.45	Dedicated M85 vehicle
6	TWC	—	—	85	NA	3.65	0.6	0.025	DNPH	0.93	FID	—	0.1	FID	0.51	Dedicated M85 vehicle
7	NCAT	—	—	85	NA	7.36	1.19	0.289	DNPH	4.88	FID	—	0.53	FID	2.78	Dedicated M85 vehicle
8	NCAT	—	—	85	NA	6.14	1.13	0.293	DNPH	4.52	FID	—	0.49	FID	2.58	Dedicated M85 vehicle
9	NCAT	—	—	85	17218	5.69	1.2	0.277	DNPH	4.13	FID	—	0.45	FID	2.36	Dedicated M85 vehicle

Source: Rows 1–9—Blair (1988).

Table A-51—'86 Toyota Carina/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	OC	NEGR	No air	85	NA	1.17	0.82	NA	DNPH	0.295	FID	—	0.13	FID	0.16	MeOH and OMHCE are estimates
2	OC	NEGR	No air	85	NA	1.03	0.74	0.0079	DNPH	0.217	FID	—	0.09	FID	0.121	MeOH and OMHCE are estimates
3	OC	NEGR	No air	85	NA	1.12	0.79	NA	DNPH	0.291	FID	—	0.12	FID	0.157	MeOH and OMHCE are estimates
4	OC	NEGR	No air	85	NA	1.11	0.69	0.0058	DNPH	0.266	FID	—	0.12	FID	0.147	MeOH and OMHCE are estimates
5	OC	NEGR	No air	85	NA	0.86	0.72	0.0068	DNPH	0.207	FID	—	0.09	FID	0.115	MeOH and OMHCE are estimates
6	OC	NEGR	No air	85	NA	1.13	0.75	0.0088	DNPH	0.28	FID	—	0.12	FID	0.155	MeOH and OMHCE are estimates
7	OC	NEGR	No air	85	NA	0.86	0.68	0.0089	DNPH	0.243	FID	—	0.11	FID	0.135	MeOH and OMHCE are estimates
8	OC	NEGR	No air	85	NA	0.73	0.65	0.0052	DNPH	0.267	FID	—	0.12	FID	0.147	MeOH and OMHCE are estimates
9	OC	NEGR	No air	85	NA	0.8	0.67	0.0045	DNPH	0.235	FID	—	0.1	FID	0.129	MeOH and OMHCE are estimates
10	OC	NEGR	No air	100	NA	0.76	0.56	0.006	DNPH	0.195	FID	—	0.07	FID	0.098	MeOH and OMHCE are estimates
11	OC	NEGR	No air	100	NA	0.79	0.53	0.0065	DNPH	0.44	FID	—	0.16	FID	0.213	MeOH and OMHCE are estimates
12	OC	NEGR	No air	100	NA	0.75	0.55	0.0073	DNPH	0.463	FID	—	0.17	FID	0.224	MeOH and OMHCE are estimates
13	OC	NEGR	No air	100	NA	0.69	0.7	0.0137	DNPH	0.219	FID	—	0.08	FID	0.11	MeOH and OMHCE are estimates
14	OC	NEGR	No air	100	NA	0.8	0.75	0.0072	DNPH	0.242	FID	—	0.09	FID	0.118	MeOH and OMHCE are estimates
15	OC	NEGR	No air	100	NA	0.73	0.82	0.0129	DNPH	0.3	FID	—	0.11	FID	0.149	MeOH and OMHCE are estimates
16	OC	NEGR	No air	100	NA	0.64	1.03	0.0115	DNPH	0.17	FID	—	0.06	FID	0.09	Improved M100 best driving PROM
17	OC	NEGR	No air	100	NA	1.14	1.19	0.0131	DNPH	0.22	FID	—	0.08	FID	0.11	Improved M100 best driving PROM
18	OC	NEGR	No air	100	NA	1.01	1.33	0.0133	DNPH	0.22	FID	—	0.08	FID	0.11	Improved M100 best driving PROM
19	OC	NEGR	No air	100	NA	0.91	1.46	0.0104	DNPH	0.2	FID	—	0.08	FID	0.1	Improved M100 best driving PROM
20	OC	NEGR	No air	100	NA	0.61	1.47	0.005	DNPH	0.18	FID	—	0.06	FID	0.09	Manifold plus underfloor catalytic system
21	OC	NEGR	No air	100	NA	0.64	1.46	0.006	DNPH	0.16	FID	—	0.06	FID	0.08	Manifold plus underfloor catalytic system
22	OC	NEGR	No air	100	NA	0.82	1.43	0.005	DNPH	0.18	FID	—	0.06	FID	0.09	Manifold plus underfloor catalytic system
23	OC	NEGR	No air	100	NA	1.3	1.19	0.012	DNPH	0.18	FID	—	0.06	FID	0.09	Higher inertia weight
24	OC	NEGR	No air	100	NA	1.22	1.27	0.012	DNPH	0.21	FID	—	0.07	FID	0.11	Higher inertia weight
25	OC	NEGR	No air	100	NA	1.21	1.54	0.015	DNPH	0.31	FID	—	0.12	FID	0.15	Higher aspect ratio tires
26	OC	NEGR	No air	100	NA	1.09	1.35	0.014	DNPH	0.29	FID	—	0.11	FID	0.14	Higher aspect ratio tires
27	OC	NEGR	No air	100	NA	0.79	1.01	0.0123	DNPH	0.22	FID	—	0.08	FID	0.11	Original PROM, 75°F soak
28	OC	NEGR	No air	100	NA	0.92	1.2	0.0096	DNPH	0.2	FID	—	0.07	FID	0.1	Original PROM, 75°F soak
29	OC	NEGR	No air	100	NA	0.93	1.22	0.092	DNPH	0.22	FID	—	0.08	FID	0.11	Original PROM, 75°F soak
30	OC	NEGR	No air	100	NA	0.96	1.28	NA	DNPH	0.25	FID	—	0.09	FID	0.12	Original PROM, 75°F soak
31	OC	NEGR	No air	100	NA	1.25	1.18	0.0197	DNPH	0.61	FID	—	0.22	FID	0.3	Original PROM, 75°F soak
32	OC	NEGR	No air	100	NA	1.11	1.17	0.0113	DNPH	0.41	FID	—	0.15	FID	0.2	Original PROM, 75°F soak
33	OC	NEGR	No air	100	1570	0.77	0.55	0.007	DNPH	0.37	FID	—	0.13	FID	0.18	Durability testing
34	OC	NEGR	No air	100	1720	0.74	0.76	0.011	DNPH	0.25	FID	—	0.09	FID	0.13	Durability testing
35	OC	NEGR	No air	100	2055	0.93	1.11	0.012	DNPH	0.19	FID	—	0.08	FID	0.1	Durability testing
36	OC	NEGR	No air	100	3850	1.84	0.73	0.011	DNPH	0.16	FID	—	0.07	FID	0.09	Durability testing
37	OC	NEGR	No air	100	4450	1	0.89	0.01	DNPH	0.12	FID	—	0.05	FID	0.07	Durability testing
38	OC	NEGR	No air	100	7550	1.22	1.01	0.01	DNPH	0.14	GC-FID	—	0.06	FID	0.08	Durability testing
39	OC	NEGR	No air	100	10800	0.92	1.42	0.012	DNPH	0.12	GC-FID	—	0.06	FID	0.08	Durability testing

Sources: Rows 1–15—Piotrowski and Murrell (1987), Rows 16–32—Piotrowski (1987), Rows 33–39—Piotrowski (1989).

Table A-52—'86 Chevrolet S-10/License No. ME-562/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	—	—	—	85	381	0.74	0.51	NA	—	0.4	FID	NA	NA	FID	0.16	OMHCE calculated with "ORNL" protocol
2	—	—	—	85	7600	8.27	0.67	NA	—	1.28	FID	NA	NA	FID	0.72	OMHCE calculated with "ORNL" protocol

Source: Rows 1 and 2—McGill, Hillis, West, and Hodgson (1989b).

Table A-53—'86 Chevrolet S-10/License No. ME-568/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	—	—	—	85	288	1.39	0.43	NA	—	0.55	FID	NA	NA	—	0.25	OMHCE calculated with "ORNL" protocol
2	—	—	—	85	8700	6.36	0.85	NA	—	0.82	FID	NA	NA	—	0.44	OMHCE calculated with "ORNL" protocol

Source: Rows 1 and 2—McGill, Hillis, West, and Hodgson (1989b).

Table A-54—'86 Ford Crown Victoria/License No. ME-572/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	793	0.76	0.62	NA	—	0.54	FID	NA	NA	—	0.18	OMHCE calculated with "ORNL" protocol
2	TWC	EGR	Air	85	32800	1.44	0.44	NA	—	NA	FID	NA	NA	—	0.7	OMHCE calculated with "ORNL" protocol

Source: Rows 1 and 2—McGill, Hillis, West, and Hodgson (1989b).

Table A-55—86 Ford Crown Victoria/License No. ME-574/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	418	1.44	0.63	NA	—	0.56	FID	NA	NA	—	0.23	OMHCE calculated with "ORNL" protocol
2	TWC	EGR	Air	85	26900	3.16	0.71	NA	—	1.17	FID	NA	NA	—	0.65	OMHCE calculated with "ORNL" protocol

Source: Rows 1 and 2—McGill, Hillis, West, and Hodgson (1989b).

Table A-56—'87 Buick Regal/License No. 9394/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	323	3.72	1.18	NA	—	0.4	FID	NA	NA	—	0.19	OMHCE calculated with "ORNL" protocol
2	TWC	EGR	Air	85	362	5.13	1.18	NA	—	0.46	FID	NA	NA	—	0.23	OMHCE calculated with "ORNL" protocol
3	TWC	EGR	Air	85	401	6	1.19	NA	—	0.6	FID	NA	NA	—	0.32	OMHCE calculated with "ORNL" protocol
4	TWC	EGR	Air	85	NA	4.95	1.18	0.033	DNPH	0.44	FID	NA	NA	—	0.26	

Sources: Rows 1–3—McGill, Hillis, West, and Hodgson (1989a), Row 4—Blair (1987).

Table A-57—'87 Buick Regal/License No. 9398/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	664	2.51	1.1	NA	—	0.42	FID	NA	NA	—	0.2	OMHCE calculated with "ORNL" protocol
2	TWC	EGR	Air	85	704	3.02	1.09	NA	—	0.43	FID	NA	NA	—	0.21	OMHCE calculated with "ORNL" protocol
3	TWC	EGR	Air	85	743	2.89	1.16	NA	—	0.41	FID	NA	NA	—	0.2	OMHCE calculated with "ORNL" protocol
4	TWC	EGR	Air	85	NA	2.81	1.12	0.035	DNPH	0.37	FID	NA	NA	—	0.22	

Sources: Rows 1–3—McGill, Hillis, West, and Hodgson (1989a), Row 4—Blair (1987).

Table A-58—'84 GM Citation/License No. E-753/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	2.23	0.79	NA	—	NA	—	NA	0.39	FID	NA	Before MeOH conversion
2	TWC	EGR	Air	88	NA	1.87	0.66	NA	—	NA	—	NA	0.98	FID	NA	After MeOH conversion

Source: Rows 1 and 2—McGill et al. (1987).

Table A-59—'84 GM Citation/License No. E-754/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	7.86	1.15	NA	—	NA	—	NA	0.21	FID	NA	Before MeOH conversion
2	TWC	EGR	Air	88	NA	2.38	1.06	NA	—	NA	—	NA	0.59	FID	NA	After MeOH conversion

Source: Rows 1 and 2—McGill et al. (1987).

Table A-60—'84 GM Citation/License No. E-755/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	2.32	0.94	NA	—	NA	—	NA	0.19	FID	NA	Before MeOH conversion
2	TWC	EGR	Air	88	NA	2.27	0.8	NA	—	NA	—	NA	0.75	FID	NA	After MeOH conversion

Source: Rows 1 and 2—McGill et al. (1987).

Table A-61—'84 GM Citation/License No. E-756/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	2.89	1.01	NA	—	NA	—	NA	0.2	FID	NA	Before MeOH conversion
2	TWC	EGR	Air	88	NA	3.28	0.53	NA	—	NA	—	NA	1.27	FID	NA	After MeOH conversion

Source: Rows 1 and 2—McGill et al. (1987).

Table A-62—'84 GM Citation/License No. E-757/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	15.91	0.96	NA	—	NA	—	NA	0.44	FID	NA	Before MeOH conversion
2	TWC	EGR	Air	88	NA	1.55	0.29	NA	—	NA	—	NA	0.74	FID	NA	After MeOH conversion

Source: Rows 1 and 2—McGill et al. (1987).

Table A-63—'88 GM Corsica/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	NA	2.62	0.22	0.005	DNPH	0	GC	—	0.32	GC	0.32	Emissions data are averages of three tests at 75°F
2	TWC	EGR	Air	25	NA	2.45	0.24	0.009	DNPH	0.11	GC	—	0.22	GC	0.28	Emissions data are averages of three tests at 75°F
3	TWC	EGR	Air	50	NA	2.9	0.26	0.014	DNPH	0.21	GC	—	0.17	GC	0.27	Emissions data are averages of three tests at 75°F
4	TWC	EGR	Air	85	NA	2	0.26	0.027	DNPH	0.29	GC	—	0.11	GC	0.24	Emissions data are averages of three tests at 75°F
5	TWC	EGR	Air	100	NA	3.06	0.27	0.041	DNPH	0.82	GC	—	0.04	GC	0.42	Emissions data are averages of three tests at 75°F

Source: Rows 1–5—Gabele (1990).

Table A-64—'85 Ford Escort/License No. T020/Mix Method: Fuel Injection/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	0	4000	2.94	0.44	0.001	FTIR	0.014	FTIR	NA	0.358	FTIR/FID	0.365	Emissions data are multiple-test averages for "aged" catalysts
2	TWC	EGR	Air	50	4000	2.7	0.41	0.024	FTIR	0.149	FTIR	NA	0.309	FTIR/FID	0.384	Emissions data are multiple-test averages for "aged" catalysts
3	TWC	EGR	Air	85	4000	2.47	0.43	0.046	FTIR	0.591	FTIR	NA	0.146	FTIR/FID	0.423	Emissions data are multiple-test averages for "aged" catalysts
4	TWC	EGR	Air	100	4000	4.64	0.26	0.053	FTIR	1.128	FTIR	NA	0.273	FTIR/FID	0.786	Emissions data are multiple-test averages for "aged" catalysts
5	TWC	EGR	Air	85	50000	4.59	0.54	0.059	FTIR	1.096	FTIR	NA	0.293	FTIR/FID	0.795	Emissions data are multiple-test averages for "aged" catalysts
6	TWC	EGR	Air	100	50000	3.56	0.56	0.07	FTIR	1.263	FTIR	NA	0.129	FTIR/FID	0.708	Emissions data are multiple-test averages for "aged" catalysts

Source: Rows 1–6—Nichols et al. (1988).

Table A-65—'85 Ford Escort/License No. T022/Mix Method: Fuel Injection/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	100	4000	2.59	0.45	0.042	FTIR	1.173	FTIR	NA	0.124	FTIR/FID	0.652	Emissions data are multiple-test averages for "aged" catalysts
2	TWC	EGR	Air	0	50000	1.89	0.82	0.003	FTIR	0.005	FTIR	NA	0.354	FTIR/FID	0.357	Emissions data are multiple-test averages for "aged" catalysts
3	TWC	EGR	Air	50	50000	2.09	0.89	0.031	FTIR	0.166	FTIR	NA	0.273	FTIR/FID	0.359	Emissions data are multiple-test averages for "aged" catalysts
4	TWC	EGR	Air	85	50000	2.66	0.65	0.048	FTIR	0.553	FTIR	NA	0.183	FTIR/FID	0.444	Emissions data are multiple-test averages for "aged" catalysts
5	TWC	EGR	Air	100	50000	3.19	0.55	0.069	FTIR	0.711	FTIR	NA	0.203	FTIR/FID	0.543	Emissions data are multiple-test averages for "aged" catalysts
6	NCAT	EGR	Air	85	50000	12.68	2.74	0.181	FTIR	1.547	FTIR	NA	0.435	FTIR/FID	1.189	Emissions data are multiple-test averages for "aged" catalysts
7	NCAT	EGR	Air	100	50000	13.08	2.57	0.244	FTIR	2.53	FTIR	NA	0.226	FTIR/FID	1.435	Emissions data are multiple-test averages for "aged" catalysts

Source: Rows 1–7—Nichols et al. (1988).

Table A-66—'87 Ford Crown Victoria/License No. T-500/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	7599	0.35	0.52	0.005	DNPH	0.047	FTIR	NA	NA	—	NA	Emissions data are multiple-test averages
2	TWC	EGR	Air	85	11690	0.79	0.59	0.027	DNPH	NA	FTIR	NA	NA	—	NA	Emissions data are multiple-test averages
3	TWC	EGR	Air	85	15834	0.93	0.59	0.022	DNPH	NA	FTIR	NA	0.171	FTIR/FID	0.349	Emissions data are multiple-test averages
4	TWC	EGR	Air	85	19931	1.02	0.64	0.031	DNPH	NA	FTIR	NA	NA	—	NA	Emissions data are multiple-test averages
5	TWC	EGR	Air	85	24389	0.84	0.65	0.032	DNPH	0.093	FTIR	NA	0.132	FTIR/FID	0.185	Emissions data are multiple-test averages

Source: Rows 1–5—Nichols et al. (1988).

Table A-67—'87 Ford Crown Victoria/License No. T-520/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	CO	NO_x	HCHO	HCHO Method	MeOH	MeOH Method	Methane	THC	THC Method	OMHCE	Comments
1	TWC	EGR	Air	85	3000	0.55	0.7	0.018	DNPH	0.125	FTIR	NA	0.085	FTIR/FID	0.148	Emissions data are multiple-test averages for "aged" catalysts
2	NCAT	EGR	Air	85	3000	15.18	1.4	0.443	DNPH	3.549	FTIR	NA	1.144	FTIR/FID	2.904	Emissions data are multiple-test averages for "aged" catalysts
3	TWC	EGR	Air	0	12500	1.04	0.75	0.026	DNPH	0.219	FTIR	NA	0.107	FTIR/FID	0.213	Emissions data are multiple-test averages for "aged" catalysts
4	TWC	EGR	Air	85	18000	0.96	0.79	0.043	DNPH	0.155	FTIR	NA	0.122	FTIR/FID	0.21	Emissions data are multiple-test averages for "aged" catalysts
5	TWC	EGR	Air	100	3000	3.37	0.45	0.035	DNPH	1.452	FTIR	NA	0.169	FTIR/FID	0.813	Emissions data are multiple-test averages for "aged" catalysts
6	NCAT	EGR	Air	100	3000	17.05	1.1	0.647	DNPH	6.359	FTIR	NA	0.542	FTIR/FID	3.608	Emissions data are multiple-test averages for "aged" catalysts
7	TWC	EGR	Air	100	3000	3.89	0.53	0.044	DNPH	1.288	FTIR	NA	0.227	FTIR/FID	0.802	Emissions data are multiple-test averages for "aged" catalysts

Source: Rows 1–7—Nichols et al. (1988).

APPENDIX B—EVAPORATIVE EMISSIONS DATA

Table B-1—'81 Ford Escort/License No. 276/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	95	25336	0.13	—	2.23	—	2.36	—	—	NA	NA	FID evap HC data uncorrected for MeOH response
2	TWC	EGR	Air	90	36978	0.15	—	1.27	—	1.42	—	—	NA	NA	FID evap HC data uncorrected for MeOH response

Source: Rows 1 and 2—California Air Resources Board (1986).

Table B-2—'81 Ford Escort/License No. 882/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	34888	0.03	0.25	0.33	3.05	0.36	3.3	—	NA	NA	
2	TWC	EGR	Air	90	45369	0.59	0.55	0.07	5.46	0.66	6.01	—	NA	NA	

Source: Rows 1 and 2—California Air Resources Board (1986).

Table B-3—'81 VW Rabbit/License No. 995/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	NEGR	No air	90	23287	0.29	3.71	0.08	1.83	0.37	5.54	2.77	NA	NA	
2	TWC	NEGR	No air	85	24896	0.06	0.18	0.08	1.22	—	1.4	—	NA	NA	Evap HC species for C_2–C_5 only
3	TWC	NEGR	No air	85	46500	0.01	0.49	0.07	1.82	—	2.31	—	NA	NA	Evap HC species for C_2–C_5 only
4	TWC	NEGR	No air	85	59384	0.18	0.25	0.27	1.21	0.45	1.46	1.08	NA	NA	

Source: Rows 1–4—California Air Resources Board (1988).

Table B-4—'81 VW Rabbit/License No. 989/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	NEGR	No air	85	26237	—	0.18	—	1.21	—	1.39	—	NA	NA	New fuel, cold start injectors, and other fuel system parts
2	TWC	NEGR	No air	85	35428	0.05	0	0.39	1.21	0.07	1.21	0.59	NA	NA	

Source: Rows 1 and 2—California Air Resources Board (1988).

Table B-5—'81 Ford Escort/License No. 920/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	85371	0.02	0.19	0.33	4.27	0.35	4.46	—	—	—	
2	TWC	EGR	Air	90	115590	NA	NA	NA	12.29	NA	NA	—	—	—	

Source: Rows 1 and 2—California Air Resources Board (1986).

Table B-6—'83 Ford Escort/License No. 359/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	167	0.04	0.06	0.01	0.24	0.05	0.3	0.18	NA	NA	Evap HC species for C_2–C_5 only
2	TWC	EGR	Air	90	208	—	0.06	—	0.36	—	0.42	—	NA	NA	
3	TWC	EGR	Air	85	13584	0.003	0.12	0.23	0.24	0.23	0.36	0.39	NA	NA	
4	TWC	EGR	Air	85	20394	0.03	0	0.14	0.21	0.17	0.21	0.26	NA	NA	
5	TWC	EGR	Air	85	27050	0.06	0.12	0.1	0.06	0.16	0.18	0.24	NA	NA	Tests after new converter, O_2 sensor, EGR valve installed

Source: Rows 1–5—California Air Resources Board (1988).

Table B-7—'83 Ford Escort/License No. 365/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	85	0.04	0.19	0.01	0.43	0.05	0.62	0.33	NA	NA	15°BTDC timing; ported vacuum signal to EGR (with restrictor)
2	TWC	EGR	Air	85	8329	—	0.12	0.19	0.3	—	0.42	—	NA	NA	
3	TWC	EGR	Air	85	12265	0.03	0.18	0.02	0.3	—	0.48	—	NA	NA	
4	TWC	EGR	Air	85	21594	0.22	0.19	0.09	0.24	0.31	0.43	0.5	NA	NA	Replaced leaking EGR tube
5	TWC	EGR	Air	85	27554	0.1	0.12	0.02	0.3	0.12	0.42	0.31	NA	NA	Tested with new converter, EGR valve, O_2 sensor
6	TWC	EGR	Air	85	34027	0.16	0.37	0.03	0.43	0.19	0.8	0.55	NA	NA	

Sources: Rows 1–5—California Air Resources Board (1988); Row 6—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table B-8—'83 Ford Escort/License No. 366/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	137	0.06	0.25	0.02	0.24	—	0.49	—	NA	NA	
2	TWC	EGR	Air	85	262	2.76	0.43	0.67	0.36	3.43	0.79	3.68	NA	NA	
3	TWC	EGR	Air	85	9409	1.45	0.49	0.02	0.43	1.47	0.92	1.71	NA	NA	Vacuum hose not connected to canister purge line
4	TWC	EGR	Air	85	15341	0.09	0.12	0.2	0.36	0.29	0.48	0.5	NA	NA	
5	TWC	EGR	Air	85	25088	0.18	0.19	0.16	2.44	0.34	2.63	1.51	NA	NA	

Source: Rows 1–5—California Air Resources Board (1988).

Table B-9—'85 Toyota Camry/License No. 444/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	473	0.13	0.19	0.17	0.24	—	0.43	—	NA	NA	C_6–C_{10} evap HC species only
2	TWC	EGR	Air	85	3812	0.01	0.25	0.21	0.5	—	—	—	NA	NA	
3	TWC	EGR	Air	85	8990	0.25	0.19	0.22	0.31	0.47	0.5	0.69	NA	NA	
4	TWC	EGR	Air	85	15597	0.16	0.19	0.14	0.02	0.3	0.21	0.39	NA	NA	Replaced fuel pump
5	TWC	EGR	Air	85	26270	0	0.06	0.06	0.18	0.06	0.24	0.17	NA	NA	

Source: Rows 1–5—California Air Resources Board (1988).

Table B-10—'86 Toyota Carina/License No. 145/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	OC	NEGR	No air	85	1006	0.18	0.18	0.13	0.24	0.31	0.42	0.5	NA	NA	
2	OC	NEGR	No air	85	3544	2.03	0.62	0.22	0.37	2.25	0.97	2.69	NA	NA	Leak in test cap at filler neck
3	OC	NEGR	No air	85	8648	0.01	0	0.06	0.49	0.07	0.49	0.29	NA	NA	Test after fuel injector replaced and tested at 2250 lbs. IW
4	OC	NEGR	No air	85	13012	0.03	0.12	0.09	0.49	0.12	0.61	0.39	NA	NA	Tested at 2500 lbs. IW

Sources: Rows 1–3—California Air Resources Board (1988); Row 4—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table B-11—'87 Ford Crown Victoria/License No. 927/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	177	1.22	0.31	0.27	1.22	1.49	1.53	2.15	NA	NA	Suspect leak in test connection
2	TWC	EGR	Air	50	195	0.52	0.49	0.21	0.43	0.73	0.92	1.14	NA	NA	
3	TWC	EGR	Air	85	5826	0.06	0.14	0.12	0.29	0.18	0.43	0.37	NA	NA	
4	TWC	EGR	Air	85	8057	0.11	0.06	0.28	0.22	0.39	0.28	0.51	NA	NA	
5	TWC	EGR	Air	85	19878	0.1	0.11	0.17	0.54	0.27	0.66	0.51	NA	NA	
6	TWC	EGR	Air	50	19910	0.94	0.25	0.2	0.42	1.14	0.67	1.44	NA	NA	

Sources: Rows 1–4—California Air Resources Board (1988); Rows 5 and 6—California Air Resources Board, "Quarterly Summary" (6/88–8/88).

Table B-12—'87 Ford Crown Victoria/License No. 928/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	244	0.37	0.25	0.23	0.43	0.6	0.68	0.91	NA	NA	
2	TWC	EGR	Air	50	262	0.43	0.19	0.46	0.61	0.89	0.8	1.26	NA	NA	
3	TWC	EGR	Air	85	5334	0.28	0.28	0.42	0.67	0.7	0.85	1.09	NA	NA	
4	TWC	EGR	Air	85	6724	0.14	0.12	0.21	0.36	0.35	0.48	0.57	NA	NA	

Source: Rows 1–4—California Air Resources Board (1988).

Table B-13—'87 Ford Crown Victoria/License No. 779/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	7666	0.12	0.06	0.18	0.61	0.3	0.67	0.6	NA	NA	New fuel injector, spark plugs, fuel pressure regulator at 3854 mi

Source: Row 1—California Air Resources Board (1988).

Table B-14—'87 Ford Crown Victoria/License No. 778/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	200	0.44	0.19	0.1	0.18	0.54	0.37	0.71	NA	NA	
2	TWC	EGR	Air	50	218	0.81	0.31	0.16	0.37	0.97	0.68	1.27	NA	NA	
3	TWC	EGR	Air	85	8584	0.03	0.12	0.02	0.24	0.05	0.36	0.21	NA	NA	New fuel injector, spark plugs, fuel pressure regulator at 3318 mi

Source: Rows 1–3—California Air Resources Board (1988).

Table B-15—'87 Ford Crown Victoria/License No. 963/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	242	0.18	0.37	0.002	0.55	0.18	0.92	0.58	NA	NA	
2	TWC	EGR	Air	50	261	0.28	0.12	0.27	0.37	0.55	0.49	0.76	NA	NA	
3	TWC	EGR	Air	50	8391	0.17	0.18	0.23	0.42	0.4	0.6	0.66	NA	NA	
4	TWC	EGR	Air	25	15019	2.97	0.37	0.396	0.42	3.37	0.79	3.72	NA	NA	

Source: Rows 1–4—California Air Resources Board (1988).

Table B-16—'83 Ford Escort/License No. 319/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	4553	NA	0.25	0.34	2.44	NA	2.69	—	NA	NA	

Source: Row 1—California Air Resources Board (1986).

Table B-17—'83 Ford Escort/License No. 893/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	20267	NA	0.3	NA	4.2	NA	4.5	—	NA	NA	
2	TWC	EGR	Air	85	31835	5.36	1.85	1.92	2.43	7.28	4.28	—	—	—	

Source: Rows 1 and 2—California Air Resources Board (1986).

Table B-18—'83 Ford Escort/License No. 570/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	5030	NA	3.58	NA	5.95	NA	9.53	—	NA	NA	

Source: Row 1—California Air Resources Board (1986).

Table B-19—'83 Ford Escort/License No. 778/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	6044	NA	0.24	NA	1.81	NA	2.05	—	—	—	

Source: Row 1—California Air Resources Board (1986).

Table B-20—'82 GM Citation/License No. 112/Mix Method: Fuel Injection/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	90	30652	NA	0.12	NA	0.54	NA	0.66	—	NA	NA	Midrange GC not available, so THC by GC not calculated

Source: Row 1—California Air Resources Board (1986).

Table B-21—'87 Ford Crown Victoria/License No. 653/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	388	0.22	0.18	0.19	0.49	0.41	0.67	0.7	NA	NA	
2	TWC	EGR	Air	50	406	0.69	0.37	0.3	0.49	0.99	0.86	1.36	NA	NA	
3	TWC	EGR	Air	85	7630	0.1	0.12	0.19	0.42	0.29	0.54	0.52	NA	NA	
4	TWC	EGR	Air	85	23205	0.07	0.12	0.13	0.37	0.2	0.49	0.42	NA	NA	

Sources: Rows 1–3—California Air Resources Board (1988); Row 4—California Air Resources Board, "Quarterly Summary" (12/88–2/89).

Table B-22—'83 Ford Escort/License No. 484/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	17672	0.28	0.37	1.03	1.77	1.31	2.14	2.26	NA	NA	

Source: Row 1—California Air Resources Board (1988).

Table B-23—'83 Ford Escort/License No. 485/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	22773	0.18	0.19	0.95	3.05	1.13	3.24	2.57	NA	NA	

Source: Row 1—California Air Resources Board (1988).

Table B-24—'87 Ford Crown Victoria/License No. 610/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	5984	0.09	0.12	0.13	0.3	0.22	0.42	0.4	NA	NA	

Source: Row 1—California Air Resources Board (1988).

Table B-25—'88 GM Corsica/License No. AHU/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	3990	0.38	0.12	0.35	0.24	0.73	0.36	0.89	NA	NA	
2	TWC	EGR	Air	50	4133	0.96	0.37	0.5	0.44	1.46	0.81	1.81	NA	NA	
3	TWC	EGR	Air	50	4191	0.88	0.25	0.63	0.3	1.51	0.55	1.75	NA	NA	
4	TWC	EGR	Air	85	4509	0.8	0.12	0.33	0.24	1.13	0.36	1.29	NA	NA	
5	TWC	EGR	Air	100	4548	—	0.12	0.32	0.18	—	0.43	—	NA	NA	

Source: Row 1—California Air Resources Board (1988).

Table B-26—GM Prototype VFV/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	UNK	UNK	0	NA	—	—	—	—	1.462	0	—	—	—	Evap in grams per test
2	TWC	UNK	UNK	15	NA	—	—	—	—	1.265	0.707	—	—	—	Evap in grams per test
3	TWC	UNK	UNK	50	NA	—	—	—	—	0.978	0.925	—	—	—	Evap in grams per test
4	TWC	UNK	UNK	85	NA	—	—	—	—	0.426	1.246	—	—	—	Evap in grams per test; Howell EEE fuel
5	TWC	UNK	UNK	85	NA	—	—	—	—	0.559	1.701	—	—	—	Evap in grams per test; Amoco 91 fuel
6	TWC	UNK	UNK	100	NA	—	—	—	—	0.148	1.108	—	—	—	Evap in grams per test

Source: Rows 1–6—Williams et al. (1990)

Table B-27—Prototype Operated by SOHIO

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	UNK	UNK	UNK	90	NA	—	—	—	—	6.308	3.804	—	—	—	Evap in grams per test; isocrackate

Source: Row 1—Williams et al. (1990).

Table B-28—GM M100 Prototype/Mix Method: Fuel Injection

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
15	UNK	UNK	UNK	100	NA	—	—	—	—	0.024	0.144	0.087	—	—	

Source: Row 1—Williams et al. (1990).

Table B-29—'83 Ford Escort/Mix Method: Carburetion/ECU: NFB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	85	NA	—	—	—	—	0.17	0.31	—	0.2	—	Refueling: (0.05 MeOH/0.15 NMHC)

Source: Row 1—Stump and Braddock (1989).

Table B-30—'86 Toyota Carina/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	OC	NEGR	No air	85	NA	0.32	NA	0.2	NA	0.52	NA	NA	NA	NA	MeOH and OMHCE are estimates
2	OC	NEGR	No air	85	NA	0.49	NA	0.21	NA	0.7	NA	NA	NA	NA	MeOH and OMHCE are estimates
3	OC	NEGR	No air	85	NA	0.66	NA	0.25	NA	0.91	NA	NA	NA	NA	MeOH and OMHCE are estimates
4	OC	NEGR	No air	100	NA	0.13	NA	0.19	NA	0.32	NA	NA	NA	NA	MeOH and OMHCE are estimates
5	OC	NEGR	No air	100	NA	0.1	NA	0.16	NA	0.26	NA	NA	NA	NA	MeOH and OMHCE are estimates
6	OC	NEGR	No air	100	NA	0.09	NA	0.13	NA	0.22	NA	NA	NA	NA	MeOH and OMHCE are estimates

Source: Rows 1–6—Piotrowski and Murrell (1987).

Table B-31—'88 GM Corsica/Mix Method: Fuel Injection/ECU: FB

Row	Catalyst	EGR	Air	Fuel	Odometer	Diurnal HC	Diurnal MeOH	Hot Soak HC	Hot Soak MeOH	Total HC	Total MeOH	Total Organics	Refueling	Running Losses	Comments
1	TWC	EGR	Air	0	NA	NA	NA	NA	NA	0.82	0	0.82	NA	NA	Emissions data are averages of 3 tests at 75°F
2	TWC	EGR	Air	25	NA	NA	NA	NA	NA	1.34	0.26	1.45	NA	NA	Emissions data are averages of 3 tests at 75°F
3	TWC	EGR	Air	50	NA	NA	NA	NA	NA	0.46	0.28	0.59	NA	NA	Emissions data are averages of 3 tests at 75°F
4	TWC	EGR	Air	85	NA	NA	NA	NA	NA	0.49	0.25	0.64	NA	NA	Emissions data are averages of 3 tests at 75°F
5	TWC	EGR	Air	100	NA	NA	NA	NA	NA	0.12	0.58	0.4	NA	NA	Emissions data are averages of 3 tests at 75°F

Source: Rows 1–5—Gabele (1990).

APPENDIX C—SUMMARY OF METHANOL VEHICLE EMISSIONS STUDIES

This appendix summarizes relevant methanol vehicle emissions studies. These summaries focus on emission results and do not indicate the entire scope or objectives of the studies.

Alson (1988)

Alson (1988) identified emissions reductions that were possible from the use of methanol and compressed natural gas in light-duty vehicles. Emission factors from those fuels were compared with emission factors from gasoline vehicles. Alson presented data showing that emissions from new gasoline cars had been reduced 84–98 percent between the years 1966 and 1986. Average emissions from current-technology methanol vehicles for CO and NO_x were higher than zero-mile emissions from current gasoline vehicles. He therefore did not expect CO and NO_x emissions to be affected by the use of methanol vehicles.

Blair (1988)

Blair (1988) described emissions testing conducted at EPA's Motor Vehicle Emissions Laboratory on a turbocharged Sentra that was designed by Nissan to use M85 fuel. The vehicle's chassis was a late-1986 model, and the engine was a 1983 1.3-liter design. The Sentra was supplied by Nissan to EPA for purposes of evaluating the manufacturer's methanol technology. The Sentra was tested after the fuel injectors were replaced because of faulty operation as a result of corrosion of the injectors' fuel inlet side. Exhaust emissions of hydrocarbons, NO_x, CO, CO_2, and formaldehyde were measured. The reported hydrocarbon emission values were based on calculations because methanol emissions were not measured by EPA at the time the tests were conducted. Therefore, the reported results were computed with an FID response factor of 0.75 and an assumed hydrocarbons-to-methanol factor of $x/0.85$, where x was the fraction, in parts per million, of methanol in a methanol–gasoline blend. Blair reported that formaldehyde emission levels were 286 milligrams per mile during engine-out tests and 26 milligrams per mile with the catalyst installed. It was noted that the gas chromatograph readings for formaldehyde emissions were in error (+15 percent) because of mechanical problems with the analytical instrumentation during part of the test program.

Blair concluded that work was needed in the design of more methanol-tolerant fuel system components or possibly fuel additives to improve the Sentra's injector life. He recommended that more work be done on the Sentra's evaporative emissions system, because FID-measured hydrocarbon and CO tailpipe emissions increased significantly when a diurnal heat-build test was conducted before the FTP driving cycle. He also recommended that a more effective catalyst system be developed, allowing quicker light-off during cold starting conditions.

California Air Resources Board (1983)

The California Air Resources Board (1983) evaluated a 1981 Chevrolet Citation and a 1983 Pontiac Phoenix. Exhaust emissions for city and highway cycles were reported for formaldehyde, methanol, and nonoxygenated hydrocarbons. Evaporative emissions, including nonoxygenated hydrocarbons, were measured by gas chromatograph.

California Air Resources Board (1988)

In a cooperative program with the California Energy Commission (CEC), CARB has been periodically testing methanol-fueled fleet vehicle emissions since October 1980. The "Eighth Interim Report" summarizes all test data for each test vehicle from October 1980 to June 1988. (A "Ninth Interim Report" has subsequently been released.) Sixteen vehicles were tested. The fuel tested was primarily M85, but M100 was used in a few tests with FFVs. CARB reported that only the Ford Escorts were able to meet the California NO_x standard. They reported that all of the vehicles (except the Ford Crown Victorias) experienced deterioration of driveability and emission control because of fuel injector fouling, fuel filter clogging, or both. These problems were more severe with vehicles at relatively low mileage. Several fuel pump failures in both the Escorts and the Crown Victorias caused Ford Motor Company to perform extensive testing on more durable replacements. Toyota installed new ball fuel injectors after fuel injector fouling was experienced. Initial tests indicated NO_x levels below the California standard, but after 10,000 miles, NO_x emissions were above the standard. CARB reported that the 1981 Volkswagen accumulated the most mileage (66,900 miles) of any vehicle in the fleet with "generally good driveability." However, during the last 10,000 miles the 1981 Volkswagen experienced "difficult cold starts, rough running and stalling." High hydrocarbon and CO emissions were observed at 66,486 miles.

CARB used two analytical instruments to test for total hydrocarbons in the exhaust. This was done because FID, which is used to analyze hydrocarbons, cannot distinguish between hydrocarbons and methanol, which are both present in the exhaust from methanol-fueled vehicles. FID measures the combined amount of hydrocarbons and methanol in the exhaust. This combined measurement underestimates the total amount of these species because FID only partially responds to methanol. Because FID can miss 15–25 percent of the methanol, some researchers divide FID results by a correction factor of 0.8, and others rely on more accurate results

from gas chromatography. Consequently, CARB conducted a separate gas chromatographic analysis to properly quantify methanol and hydrocarbon in the exhaust.

DeLuchi, Johnston, and Sperling (1988)

DeLuchi, Johnston, and Sperling (1988) conducted a comparative analysis of methanol, compressed natural gas, and liquefied natural gas as automotive fuels. In their paper, they summarized emissions data on methanol vehicles from several authors. A total of 15 vehicles using methanol fuels ranging from M50 to M100 were analyzed. DeLuchi et al. pointed out that one serious problem with methanol use is the difficulty of starting and driving the car in cold weather. It was their belief that if methanol vehicles continued to have difficulty starting, they might produce more CO than would gasoline vehicles during the cold transient cycle. Their analyses of available data indicated decreased NO_x emissions from dual-fuel vehicles. However, emissions from dedicated methanol vehicles were generally higher than those from gasoline vehicles. They agreed with EPA's claims that NO_x emissions from methanol vehicles were not likely to be much lower than those from gasoline vehicles.

Their data analysis showed that formaldehyde emissions from methanol vehicles were higher than those from gasoline vehicles. They reported that properly operating gasoline vehicles with three-way catalysts emitted only 0–10 milligrams per mile of formaldehyde, whereas current-technology methanol vehicles emitted about 10–80 milligrams per mile.

Evaporative emissions from methanol vehicles were less than those from gasoline vehicles because methanol is less volatile than gasoline. However, the authors pointed out that if volatility enhancers were added to methanol to assist cold starting, evaporative emissions could increase. They concluded that the benefits from methanol use may range from insignificant to substantial.

Dunlap, Cross, and Drachand (1989)

Dunlap, Cross, and Drachand (1989) presented an overview of current CARB methanol vehicle emissions testing. They discussed data from light-duty methanol vehicle fleet test programs and described recent formaldehyde emission standards promulgated by CARB. Although CARB has been conducting emission testing since 1985 on Ford Pintos, Ford Escorts, Volkswagen Rabbits, a Toyota Camry, a Toyota Carina, and Ford Crown Victorias, this paper focused on emissions from three vehicles—the Toyota Camry, the Toyota Carina, and a flexible-fuel Ford Crown Victoria. These vehicles were modified for methanol use. For example, the Toyota Camry used a three-way catalyst, exhaust gas recirculation, multipoint electronic fuel injection, and a modified head for high (10:1) compression, with a swirl control valve, an oxygen sensor, and loop control. Even with these modifications, the Camry experienced driveability problems (plugged fuel injectors) and high NO_x emissions. The authors reported CARB's difficulty in analyzing emission trends from these vehicles as a result of of intermittent fouling of the fuel injectors, causing variability in the emissions data. They recommended that improvements be made to the design of the fuel injectors for use with methanol fuel. In addition, they pointed out that to gain benefits in air quality, advancements in catalyst design are needed to achieve low formaldehyde and NO_x emissions from methanol cars. They indicated that methanol-fueled vehicles emit higher levels of ozone-forming formaldehyde than do gasoline- or diesel-fueled vehicles. Emission test data showed that formaldehyde emissions from methanol-fueled light-duty vehicles typically ranged from 30 to 70 milligrams per mile using current-technology emission controls. In contrast, current gasoline-fueled light-duty vehicles emitted formaldehyde at a maximum of 15 milligrams per mile. Despite the poor driveability reported in the maintenance data, they concluded that overall driveability and performance was very good. However, they stated that all the vehicles (except the Ford FFVs) experienced occasional driveability problems because of fuel injector fouling.

Edwards and Baisley (1981)

Edwards and Baisley (1981) assessed the performance of a Ford three-way catalyst feedback control system when neat methanol fuel was used. The carburetors of three 1979 Ford Pinto 2.3-liter vehicles were modified to reflect differences in stoichiometric conditions between methanol and gasoline combustion. The modifications required precise attention to the fuel/air ratio over all speed and load changes.

The data indicated that CO emissions were about the same for neat methanol and Indolene. Methanol and NO_x emissions were reduced to one-half and two-thirds of the Indolene emission levels, respectively. Aldehydes were reported to increase by a factor of three with neat methanol fuel, and most of the aldehyde emissions were emitted during the cold treatment test phase.

Fuel economy for methanol and Indolene were reported to be comparable. Edwards and Baisley's data indicated that urban fuel economy was slightly lower for methanol than for Indolene. The highway fuel economy of the methanol vehicles was shown to be higher than that of the gasoline vehicles.

Emissions data over a 10,000-mile, 18-month test period indicated no emissions control system problems, but tests were terminated after 12,000 miles because of severe upper cylinder wear.

Gabele, Baugh, Black, and Snow (1985)

Gabele, Baugh, Black, and Snow (1985) examined exhaust and evaporative emissions from vehicles fueled both

with M90 and with a blend consisting of 90-percent gasoline, 5-percent methanol, and 5-percent tertiary butyl alcohol. The test vehicles used in this study were a 1984 Ford Mustang, a 1984 Chevrolet Cavalier, and a 1983 Ford Escort. The Ford Escort was a modified version of its gasoline-fueled counterpart. Its compression ratio was increased to 11.4:1, and its carburetor was recalibrated to deliver larger quantities of fuel. Ignition timing was optimized to account for changes in the compression ratio and methanol's higher flame speed. The Cavalier and Mustang were used to test baseline emissions from premium gasoline fuel.

When the Mustang was run on baseline gasoline, regulated exhaust emissions (HC, CO, and NO_x) exceeded 1984 emission standards (0.41 gram per mile for hydrocarbons, 3.4 grams per mile for CO, and 1.0 gram per mile for NO_x). Emission levels from the Cavalier were lower than those from the Mustang. Regulated exhaust emission rates were reported to be about the same for both baseline and blended fuels. Exhaust methanol emissions were not detected. Gabele et al. assumed, however, that methanol emissions were less than 2 milligrams per mile from the blended fuels. Aldehyde emissions from blended fuel were reported to be twice as high as those from baseline fuels, with most of them being formaldehyde. No significant differences in fuel economy were observed between the baseline and the blended fuels.

The data on methanol emissions from the Ford Escort indicated that CO emissions exceeded the standard of 3.4 grams per mile. Methanol emission rates were reported to be three times higher than nonmethanol hydrocarbon emission rates. Aldehyde emissions an order of magnitude higher than those from gasoline-fueled automobiles were reported. Hydrocarbon emissions from the methanol Ford Escort were reported to be similar in composition to those from gasoline vehicles. It was assumed that these hydrocarbons were a result of combustion products from the gasoline fraction of the blended fuel. The average hydrocarbon composition was 65 percent paraffins, 25 percent aromatics, and 10 percent olefins. The Ford Escort's methanol evaporative emissions, comprising diurnal and hot-soak emissions, were 40 percent and 65 percent, respectively.

Gold and Moulis (1987)

Gold and Moulis (1987) compiled exhaust and evaporative emissions data for methanol-fueled vehicles from a number of different sources into three different data bases (exhaust city and highway, exhaust idle, and evaporative emissions). Their paper describes each data base and presents the results of a limited statistical evaluation of the data. The statistical evaluation calculated mean values of pollutant variables for each vehicle (CO, NO_x, formaldehyde, and methanol). The mean values for all the vehicles were averaged and reported, along with other relevant statistics. The authors made no attempt to compare the emission results with similar data from gasoline vehicles.

Gold and Moulis stated that "the data for methanol vehicles are not yet sufficient to allow for correlation of emission levels versus mileage." Their exhaust data base did not differentiate among fuel types (that is, by the methanol content of the fuel). They believed that the data might be sufficient for making general predictions of in-use methanol vehicle emissions but recognized a need for more data. They reported that "it would be useful to have data from an experiment designed specifically to evaluate the impact of fuel type, vehicle type and mileage accumulation on the ratios of organic emissions over the city and highway cycles."

Hellman (1989)

Hellman (1989) reported the results of emission testing of a prototype Nissan Sentra designed to run on M100 fuel. EPA conducted both emission and fuel economy tests. Hydrocarbon emissions were 0.01 gram per mile, methanol emissions were 0.38 gram per mile, formaldehyde emissions were 0.031 gram per mile, CO emissions were 0.43 gram per mile, and NO_x emissions were 0.57 gram per mile. The results of the fuel economy tests, expressed as gasoline-equivalent miles per gallon, were 37 miles per gallon in the city and 52 miles per gallon on the highway. During EPA's evaluation of the M100 Nissan Sentra, a cold transient driveability problem developed, and despite replacement of some parts, the problem was not solved. EPA plans to continue working with Nissan to resolve the problem. EPA compared fuel economy results from the M100 Nissan Sentra with those from a gasoline-fueled Nissan Pulsar, which had the same type of engine and transmission. In one comparison, EPA modified the M100 Sentra so that it would have the same final drive gear ratio as the gasoline-fueled Pulsar. Therefore, the ratio of engine speed, in revolutions per minute, to vehicle speed, in miles per hour (N/V), would be the same for both vehicles. Nissan has recommended that EPA modify another gasoline-fueled Pulsar to match the Sentra's N/V. EPA plans to follow Nissan's recommendation and will procure another Pulsar from Nissan.

Horn and Hoekman (1989)

Horn and Hoekman (1989) discussed the difficulty of making a comprehensive comparison of methanol- and gasoline-fueled vehicle emissions because of discrepancies in available data. These discrepancies include "inadequate emissions sampling and quantification techniques for methanol vehicles, lack of data from advanced technology methanol-fueled vehicles, and lack of emissions data from intermediate and high mileage methanol-fueled vehicles." The authors conducted tests following the EPA 1975 FTP for exhaust emissions and the Highway Fuel Economy Test (HFET) for highway fuel economy. CO, NO_x, carbon dioxide, and formaldehyde measurements were made for the

Ford Crown Victoria and Chevrolet Corsica vehicles using a range of methanol fuels from gasoline to M85. Their data show that formaldehyde levels with M85 fuel are about three to five times greater than those for the same vehicles with gasoline fuel. They noted that great care must be taken when collecting methanol and formaldehyde samples because sample condensation sometimes occurs, even when heated lines are used. When condensation droplets form, a significant amount of alcohol is trapped, leading to an underestimation of emissions. They pointed out that the tests are of prototype vehicles and do not represent future production models. Also, the vehicles are part of a well-controlled fleet and receive maintenance and care that probably exceed those provided by the general public.

McGill, Hillis, and Larson (1988)

McGill, Hillis, and Larson (1988) reported results from 2 years of operation of the Federal Methanol Fleet at Lawrence Berkeley Laboratory (LBL). Ten 1984 Chevrolet Citations were operated for DOE's Federal Methanol Fleet Project. Five cars were methanol fueled, and five cars were gasoline fueled. More than 100,000 miles were accumulated on the ten cars without serious disruption in service. The fuel consisted of 88 percent methanol and 12 percent gasoline. Emissions of CO and NO_x were shown to be lower from methanol than from gasoline vehicles, whereas hydrocarbon emissions were higher from methanol than from gasoline vehicles. Hydrocarbon emissions were apparently estimated from FID measurements and calculated as the mass of nonoxygenated hydrocarbons plus the mass of methanol minus the mass of oxygen in the methanol.

In addition to measuring emissions, LBL sampled the lubricating oil every 1000 miles and determined the wear-metal content by laboratory analysis. They reported higher engine wear rates in methanol vehicles but did not consider them to be "alarmingly high." The iron content of the lubricating oil samples was highest, followed by lead, silicon, and copper. Maintenance data collected by LBL showed that methanol vehicles required substantially more service than did gasoline vehicles.

McGill, Hillis, West, and Hodgson (1989a)

McGill, Hillis, West, and Hodgson (1989a) reported results from the first year of operation (which ended December 31, 1988) of the Federal Methanol Fleet at Oak Ridge National Laboratory (ORNL). Ten 1987 Buick Regal Coupes with 3.8-liter V-6 engines and turbochargers were operated for DOE's Federal Methanol Fleet Project. Five cars were methanol fueled, and five cars were gasoline fueled. The methanol fuel used at ORNL was M85. The methanol component of the M85 fuel was produced from coal feedstock by Eastman Chemical Products.

Emissions of CO and NO_x were shown to be higher from methanol-fueled vehicles than from vehicles using Indolene. In addition, calculated OMHCE emission levels for methanol vehicles were higher than hydrocarbon emissions from Indolene vehicles. Formaldehyde emissions from the methanol-fueled vehicles were reported to be 34 milligrams per mile. Methanol emissions in the exhaust were not measured. Consequently, the exhaust methanol values used to compute OMHCE were inferred from FID results by employing the known methanol response factor of the analyzer and assuming the relative amounts of nonoxygenated hydrocarbons and unburned methanol in the exhaust based on the percentage of methanol in the blended fuel.

In addition to measuring emissions, ORNL reported fuel consumption data and sampled lubricating oil every 1000 miles to determine the wear-metal content by laboratory analysis. Energy consumption for the five methanol cars was reported to be slightly higher than that of the five gasoline cars. McGill et al. reported higher accumulation rates of iron and lead in the oil of the methanol cars than in the oil of the gasoline cars but were not concerned with the level of contamination. The iron and lead content in the lubricating oil was three times higher than the copper content.

McGill et al. reported that the ten cars "accumulated a total of nearly 100,000 miles with very little difficulty." The authors said, however, that winter starting of methanol cars was reliable down to temperatures of only 20°F and became difficult around 15°F. Starting was extremely difficult, requiring very long cranking times, at temperatures around 10°F and lower.

McGill, Hillis, West, and Hodgson (1989b)

McGill, Hillis, West, and Hodgson (1989b) reported results from two years of operation of the Federal Methanol Fleet at the Argonne National Laboratory (ANL). Nineteen vehicles were operated for the U.S. Department of Energy's (DOE's) Federal Methanol Fleet Project. Ten of the vehicles were 1986 Chevrolet S-10 pickup trucks, five of which had been converted to operate on methanol, and nine of the vehicles were 1986 Ford Crown Victorias, five of which had been converted for methanol use. DOE was directed by the U.S. Congress to initiate a methanol fleet program in a cold climate. Because of ANL's location near Chicago, DOE selected ANL to operate the fleet. The methanol vehicles were equipped with special cold-starting systems to allow them to start and drive at temperatures as low as –20°F.

Exhaust emissions were measured according to the FTP. Test results were estimated by assuming that unburned fuel in the exhaust had the same composition as the fuel. FID-measured hydrocarbons were reported as the mass of the nonoxygenated hydrocarbons plus the mass of the methanol minus the mass of the oxygen in the methanol. Emissions from the Chevrolet methanol vehicles were slightly higher

than those from their gasoline counterparts. McGill et al. believed that the higher CO emissions from methanol vehicles could be attributed to less effective catalyst performance and that the slightly higher NO_x emissions might be caused by the methanol vehicles' higher compression ratios. The Ford methanol vehicles showed similar results.

In addition to measuring emissions, ANL sampled the lubricating oil every 1000 miles and determined the wear-metal content by laboratory analysis. The wear-metal accumulation rates in the methanol vehicles were found to be much higher than those in the gasoline vehicles. Iron was the largest contributor to lubricating oil contamination, and aluminum was the smallest. Lead and copper were at levels between iron and aluminum. Major vehicle maintenance included replacement of plugged fuel injectors and replacement of molybdenum piston rings with chrome piston rings.

Mobil Research and Development Corporation (1987)

A Mobil Research and Development Corporation (1987) memorandum discussed the results of Mobil's evaluation of a methanol-fueled 1983 Ford Escort. The discussion related mostly to driveability problems, particularly cold starting problems associated with M85 fuel. Extended cranking times were required to start the vehicle at an ambient temperature range of 10°F–15°F. It was reported that the vehicle would not start below 10°F with M85 fuel.

The methanol vehicle was tested in accordance with the FTP for both M90 and M100 fuels. The memorandum reported that at low mileage, the methanol-fueled Escort met 1983 EPA emissions standards for gasoline-fueled vehicles. The vehicle's city fuel economy was reported to be about 14 miles per gallon on M90 and 13 miles per gallon on M100, compared with an EPA rating of 27 miles per gallon for gasoline-fueled Escorts. The lower fuel economy of the methanol vehicle reflected the difference in volumetric energy content between methanol and gasoline and did not indicate greater energy consumption. The better fuel economy for the M90 blend relative to M100 fuel was reported to be the result of M90's higher energy content.

Piotrowski (1987)

Piotrowksi (1987) reported emissions and fuel economy results for a lean-burn combustion system on a Toyota Carina operating on M100 fuel.

The Carina's driveability was improved by adjustment of its idle to run 8 percent leaner. NO_x and CO emissions increased when the improved calibration was used, but aldehyde and hydrocarbon emissions remained the same.

Two catalytic converters (an underfloor converter and the original manifold converter) were installed on the Toyota Carina for the emission tests. Hydrocarbon, CO, and aldehyde emissions decreased substantially with the double catalytic converter system—formaldehyde levels were reported to be only 5 milligrams per mile. However, NO_x emissions increased to 1.45 grams per mile, well above the federal standard of 1.0 gram per mile. The vehicle was also tested with higher aspect ratio tires, simulating the use of a vehicle with a larger chassis. Emission-level efficiencies decreased by 16–50 percent with the use of the higher aspect ratio tires.

The lowest temperature at which the Toyota Carina could reliably start and run on M100 fuel was 55°F.

The inertia weight of the Carina was increased from 2250 to 2625 pounds, and the car was tested using the FTP and HFET cycles. There were few changes in emission levels, except for CO levels, which increased from 0.93 gram per mile to 1.26 grams per mile.

Three separate air/fuel ratios were used, and pollutant emissions were measured. Hydrocarbon, NO_x, and formaldehyde levels at idle were similar among the three air/fuel ratios.

Piotrowski (1989)

Piotrowski (1989) described emissions, fuel economy, and oil-sample analysis of an M100-fueled vehicle that had accumulated 6000 miles. EPA decided to test a methanol vehicle for an additional 6000 miles after discussions with industry suggested that late-model cars experience a significant change in emission levels in the 5000–15,000 mile range. Piotrowski reported that emissions of hydrocarbons, OMHCE, methanol, CO, and formaldehyde "did not substantially change" during the durability test. However, NO_x emissions did increase over the first 3000 miles, from 0.89 to 1.01 grams per mile. On completion of the test, NO_x had increased to a higher level of 1.42 grams per mile. An oil sample taken after the first 15,000 miles showed wear-metal levels twice as high as those in samples taken during the remaining part of the mileage accumulation test.

Piotrowski and Murrell (1987)

Piotrowski and Murrell (1987) evaluated Phase I testing of a Toyota lean-combustion system for methanol fuel. This system was designed to improve fuel economy and driving performance while reducing pollutant emissions. EPA reported that fuel economy improved slightly when the vehicle was operating on M85 instead of M100 fuel. The test vehicle was a 1986 Toyota Carina, which is sold in Japan but not in the United States. The vehicle had a four-cylinder, overhead-camshaft engine with a displacement of 1587 cubic centimeters. The engine was modified for lean-burn mode by provision of a lean-mixture sensor, a swirl control valve, and a timed sequential fuel injection system.

Exhaust hydrocarbon emissions were measured using FID, with no attempt to adjust for FID's partial response to methanol. NO_x emissions were measured using the chemilu-

minescent technique, and CO was measured using an infrared analyzer. Exhaust formaldehyde was measured using the dinitrophenylhydrazine technique.

Piotrowski and Murrell reported that hydrocarbon emissions from the Toyota Carina operating on M85 or M100 fuel were about one-half those from gasoline vehicles. However, CO emissions were only slightly lower than those from gasoline vehicles. NO_x emission levels measured during M100 tests were about the same as those measured during tests of a Toyota Tercel operating on gasoline. Piotrowski and Murrell reported that no attempt was made to analyze the cause of differences in emission levels between gasoline and methanol vehicles, such as vehicle weight and type of catalytic converter. They did acknowledge that these differences could be significant.

Piotrowski, Heavenrich, Bruetsch, and Cheng (1987)

Piotrowski, Heavenrich, Bruetsch, and Cheng (1987) evaluated a methanol-fueled 1986 Ford Crown Victoria, a prototype vehicle (used in a taxicab fleet sponsored by the New York City Department of Environmental Protection). The vehicle, powered by a 5-liter fuel-injected engine, was equipped to operate on both M85 and gasoline fuel.

A total of 17 tests were run on M85 fuel from two different fuel suppliers (Celanese and Howell Hydrocarbon). Seven of these tests were FTPs, four were highway tests, three were evaporative FTP tests, and three were New York City cycle tests. Both exhaust and evaporative (diurnal and hot-soak) emissions were measured. Hydrocarbon emission results were calculated using an FID response factor of 0.75 and an assumed hydrocarbons-to-methanol factor of $x/0.85$, where x was the fraction, in parts per million, of methanol in a methanol-gasoline blend. Piotrowski et al. assumed the amount of methanol in the exhaust because at the time the tests were conducted, EPA did not measure methanol emissions. Their data indicated that average formaldehyde emissions were about double the proposed California standard of 15 milligrams per mile. They reported that the variation in the data was caused by the fuel used, the age of the catalyst, and differences among drivers (with respect to car stalling).

Singh and Sekar (1988)

Singh and Sekar (1988) evaluated the emissions from a variety of methanol vehicle types and qualitatively assessed the potential effects of methanol fuel use on air quality. The methanol vehicles in the data set included 36 operated by the California Energy Commission and 21 others. Singh and Sekar concluded that CO emissions are reduced with neat methanol and methanol blends. However, they reiterated EPA's belief that the data are inconclusive. They found NO_x emissions to be increased with methanol blends and reduced with neat methanol. They reported that EPA does not expect neat methanol vehicles (M100) to have lower NO_x emissions than will gasoline-fueled vehicles. The authors believe it is too early to determine the effect of FFVs on NO_x emissions. They noted that tests have shown that exhaust hydrocarbons are reduced by methanol blends, but they reported that some measurement procedures underestimate methanol emissions. In some studies, they could not tell whether only nonoxygenated hydrocarbons or both nonoxygenated hydrocarbons and methanol were being reported.

They concluded that "methanol-fueled vehicles have not yet shown the increased reliability and durability expected of them." Their conclusion was based on federal fleet demonstrations of methanol automobiles and light trucks, which experienced fuel injector plugging, causing poorly controlled combustion and higher CO and hydrocarbon emissions. Catalyst overheating and failure, leading to excessive CO, hydrocarbon, and NO_x emissions, also contributed to the problems. The authors stated, "Such emission control failures could affect the emission deterioration rates of methanol-fueled vehicles over time." Despite these limitations, they believed that optimized vehicles could show greater emission benefits. "However," they said, "even assuming emission benefits, methanol (as neat methanol or in FFV use) is not a panacea for the near-term ozone problem affecting many of the nation's cities."

Smith (1985)

Smith (1985) evaluated exhaust emissions from a methanol-fueled Ford Escort for the Coordinating Research Council. Testing was conducted with M90 and M100 fuels in accordance with the FTP. When the cold- and hot-start segments of the FTP test cycle were compared, cold starts resulted in higher exhaust emissions. For vehicles without catalytic converters, methyl nitrite exhaust concentrations were detected when high concentrations of NO_x and methanol were present. Compared with M90, M100 yielded higher hydrocarbon, NO_x, methanol, and formaldehyde emissions and lower CO, formic acid, and methane emissions.

Smuda (1984b)

Smuda (1984b) discussed an EPA study of a 1981 Datsun 200SX with a Nissan NAPZ engine. Formaldehyde emissions were measured for city and highway cycles using the 2,4-dinitrophenylhydrazine method. No attempt was made to measure nonoxygenated hydrocarbons or methanol. Evaporative emissions were not measured.

Stump, Ray, and Braddock (1989)

Stump, Ray, and Braddock (1989) examined exhaust, evaporative, and refueling emissions from a methanol-fueled Ford Escort operated with M85 and M100 fuels. Exhaust and evaporative emissions were examined as a function of sum-

mer and winter ambient temperatures, and refueling emissions were examined at typical summer temperatures. CO, methanol, hydrocarbon, and formaldehyde exhaust emissions increased substantially when the vehicle was operated at low temperatures. Exhaust NO_x emission rates indicated little sensitivity to temperature. Diurnal hydrocarbon evaporative emissions decreased as temperature decreased. Methanol refueling emissions did not vary with changes in either fuel tank temperatures or fuel type.

Williams, Lipari, and Potter (1989)

Williams, Lipari, and Potter (1989) reported emissions data from an experimental 2.5-liter variable-fuel vehicle developed by General Motors Corporation. Methanol, formaldehyde, and hydrocarbon emissions were reported from both exhaust and evaporative emissions tests that used mixtures of methanol and gasoline as fuel. Emissions from current and developmental gasoline cars were reported for comparison.

Williams et al. reported that the largest contributor to total emissions from methanol vehicles (ranging from 50 to 80 percent) was cold-start exhaust emissions. Their data show that formaldehyde emissions increase from 7 milligrams per mile for gasoline to about 40 milligrams per mile for M100. On the other hand, exhaust hydrocarbons were highest with gasoline fuel, and values decreased to less than one-tenth those rates when vehicles were operated on M100. Evaporative emission rates for hydrocarbons were highest when M15 and M50 fuels were used. For M100 fuel, evaporative emission rates for hydrocarbons decreased to near zero.

The emissions from the variable-fuel vehicle and dedicated methanol car had similar compositions—85–90 percent methanol, 5–7 percent formaldehyde, and 3–9 percent hydrocarbons.

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