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Results from the Third Year of Operation of the Federal Methanol Fleet at Argonne National Laboratory

B. H. West
R. N. McGill
S. L. Hillis
J. W. Hodgson

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ORNL/TM-11736

Engineering Technology Division

RESULTS FROM THE THIRD YEAR OF OPERATION OF THE FEDERAL METHANOL FLEET AT ARGONNE NATIONAL LABORATORY

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ABSTRACT

Argonne National Laboratory has completed three full years of operation of 19 vehicles in the Federal Methanol Fleet Project; ten of the vehicles are fueled with M85 (85% methanol, 15% unleaded gasoline). Nearly 675,000 miles have been accumulated on the fleet vehicles so far, and comparisons of energy efficiency continue to show nearly equal performance between the methanol and gasoline vehicles. Emissions tests have revealed evidence of degradation of emission control systems for both the methanol and gasoline vehicles. Methanol vehicles continued to require more maintenance than the gasoline vehicles, and maintenance labor intensity (hours per 1000 miles) increased for all the vehicle types being monitored. Metal accumulation rates in lubricating oil of the methanol vehicles continued to be elevated compared to that of the gasoline vehicles. Driver satisfaction in the third year appeared to be about the same as the second year, with the gasoline vehicles generally being rated slightly higher than the methanol vehicles.

PREFACE

This report is one in a series of yearly reports on the results from the Federal Methanol Fleet project. Each report details the annual results from one of the three fleets participating in the project and, thus, represents only part of the entire story. Readers are directed to the other reports in the series in order to benefit from the entire context of the project rather than to risk the possibility of misreading limited results from only one report.

A brief review some of the philosophies and practices implemented in this project are presented below in order to further reduce the possibilities of data being taken out of context.

- This project resulted from a congressional appropriation in Fiscal Year 1985 and the associated mandate to begin to place methanol-fueled vehicles in government fleets and assess their performance. Funds for these purposes have totalled $2.2 million through Fiscal Year 1990.

- It was decided to use the best available "proven" technology for converting vehicles to methanol since it was impossible to obtain methanol vehicles from original equipment manufacturers. The intent was to acquire methanol converted vehicles from as many "proven" aftermarket companies as funds would permit. ("Proven" here means that the aftermarket company possessed a demonstrated record of successful conversions of gasoline vehicles to methanol.)

- It was decided to operate the methanol vehicles in all cases alongside comparable gasoline vehicles for statistical comparisons. This entailed the acquisition of the gasoline vehicles also.

- While it was desirable to achieve the lowest possible emissions with the converted methanol vehicles, it was recognized that this would be an expensive proposition because rigorous engineering and development would be necessary in order to accomplish this goal. Because of this, the methanol vehicles are not optimized for lowest emissions. Instead, the philosophy was to acquire the vehicles, measure their emissions, and track their performance over time. The important comparison would be how emissions change over time, not how they would compare to the lowest attainable. Emissions measured immediately after methanol conversions would serve as the baseline for comparison.

- All of the vehicles in the project were to be used in routine fleet service within the organizations to which they were to be assigned. This limited the extent to which very specialized tests or driving cycles could be utilized. On the other hand, the vehicles would experience a "real-world" environment, and it is within that context that they have been evaluated.

RESULTS FROM THE THIRD YEAR OF OPERATION OF THE FEDERAL METHANOL FLEET AT ARGONNE NATIONAL LABORATORY

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1. SUMMARY

The Federal Methanol Fleet operating at Argonne National Laboratory (ANL) has completed three years of operation with ten M85 (85% methanol, 15% unleaded gasoline) fueled vehicles and nine gasoline counterpart vehicles. The vehicles are all 1986 models; ten are Chevrolet S10 pickup trucks, and nine are Ford Crown Victorias. Over 170,000 miles were accumulated on the nineteen vehicles during the year bringing the three-year total to nearly 675,000 miles. Overall fuel economy and energy efficiency for the vehicles were very similar to previous years, with the energy efficiency of the methanol vehicles being equal to that of the gasoline vehicles of the same type.

Vehicles previously tested for emissions (one gasoline and two methanol Fords, and one gasoline and two methanol Chevrolets) were retested at the end of the third year to determine how the emissions control systems may have changed with use and age. Emissions from both gasoline vehicles, and both methanol Chevrolets, increased from last year for all but the oxides of nitrogen from the gasoline Ford and one methanol Chevrolet. Emissions from one of the methanol Fords stayed the same or decreased from last year, while those from the other Ford increased.

Maintenance data reveals that the frequency of maintenance (occasions of maintenance per 1000 miles) has been increasing only slightly for all three years. The methanol vehicles continue to require more visits to the shop than the gasoline vehicles, but not all of the extra visits are fuel related. Maintenance labor intensity (hours per 1000 miles) has increased at greater rates than the frequency, and methanol vehicles require more time in the shop than the gasoline cars. Again, fuel related maintenance cannot account for the differential between the gasoline and methanol vehicles.

Oil sample analyses have shown that accumulation rates of iron and lead in the methanol vehicles' engine oil remain elevated relative to the gasoline vehicles. Higher levels of lead in the Chevrolets may have been aggravated by the release of lead from plating in the fuel tanks. While a few individual samples have had some unusually high iron content, the overall rates of accumulation of metals in the oil are typical of methanol vehicles.

Drivers of Federal Methanol Fleet vehicles fill out a trip log in which they rate the vehicles' performance. The percentage of "Good" responses for "Ease of Starting," and "Driveability" did not change much from last year for all vehicle types, except in the case of the methanol Chevrolets, where some decline was evident in the "Driveability" ratings. In general, the gasoline vehicles maintain a slight advantage over the methanol vehicles.

2. INTRODUCTION

Argonne National Laboratory (ANL) has operated nineteen vehicles for over three years for the Department of Energy's Federal Methanol Fleet Project; ten of the vehicles are methanol-powered and nine are comparable gasoline vehicles. The Oak Ridge National Laboratory (ORNL) has project management responsibility for the entire Methanol Fleet Project including activities at ANL and, as such, collects and disseminates data and information related to the operation of the project. Because much of the project's background and the ANL fleet has been described in previous reports,[1-10*] it will not be discussed again at any length in this report; the reader is encouraged to refer to the earlier reports for those details. This report will deal primarily with the results and data from the third year of operation and the comparison of those data with the similar results from previous years.[1,2]

Vehicles in the project at ANL include ten 1986 Chevrolet S-10 pickup trucks (5 methanol and 5 gasoline) and nine 1986 Ford Crown Victoria Sedans (5 methanol and 4 gasoline). Methanol conversions were made by Alcohol Energy Systems, Inc. and include special provisions for cold-starting in the Illinois climate where ANL is located. On the Chevrolets, a separate gasoline fuel system is automatically engaged during cold weather to start the engine and provide about 30 seconds of running before automatically switching to the methanol fuel system. The Fords had incorporated a proprietary system developed by Ford which used only the methanol fuel mixture. Problems with this system were encountered this year, however, and the systems were disconnected in the late spring of 1989.

The methanol fuel mixture at ANL is nominally M85 (85% methanol and 15% regular unleaded gasoline), and the gasoline portion is tailored to the extent possible throughout the year to try to maintain favorable vapor pressure for cold-starting. An underground tank and associated dispensing pump are used on-site at ANL for dispensing fuel into the methanol vehicles. This is the only place that they can be refueled.

The Fords are used by the security department at ANL and are outfitted as police cars. They are used around the clock every day of the week, and typical driving patterns include considerable engine idling time and short trips. Their use is confined, for the most

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*Superscripted numbers denote references at the end of the report.

part, to the ANL site. The Chevrolet trucks are used by ANL maintenance personnel for transportation around the site to various job locations. They are used typically only during one shift per day and are also generally confined to the ANL site, which has a total of eleven miles of roads.

A small amount of data including the drivers' ratings of the vehicles' ease of starting and driveability is recorded for each trip. Fueling and maintenance data are kept by the motor pool personnel. The lubricating oil is sampled in each vehicle on a nominal 1000 mile interval and sent to a laboratory where it is analyzed for wear metal content, fuel dilution, base number, etc. All data from the methanol fleet project at ANL are forwarded to the ORNL project management office where the Federal Methanol Fleet database is maintained.

3. RESULTS

3.1 FLEET UTILIZATION AND FUEL CONSUMPTION

Tables 1, 2, and 3 summarize the fleet utilization (mileage accumulation) and fuel consumption results for the Chevrolet S-10 pickup trucks. Table 1 shows, for the third year of operation, figures for total miles driven, average miles per trip, and fuel economy (on both volume and energy bases) for individual vehicles as well as aggregate totals for each fuel type. Table 2 gives the same information for the entire three years of operation, and Table 3 summarizes the aggregate totals for each individual year as well as all three years. Tables 4,

Table 1. Fleet utilization data
Third Year — January 1, 1989 to December 31, 1989

Chevrolet S-10 Pickup Trucks

Vehicle ID	Total miles	Average miles/trip	Fuel Economy mpg	Fuel Economy km/GJ[a]
		Methanol vehicles		
ME-560	3,827	15	9.8	228
ME-562	5,450	17	10.5	245
ME-564	7,899	32	9.2	215
ME-566	3,396	16	7.1	166
ME-568	11,437	13	8.8	205
TOTAL	32,009	17[b]	9.0[b]	211[b]
		Gasoline vehicles		
ME-561	4,286	6	18.2	241
ME-563	7,717	29	17.0	225
ME-565	4,096	12	15.6	206
ME-567	12,367	16	16.7	221
ME-569	6,720	27	14.7	194
TOTAL	35,186	15[b]	16.4[b]	216[b]

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

Table 2. Fleet utilization data
Three Years — Through December 31, 1989

Chevrolet S-10 Pickup Trucks

Vehicle ID	Total miles	Average miles/trip	Fuel Economy mpg	Fuel Economy km/GJ[a]
Methanol vehicles				
ME-560	24,190	16	9.6	225
ME-562	16,340	19	9.5	222
ME-564	21,685	29	9.5	221
ME-566	15,726	23	8.0	187
ME-568	27,653	12	9.3	216
TOTAL	105,594	17[b]	9.2[b]	215[b]
Gasoline vehicles				
ME-561	22,667	9	17.3	229
ME-563	24,781	30	17.1	227
ME-565	26,834	18	17.0	225
ME-567	20,912	14	16.3	216
ME-569	22,362	25	15.8	209
TOTAL	117,556	16[b]	16.7[b]	221[b]

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

5, and 6 show similar information for the Ford Crown Victorias. Note that the aggregate totals for the gasoline Fords are for four vehicles, not five.

Over 170,000 miles were accumulated on the nineteen fleet vehicles during the third year, with the Fords accounting for more than 60 percent of the total. Over the three years, nearly 675,000 miles have been accumulated. Average trip length for all four car types was

Table 3. Fleet utilization data
Summary of Three Years

Chevrolet S-10 Pickup Trucks

	Total miles	Average miles/trip[b]	Fuel Economy mpg[b]	Fuel Economy km/GJ[a,b]
	Methanol vehicles			
1st yr	43,035	16	9.6	224
2nd yr	30,550	19	9.0	211
3rd yr	32,009	17	9.0	211
All 3 yrs	105,594	17	9.2	215
	Gasoline vehicles			
1st yr	46,426	16	16.9	219
2nd yr	35,944	18	17.2	227
3rd yr	35,186	15	16.4	216
All 3 yrs	117,556	16	16.7	221

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

about the same as last year, although the Fords' trip lengths were longer last year than the first year. It is not likely that the Fords' service changed drastically from the first to the second year, as the fuel economy has held relatively constant, so the change in average trip length is probably due to drivers filling out the trip log less frequently. The Chevrolets have also shown little change in fuel economy and energy efficiency over the three years.

Table 4. Fleet utilization data
Third Year — January 1, 1989 to December 31, 1989

Ford Crown Victorias

Vehicle ID	Total miles	Average miles/trip	Fuel Economy mpg	Fuel Economy km/GJ[a]
Methanol vehicles				
ME-570	14,756	32	6.3	146
ME-572	11,309	24	6.2	144
ME-574	14,115	30	6.2	144
ME-576	9,432	27	6.1	142
ME-578	13,422	28	5.9	137
TOTAL	63,034	28[b]	6.1[b]	143[b]
Gasoline vehicles				
ME-571	12,681	31	10.1	134
ME-573	8,303	29	9.9	131
ME-575	14,625	28	10.6	140
ME-579	7,125	39	11.5	152
TOTAL	42,734	30[b]	10.4[b]	138[b]

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

Table 5. Fleet utilization data
Three Years — Through December 31, 1989

Ford Crown Victorias

Vehicle ID	Total miles	Average miles/trip	Fuel Economy mpg	Fuel Economy km/GJ[a]
Methanol vehicles				
ME-570	46,693	18	6.4	150
ME-572	53,886	15	6.3	146
ME-574	51,078	17	6.3	146
ME-576	38,630	16	5.9	139
ME-578	46,051	17	5.8	136
TOTAL	236,338	17[b]	6.2[b]	144[b]
Gasoline vehicles				
ME-571	47,611	15	10.2	135
ME-573	61,277	14	10.3	137
ME-575	46,526	14	10.3	137
ME-577	59,090	16	11.0	145
TOTAL	214,504	15[b]	10.5[b]	138[b]

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

Table 6. Fleet utilization data
Summary of Three Years

Ford Crown Victorias

	Total miles	Average miles/trip[b]	Fuel Economy mpg[b]	Fuel Economy km/GJ[a,b]
		Methanol vehicles		
1st yr	97,389	11	6.2	145
2nd yr	75,915	28	6.2	145
3rd yr	63,034	28	6.1	143
All 3 yrs	236,338	17	6.2	144
		Gasoline vehicles		
1st yr	114,496	11	10.5	139
2nd yr	57,274	25	10.5	139
3rd yr	42,734	30	10.4	138
All 3 yrs	214,504	15	10.5	138

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal: hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

3.2 EMISSIONS TESTS

All of the vehicles at ANL were tested for emissions on gasoline prior to conversion to methanol, and on methanol fuel immediately after conversion. Results of the initial tests (round 1) on all ten methanol vehicles can be found tabulated in a previous report.[1] Six of the vehicles (one gasoline and two methanol Chevrolets, and one gasoline and two methanol Fords) were retested during the second year and again this year to see how emissions may have changed with use and age. Results from the most recent testing (round 3) are compared with the other emissions tests (rounds 1 and 2) in this section.

3.2.1 Introduction

The most recent emissions tests were conducted by the Amoco Research Laboratories in Naperville, Illinois. Unlike the previous tests on the vehicles, the latest round of testing

included direct determinations of both methanol and aldehydes in the exhaust. Also, duplicate tests were performed on one of each of the methanol vehicles to test for repeatability (designated as rounds 3A and 3B).

Knowing the methanol and formaldehyde levels in the exhaust makes it possible to interpret more precisely the output from the hydrocarbon analyzer. Since the typical flame ionization detector, FID, used for hydrocarbon determinations responds only partially to methanol in the exhaust and has no sensitivity to formaldehyde, its response to the exhaust from a methanol vehicle is subject to some interpretation. This has led to the development of several different protocols for dealing with the FID output and to the use of various terminologies for reporting the results. Unfortunately, there does not seem to be a consensus regarding terminology and the same term is sometimes used for different computed results. In particular, there are at least three different quantities that are referred to as "total hydrocarbons" or "hydrocarbons" by different laboratories. The following terminology is used in this report:

> **Non-oxygenated Hydrocarbons (NOHC):** Hydrocarbons in the exhaust that do not contain oxygen.* This is the same as "HC" used by the E.P.A. in the published procedures[11] for computing emissions from methanol-fueled vehicles and is assumed to be $CH_{1.85}$. This has also been termed "total hydrocarbons" (THC) by some.
>
> **Organic Material Hydrocarbon Equivalent (OMHCE):** This EPA-defined quantity takes the NOHC, methanol (MeOH), and formaldehyde (HCOH) in the exhaust and lumps them together to give the mass of $CH_{1.85}$ that would contain the same total mass of carbon present in the three substances considered. For gasoline-fueled vehicles which produce very little methanol and formaldehyde, the OMHCE and the NOHC are virtually the same and are the "hydrocarbons" or "unburned hydrocarbons" reported from emission tests. The EPA standards for production methanol-fueled vehicles[11] will require the OMHCE to be no more than 0.41 grams per mile when the vehicle is tested over the FTP (Federal Test Procedure) driving cycle. In order to compute the OMHCE one must have values for the NOHC, MeOH, and HCOH.

It is, however, common for emissions testing facilities to take the FID output and use it directly (with no corrections for methanol response) to report a value for hydrocarbons which is often referred to as "hydrocarbons" or "total hydrocarbons". This approach was used

---

*It is acknowledged that the term "non-oxygenated hydrocarbons" may, to some, be redundant. Unfortunately, the use of the term "hydrocarbons" is sometimes meant to (erroneously) include oxygenated hydrocarbons (such as methanol) — thus the adoption of the redundancy for emphasis.

by the Amoco Research Laboratory in reporting the values for the latest round (round 3) of testing.

In this report, round 3 emissions test results will be compared to previous results. While round 3 results included laboratory determinations of methanol, aldehydes, and NOHC, the results from rounds 1 and 2 did not, so the "ORNL Protocol"[9] was developed so that the OMHCE could be estimated. Basically, this protocol assumes that the relative mole fractions of methanol and NOHC in the exhaust are the same as the relative mole fractions of methanol and gasoline in the M85 fuel. It then uses the FID methanol response factor to compute values for the methanol and NOHC concentrations in the exhaust. The results are then used to calculate OMHCE. It is important to note that the protocol has no effect on the reported values of CO and NO_x. The ORNL Protocol has been used in calculating the OMHCE used in generating figures in which rounds 1, 2, and 3 are compared. Appendix A also compares the accuracy of the ORNL Protocol to the EPA Protocol, which uses the laboratory determinations of methanol and aldehydes.

3.2.2 Emissions Tests Results

Since there is no ambiguity regarding the hydrocarbon emission results when gasoline is the vehicle fuel, comparisons among the three rounds of testing involving the gasoline-fueled vehicles are straight-forward. The figures and tables presented herein will refer only to OMHCE for consistency, however, as stated above, this is the same as "HC" (hydrocarbons) for the gasoline vehicles.

The OMHCE emissions of the Chevrolets are shown in Fig. 1. Note that the OMHCE emissions of the gasoline vehicle (565) increased slightly in round 2 and nearly doubled in round 3. The OMHCE emissions of the methanol vehicles (562 and 568) also increased in round 2, but decreased in round 3.

The Chevrolets' CO (carbon monoxide) emissions, shown in Fig. 2, follow trends similar to the OMHCE emissions in Fig. 1, with the gasoline vehicle's emissions increasing each round, and the methanol vehicles' emissions increasing in round 2 and decreasing in round 3.

The Chevrolets' emissions of NO_x (oxides of nitrogen, NO and NO_2) are presented in Fig. 3. The gasoline Chevrolet's NO_x emissions nearly doubled in round 2 but stabilized at a level near that of methanol vehicle 562. Methanol vehicle 568 shows increases in NO_x emissions each year, doubling in round 2, and increasing only slightly in round 3.

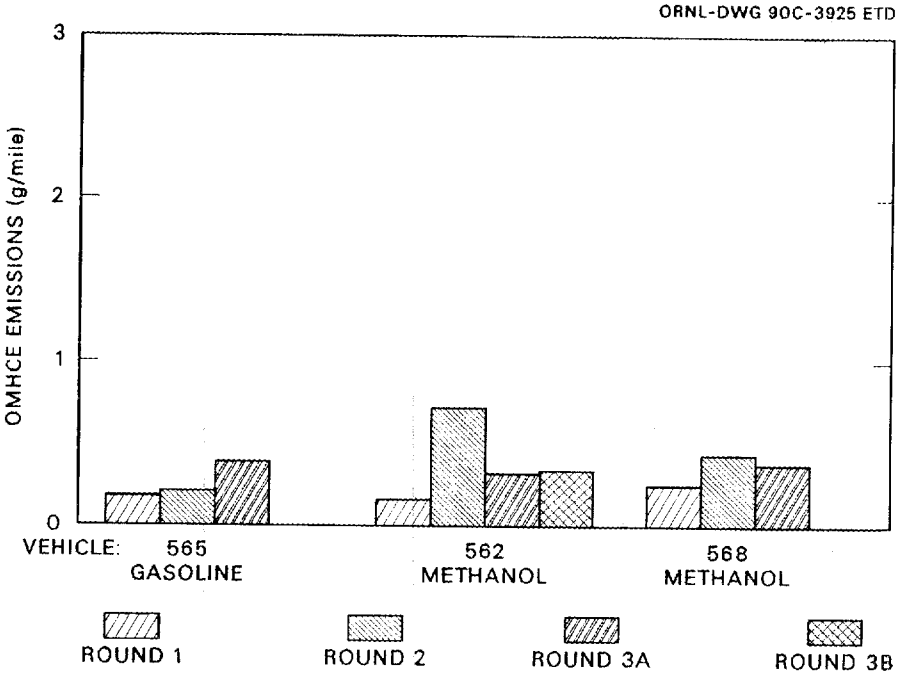

Fig. 1. OMHCE emissions from the Federal Test Procedure for Chevrolet S10 Pickup Trucks.

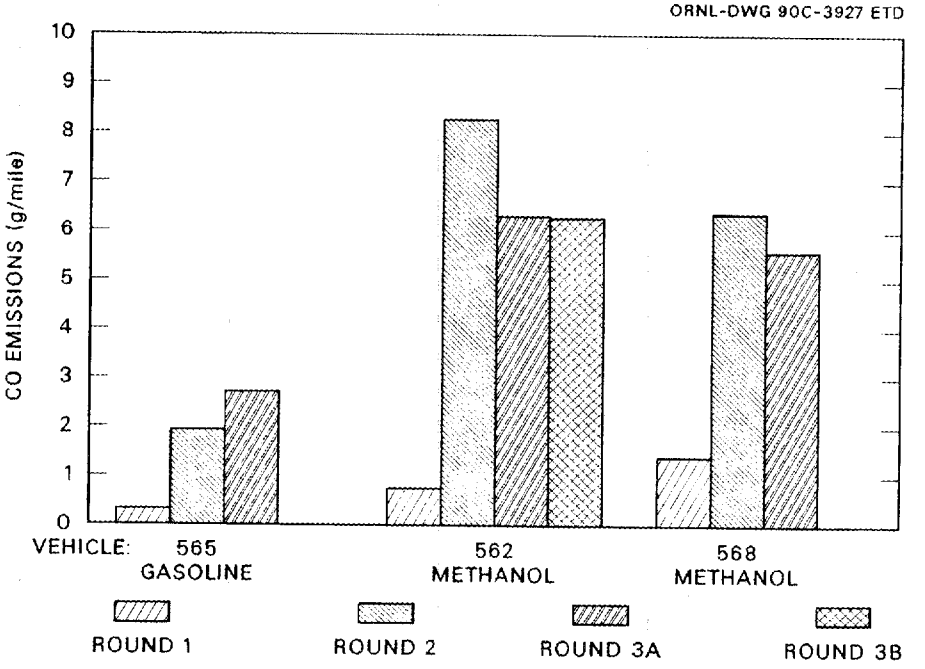

Fig. 2. CO emissions from the Federal Test Procedure for Chevrolet S10 Pickup Trucks.

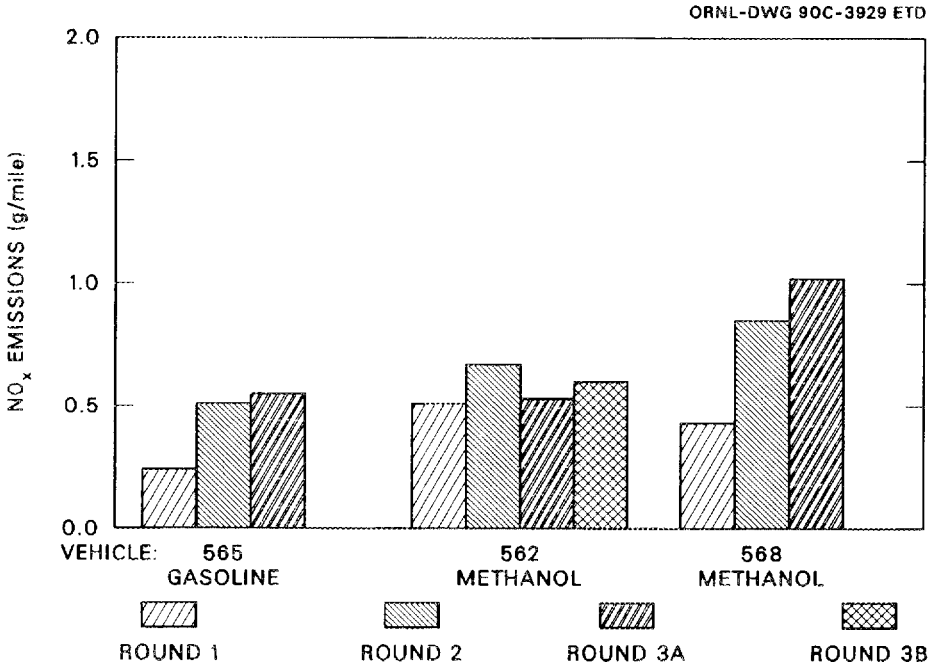

Fig. 3. NO_x emissions from the Federal Test Procedure for Chevrolet S10 Pickup Trucks.

The emissions data for the Fords are shown in Figs. 4-6. Note in Fig. 4 that the gasoline Ford (575) had higher OMHCE emissions each year, as did methanol Ford 574, while the other methanol Ford (572) increased only in round 2 testing. The Fords' CO emissions in Fig. 5 mimic their OMHCE emissions, as did the Chevrolets.

The NO_x emissions of the gasoline Ford increased substantially from the first to the second round, but decreased in the third to a median value, as shown in Fig. 6. Methanol vehicle 572's NO_x emissions were highest in round 2, while vehicle 574's increased steadily each year.

The third round of testing showed an increase in CO for both of the gasoline vehicles and, correspondingly, an increase in the OMHCE. The reason for the increased CO is not known. The NO_x for gasoline vehicle 575 showed a decrease which could, in part, be attributable to a possible fuel enrichment reflected by the higher CO values, although the same thing cannot be said for gasoline vehicle 565 which showed an <u>increase</u> in NO_x with an increase in CO.

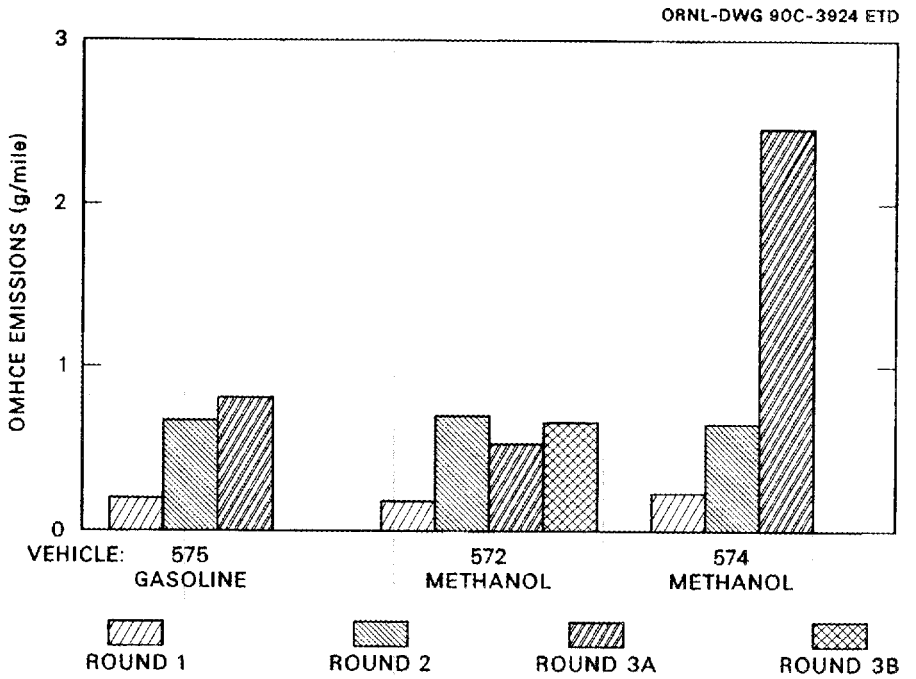

Fig. 4. OMHCE emissions from the Federal Test Procedure for Ford Crown Victorias.

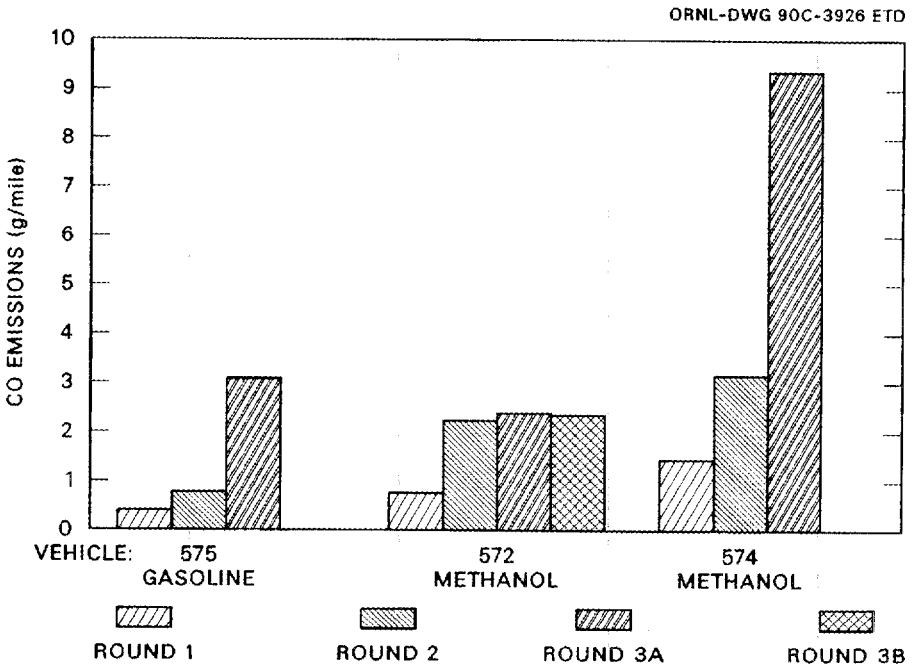

Fig. 5. CO emissions from the Federal Test Procedure for Ford Crown Victorias.

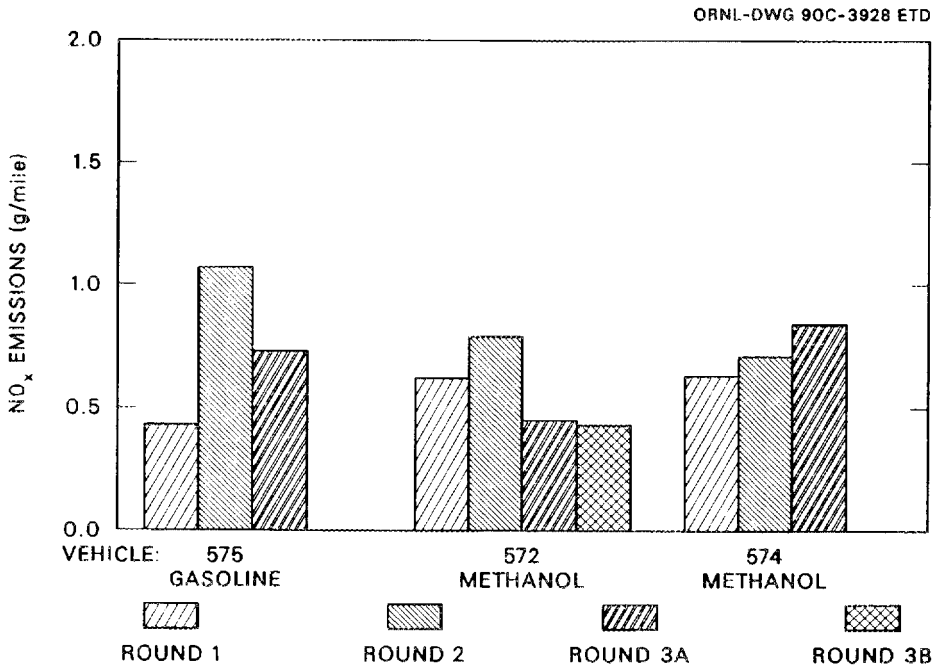

Fig. 6. NO_x emissions from the Federal Test Procedure for Ford Crown Victorias.

3.2.3 Results with Swapped Catalysts

Shortly after round 3 emissions testing, one methanol Ford (vehicle 572) was returned to the testing labs for a "catalyst swap." One of Amoco's gasoline powered (1987) Ford Crown Victorias was tested first with its own catalyst, and then with the catalyst from methanol vehicle 572. Vehicle 572 was likewise tested with the gasoline vehicle's catalyst. Results of the swapped catalyst emissions tests are shown in Table 7. Note that the methanol vehicle's OMHCE emissions were more than cut in half, and the CO emissions reduced to about one-third by the gasoline vehicle's catalyst. The formaldehyde emissions were also greatly reduced, from around 300 mg/mile to 60 mg/mile. The formaldehyde emissions of the gasoline Ford were unaffected by the catalyst swap, although the OMHCE emissions more than doubled, and the CO emissions more than tripled. NO_x emissions on both vehicles were only slightly affected, being about 10 percent higher on either vehicle with the methanol vehicle's catalyst.

The data from the catalyst swap suggest that the methanol vehicle may have degraded its catalyst at a higher rate than the gasoline vehicle (although the methanol vehicle had 32%

Table 7. Emissions tests results with swapped catalysts

Vehicle I.D.	ODOMETER (miles)	OMHCE	CO	NO_x	HCOH
		(grams/mile)			
	Ford Crown Victorias				
Methanol vehicle, orginal catalyst (repeated from Table A.1)					
572	53,300	0.63	2.39	0.45	0.312
	53,300	0.66	2.35	0.43	0.299
Methanol vehicle, gasoline catalyst					
572	58,400	0.27	0.76	0.37	0.060
Gasoline vehicle, original catalyst					
Amoco vehicle	40,200	0.40	1.34	0.89	0.021
	40,200	0.38	1.39	0.90	0.022
Gasoline vehicle, methanol catalyst					
Amoco vehicle	40,800	0.91	4.12	0.97	0.021

more miles on it at its initial round 3 test). Catalytic converters common in today's vehicles have been developed for gasoline engines, and it is well known that they can be "poisoned" by metals such as lead. While the gasoline portion of the M85 used at ANL is lead-free, there is a possibility that metals such as zinc and phosphorous from engine oil additives may have "poisoned" the catalyst. Whether the fuel itself is guilty of accelerating catalyst degradation on methanol vehicles is not known. Perhaps OEMs are presently developing different catalyst materials for methanol vehicles. In the near future, efforts will be made to analyze some of the apparently failed catalysts from Federal Methanol Fleet Vehicles to determine cause(s) of failure.

For further discussion of emissions test results, the reader is encouraged to refer to Appendix A. Tabulated data from which Figs. 1-6 were produced are provided, as well as discussion of formaldehyde emissions, possible reasons for high CO levels, and an evaluation of the ORNL protocol.

3.3 COMPARISON OF MAINTENANCE AND SERVICE - METHANOL AND GASOLINE VEHICLES

Stacked bar graphs comparing maintenance of the methanol and gasoline vehicles are presented which show the vehicles' maintenance frequency (occasions of maintenance per 1000 miles) and intensity (labor hours per 1000 miles). The sum of "Fuel Related" maintenance and "All Other" maintenance includes all occasions for which a service work order was written, and thus includes occasions of routine maintenance such as oil changes and tire maintenance in addition to occasions of unusual maintenance, i.e. those occasions that are prompted by complaints or malfunctions. The occasions that have been designated as "Fuel Related" are those which have been identified as being intimately related to and/or caused by the nature of the fuel and/or fuel delivery systems. These designations are used only in an attempt to determine how much of the total difference in maintenance between methanol and gasoline vehicles can be traced to the methanol fuel or its systems.

Frequency of maintenance for the gasoline Chevrolets (Fig. 7) and Fords (Fig. 8) has been relatively stable for three years, while that for the methanol vehicles has increased slightly each year. The maintenance intensity for the gasoline Chevrolets has also increased only slightly over the three years, while it has more than tripled for the methanol pickups, with a steady increase in fuel related maintenance hours. The maintenance intensity for the Fords has grown steadily each year for both the gasoline and methanol vehicles. In all cases, the "Fuel Related" maintenance does not account for the greater frequency or intensity of maintenance for the methanol cars.

This suggests that perhaps drivers are more sensitive to mechanical problems in the methanol vehicles, and request maintenance on occasions that they might overlook in a gasoline vehicle.

3.4 OIL SAMPLE ANALYSES

Samples of the lubricating oil are drawn from the crankcases of the nineteen vehicles at approximately 1000 mile intervals. (Oil change interval is every 3000 miles for all of the vehicles.) The oil samples are analyzed for total base number, kinematic viscosity, and concentrations of iron, lead, copper, aluminum, chromium, sodium, and silicon. Generally, a fleet operator uses information from oil sample analyses as a diagnostic tool for implementing necessary preventive or corrective maintenance. In this project, however, the

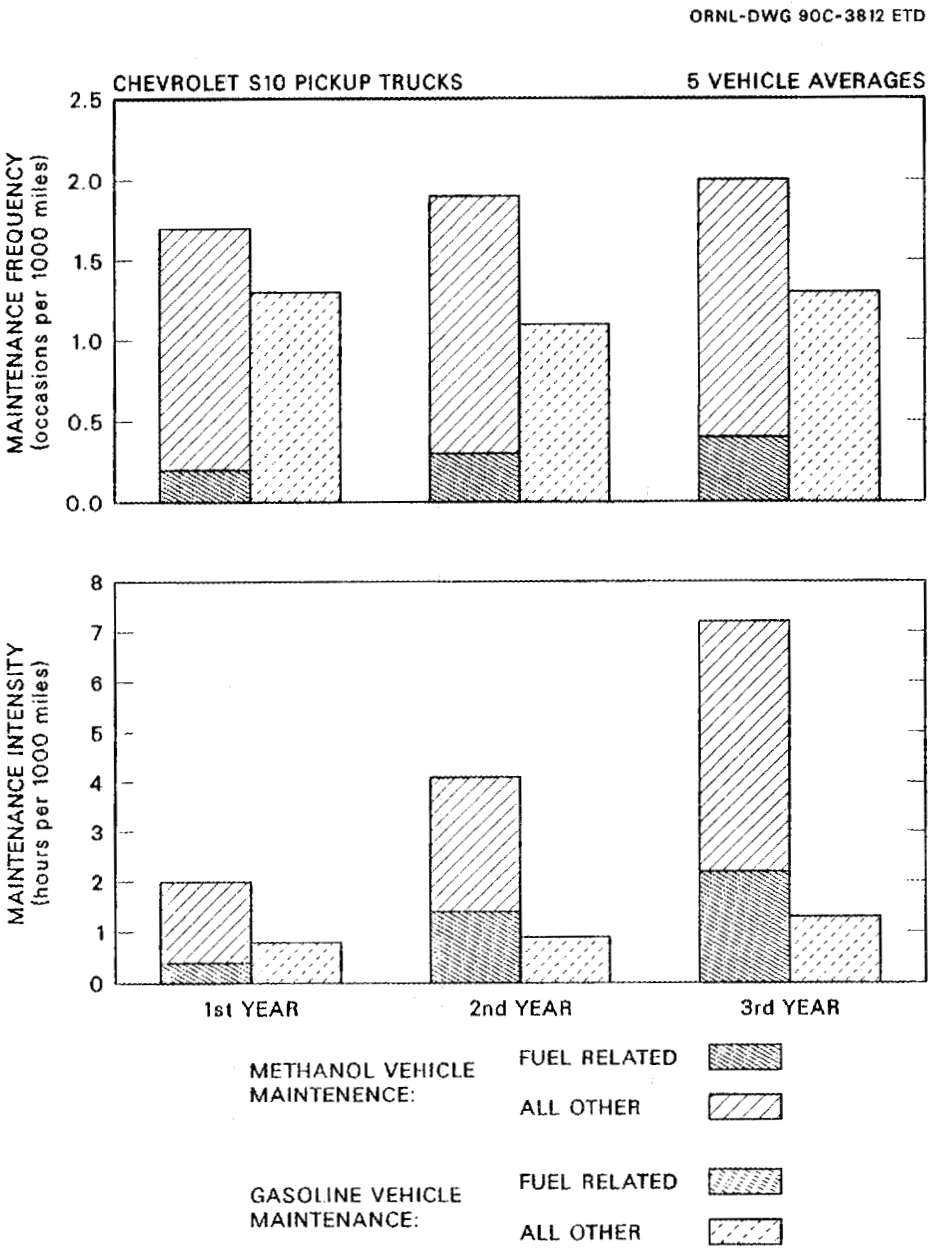

Fig. 7. Maintenance frequency and intensity for Chevrolet S10 Pickup Trucks.

information is not generally used to intervene in the natural processes that are progressing in the engines under study.

Lubricating oil for the methanol vehicles has been supplied by the Lubrizol Corporation and is a 10W-30 multi-grade oil with a proprietary additive developed by Lubrizol which is intended to reduce engine wear and corrosion that may be caused by the methanol fuel.

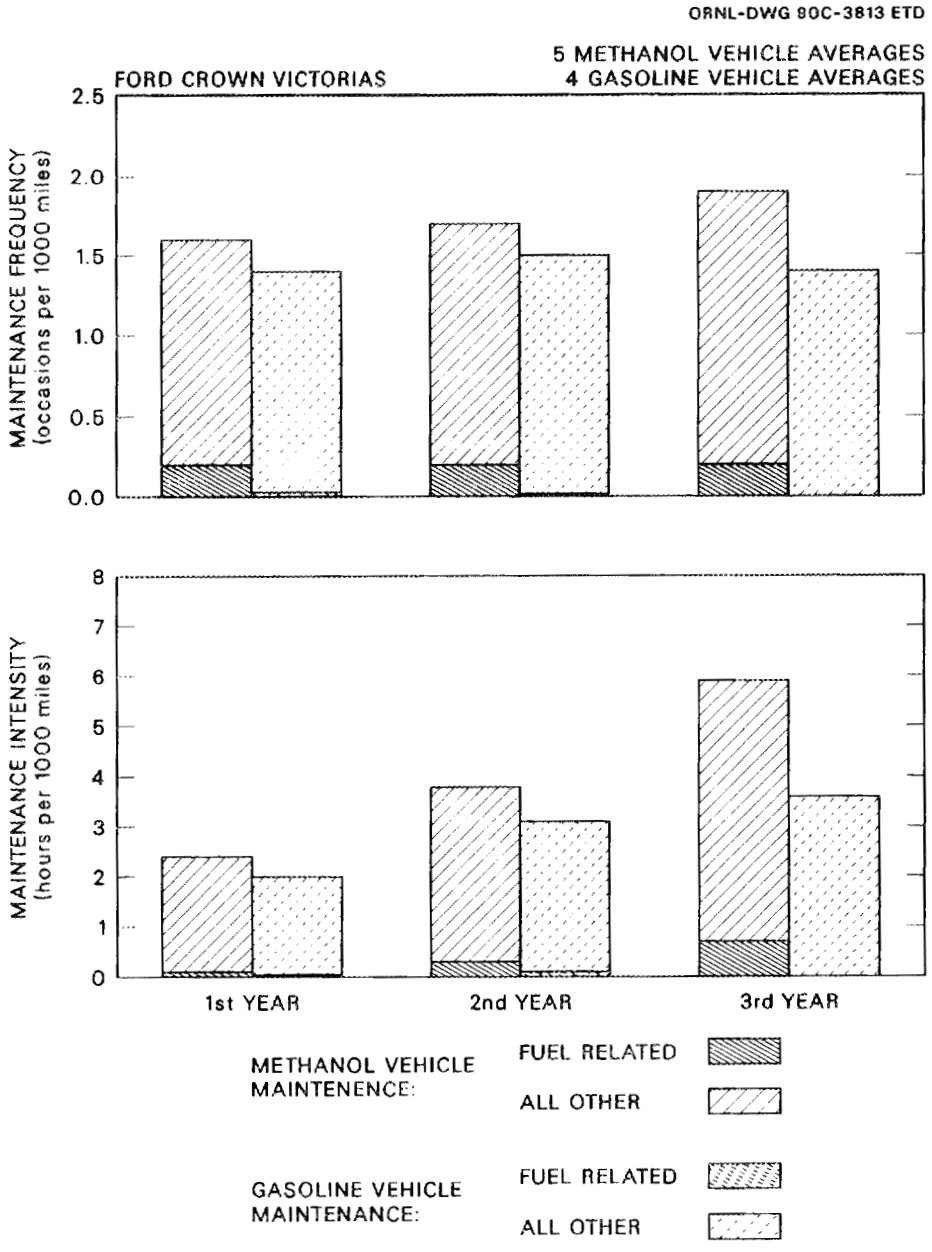

Fig. 8. Maintenance frequency and intensity for Ford Crown Victorias.

The gasoline vehicles use standard 10W-30 multi-grade lubricating oil approved by the manufacturers for regular use in their vehicles and stocked routinely by ANL.

No significant abnormal trends have been observed in either the total base number or the kinematic viscosity of the oil of any of the cars for the period of this project. For the ANL vehicles, chromium and sodium do not accumulate in the lubricating oil in any amounts

that would warrant further attention here. Iron is usually the largest contributor to lubricating oil contamination in both methanol vehicles and gasoline vehicles.

Results are presented in Tables 8 and 9 for accumulation rates of metals (iron, lead, and copper) in the lubricating oil for each of the three years for each vehicle type. Accumulation rates are found by (1) fitting linear regressions (least squares curve-fits) to data of wear metals concentration as a function of distance since oil change, and (2) determining the slopes (accumulation rates) of the regressions. For the methanol Chevrolets, shown in Table 8, the accumulation rate of iron and lead increased in the second year, and decreased in the third. The increase in lead may have been caused by some degradation of the fuel tanks. These vehicles were supplied with fuel tanks that had an epoxy coating over the original terneplate

Table 8. Wear metals accumulation rates

Chevrolet S-10 Pickup Trucks

Wear Metal	ppm per 1000 miles					
	Methanol Vehicles			Gasoline Vehicles		
	First year	Second year	Third year	First year	Second year	Third year
Iron	42	97	67	32	19	18
Lead	64	136	102	17	23	6
Copper	4	5	2	5	7	5

Table 9. Wear metals accumulation rates

Ford Crown Victorias

Wear Metal	ppm per 1000 miles					
	Methanol Vehicles			Gasoline Vehicles		
	First year	Second year	Third year	First year	Second year	Third year
Iron	67	73	41	10	17	40
Lead	10	9	5	13	10	7
Copper	3	3	3	7	6	5

(which contains lead), and the epoxy was thought to be resistant to methanol. However, evidence of deterioration of the epoxy coating appeared during the second year. This would leave the terneplate exposed to attack by the methanol and would probably release quantities of lead into the fuel, then into the engine, and ultimately into the crankcase oil. The increase in iron accumulation rate may also be related to epoxy degradation if enough plating has been removed from the inside tank surfaces to reveal the steel surface. If the increased iron is not from the fuel tanks, it most likely is from cylinder walls and/or piston rings. One fuel tank was replaced during the second year, and four tanks were replaced in the third year with replacements supplied by General Motors. One of the vehicles has had its tank changed twice, and one vehicle still has its original tank (from the initial conversion).

The methanol Fords exhibited a slight increase in accumulation rate of iron in the second year, and a decrease in the third as shown in Table 9. The accumulation rate of iron in the gasoline Fords doubled from last year, matching that of the methanol Fords. Rates of accumulation of lead and copper in the Fords have been nominal for all three years.

Tables 8 and 9 use an entire year of data for the linear regressions. Similar regressions were also performed on data from each season to investigate any weather-related trends that might exist. The results for the Chevrolets are shown in Figs. 9 and 10 for iron and lead accumulation rates, respectively; and Fig. 11 shows the iron accumulation rates in the Fords. Note that the metal accumulation rates fluctuate seasonally, with the iron rate in the methanol Chevrolets being highest in the winters of the first and second years and the spring of the second year. The gasoline Chevrolets exhibited higher than average iron accumulation rates in the spring and summer of the first year, and in the winter of the third year. The lead accumulation rates in the methanol Chevrolets were highest in the winters of the first and second years, and the spring of the third, while that of the gasoline vehicles was unusually high only in the spring of the third year.

The methanol Fords exhibited high iron accumulation rates in the winter of the first year, and the summer of the third. The gasoline Fords showed largely nominal accumulation rates of iron except for increases in the winter of the second year and spring of the third.

Reasons for these fluctuations are not entirely clear, although cold weather is believed to play a role in accelerated engine wear, especially when coupled with short trip driving. Hot weather can also accelerate engine wear when combined with high load service.[12,13] This may

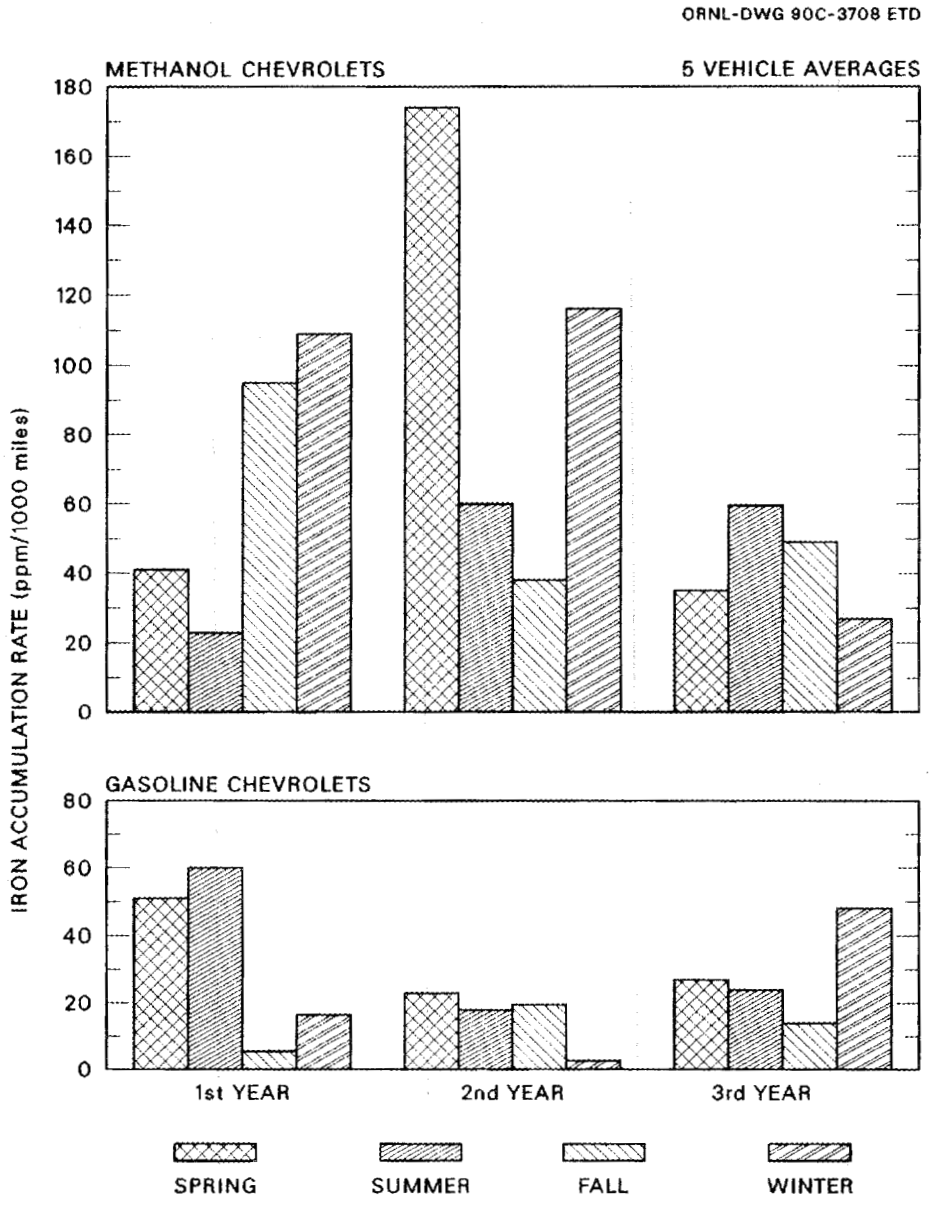

Fig. 9. Iron accumulation rate as a function of season for Chevrolet S10 Pickup Trucks.

partially account for some of the high iron and lead accumulation rates evident in Figs. 9, 10, and 11.

Note that the linear regressions performed for each individual season used as few as 4 (only one case) and as many as 41 data points (the average numbers were 12 for the Chevrolets, and 22 for the Fords). The reader should also note that the possibility certainly

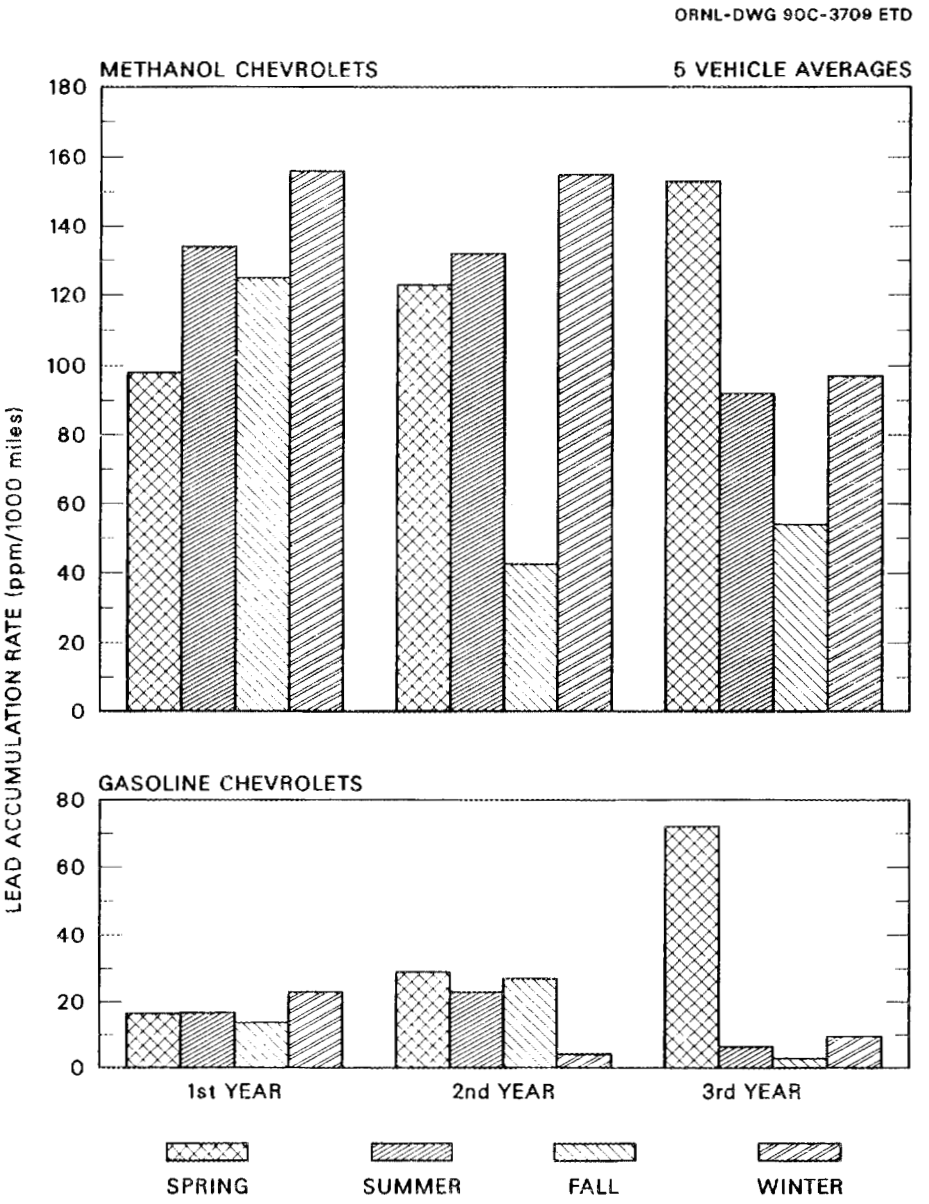

Fig. 10. Lead accumulation rate as a function of season for Chevrolet S10 Pickup Trucks.

exists that oil samples can be drawn (and analyzed) during a season subsequent to the season in which the metal accumulation actually occurred. Also, driving style can contribute to or nullify the effects of weather on engine wear. Hence, the seasonal metals accumulation data represent trends and serve only to suggest that engine wear is affected by ambient temperature.

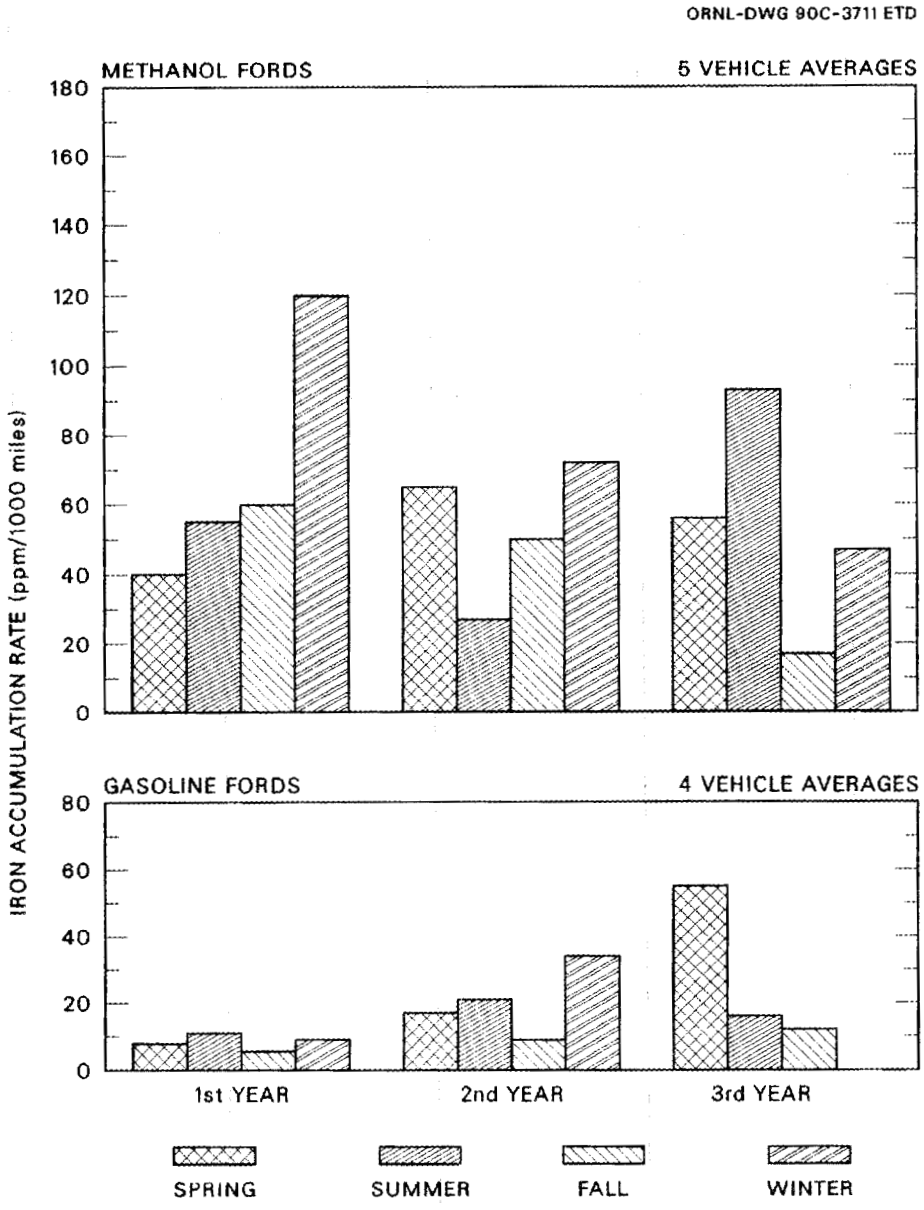

Fig. 11. Iron accumulation rate as a function of season for Ford Crown Victorias.

3.5 DRIVERS' PERCEPTIONS OF VEHICLE PERFORMANCE

3.5.1 Drivers' Ratings of Vehicle Performance — Daily Trip Logs

Drivers at ANL evaluate the vehicle's ease of starting and driveability at the end of each trip by making a check mark under either "Good", "Average", or "Poor" on the trip log

for both "Ease of Starting" and "Driveability". This simple process yields a profile of the drivers' general impressions of the cars' performance and how their impression may change over time.

In the third year 4335 trips were recorded in the Chevrolets (1928 methanol and 2407 gasoline) and 3633 trips in the Fords (2226 methanol and 1407 gasoline). For the three years, this brings the totals to 13,637 recorded trips in the Chevrolets and 28,695 for the Fords.

Results of drivers' ratings during the three years are shown in Figs. 12-15, and are tabulated in Appendix B. Figures 12 and 14 show the percentages of "good," "average," and

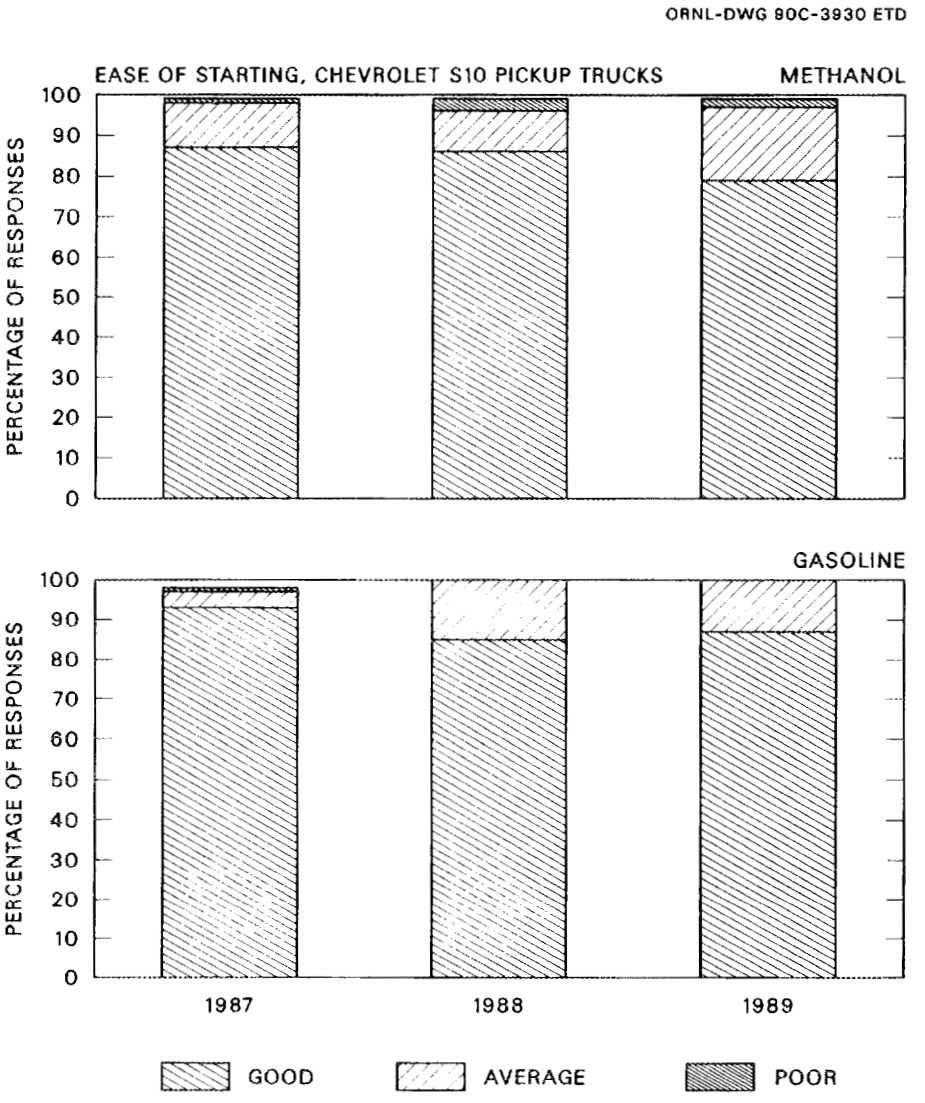

Fig. 12. Driver ratings of ease of starting for Chevrolet S10 Pickup Trucks.

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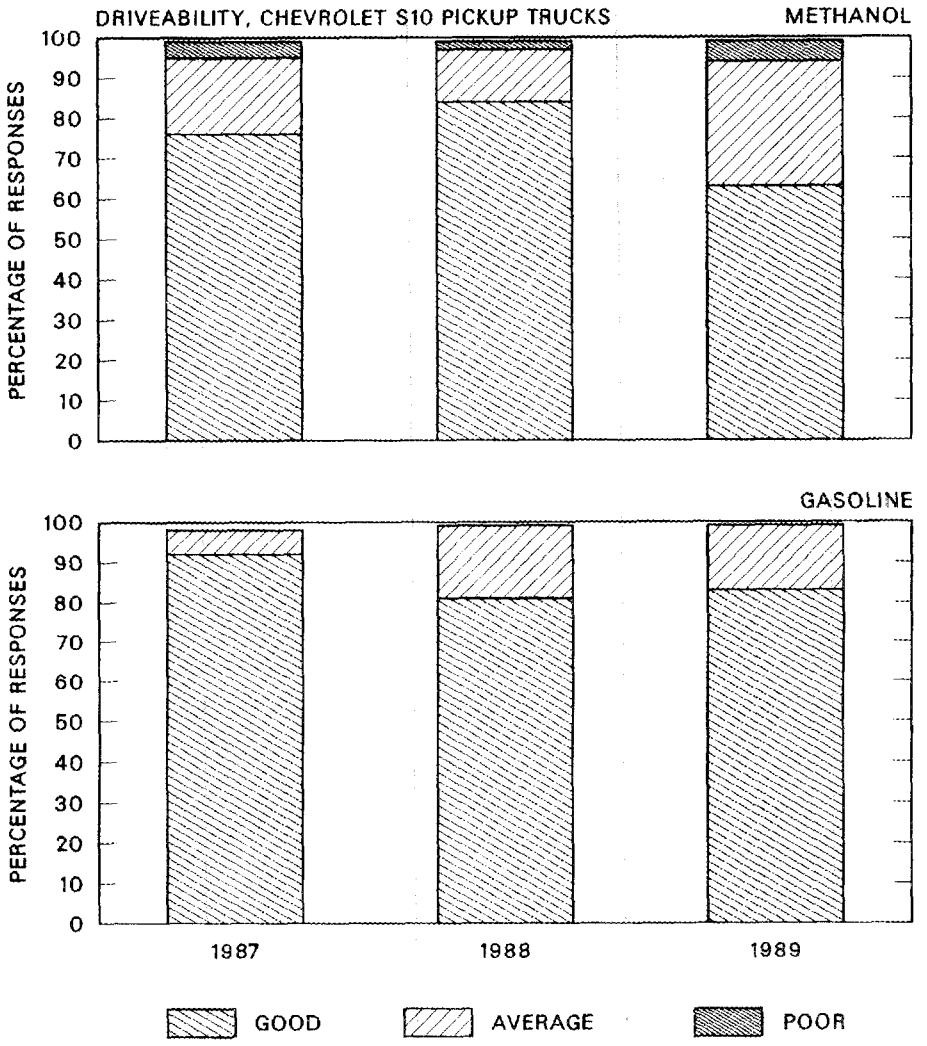

Fig. 13. Driver ratings of driveability for Chevrolet S10 Pickup Trucks.

"poor" responses for ease of starting for the Chevrolets and Fords, respectively, while Figs. 13 and 15 show the driveability responses. Note in Fig. 12 that the number of good responses for ease of starting of the methanol Chevrolets has declined only a few percent over the three years. The percentage of good ratings for the gasoline Chevrolets declined slightly last year, and rebounded slightly this year to maintain a small advantage over their methanol counterparts. In Fig. 13 it can be noted that the number of good driveability ratings for the gasoline Chevrolets decreased in the second year and held relatively constant, while that of the methanol Chevrolets increased in the second year only to decrease in the third.

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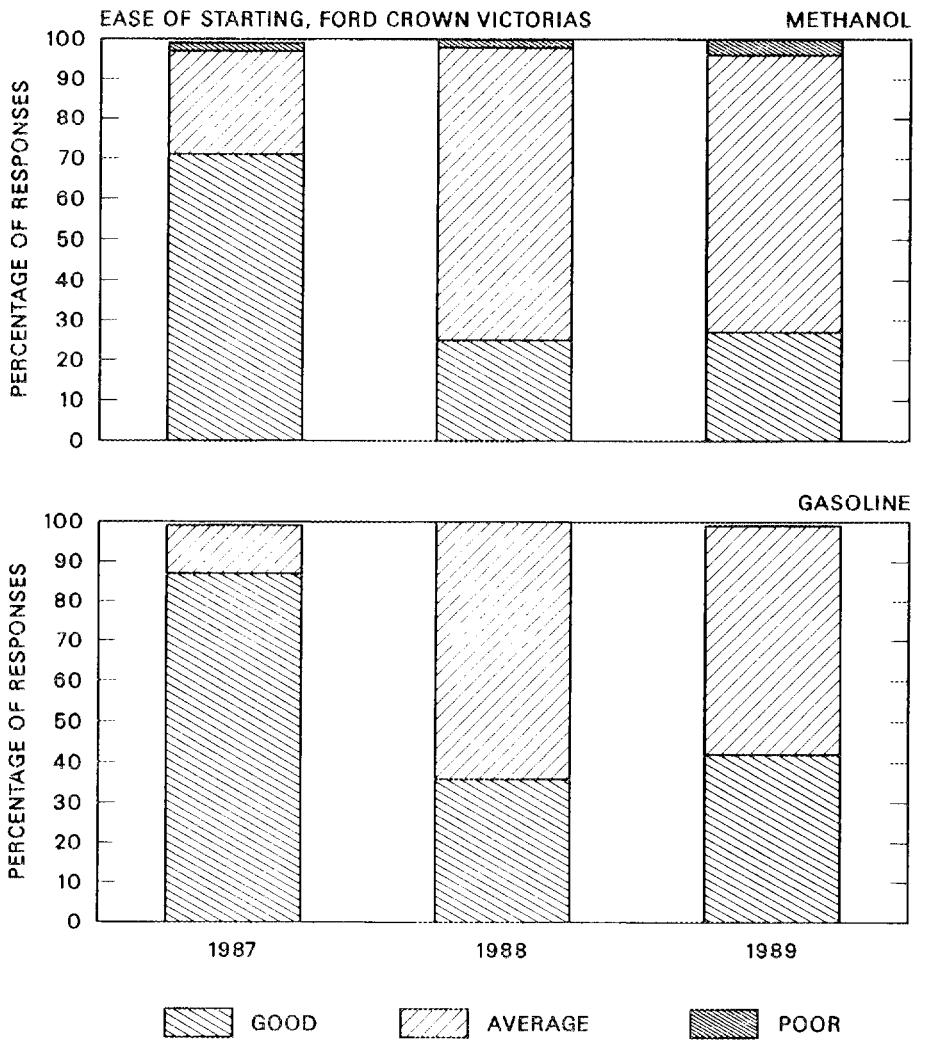

Fig. 14. Driver ratings of ease of starting for Ford Crown Victorias.

In Figs. 14 and 15, the data suggest that drivers' perceptions of the ease of starting and driveability of the Ford Crown Victorias declined in the second year. The number of good responses declined drastically for both vehicle types in the second year, and held relatively constant or rebounded slightly in the third. Reasons for these fluctuations are not clear, however it seems that drivers are satisfied with both the gasoline and the methanol vehicles (Fords and Chevrolets), rating their ease of starting and driveability as good or average over 90 percent of the time in most cases.

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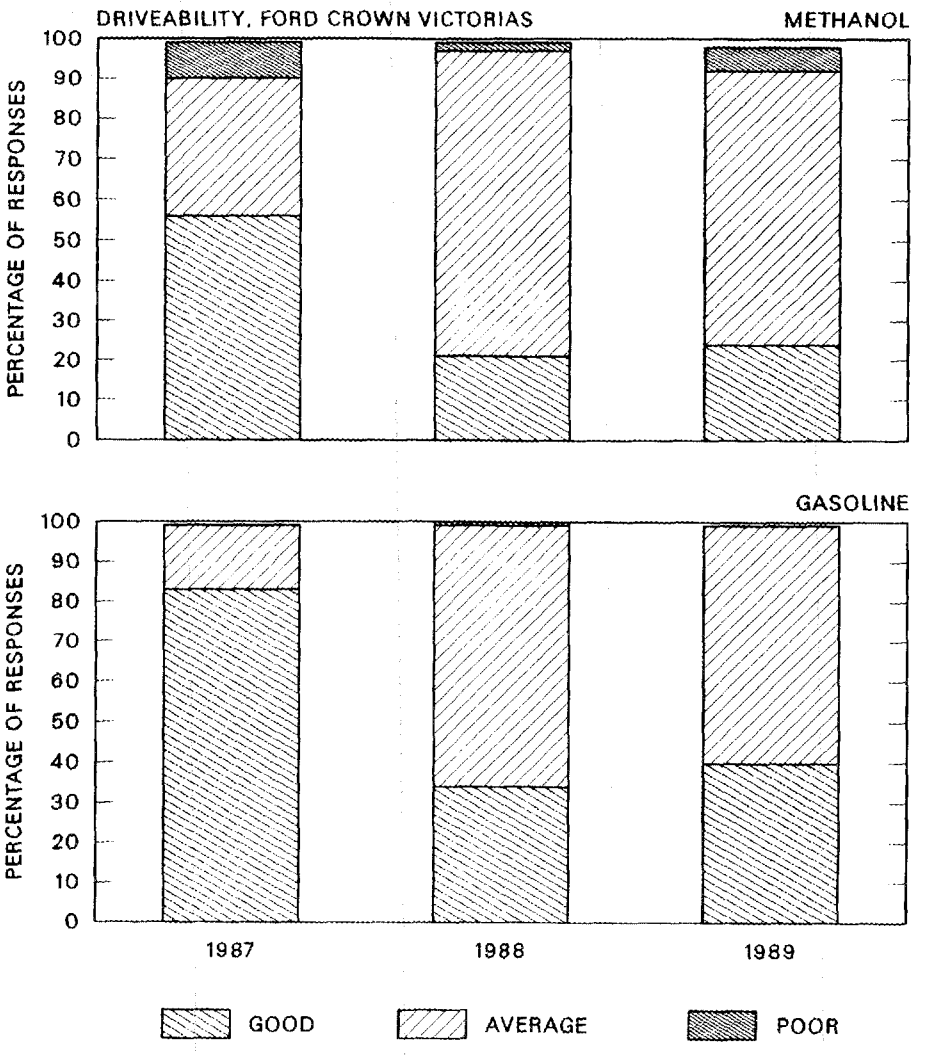

Fig. 15. Driver ratings of driveability for Ford Crown Victorias.

3.5.2 Variation of Ratings with Ambient Temperature

As well as providing opinions of ease of starting and driveability, drivers at ANL also provide an estimate of ambient temperature for each trip logged in any of the vehicles. Three ranges of temperatures are indicated on the trip log, and drivers check the one that fits their estimate. Ranges are: Greater than 40°F, 6 to 40°F, and 5°F or less. Using this simple system, it can be determined how the drivers' ratings of ease of starting and driveability may be affected by the ambient temperature. The drivers' ratings as a function of their

estimates of ambient temperature for the last three years are shown in Figs. 16-19, and tabulated in Appendix B. Table 10 shows the frequency of temperatures as estimated by the drivers. The ease of starting results are in Fig. 16 for the Chevrolets, and Fig. 18 for the Fords. The driveability results are in Figs. 17 and 19 for Chevrolets and Fords, respectively. Note in Fig. 16 that drivers have rated the ease of starting of both methanol and gasoline Chevrolets as good over 70 percent of the time, regardless of the temperature. This suggests

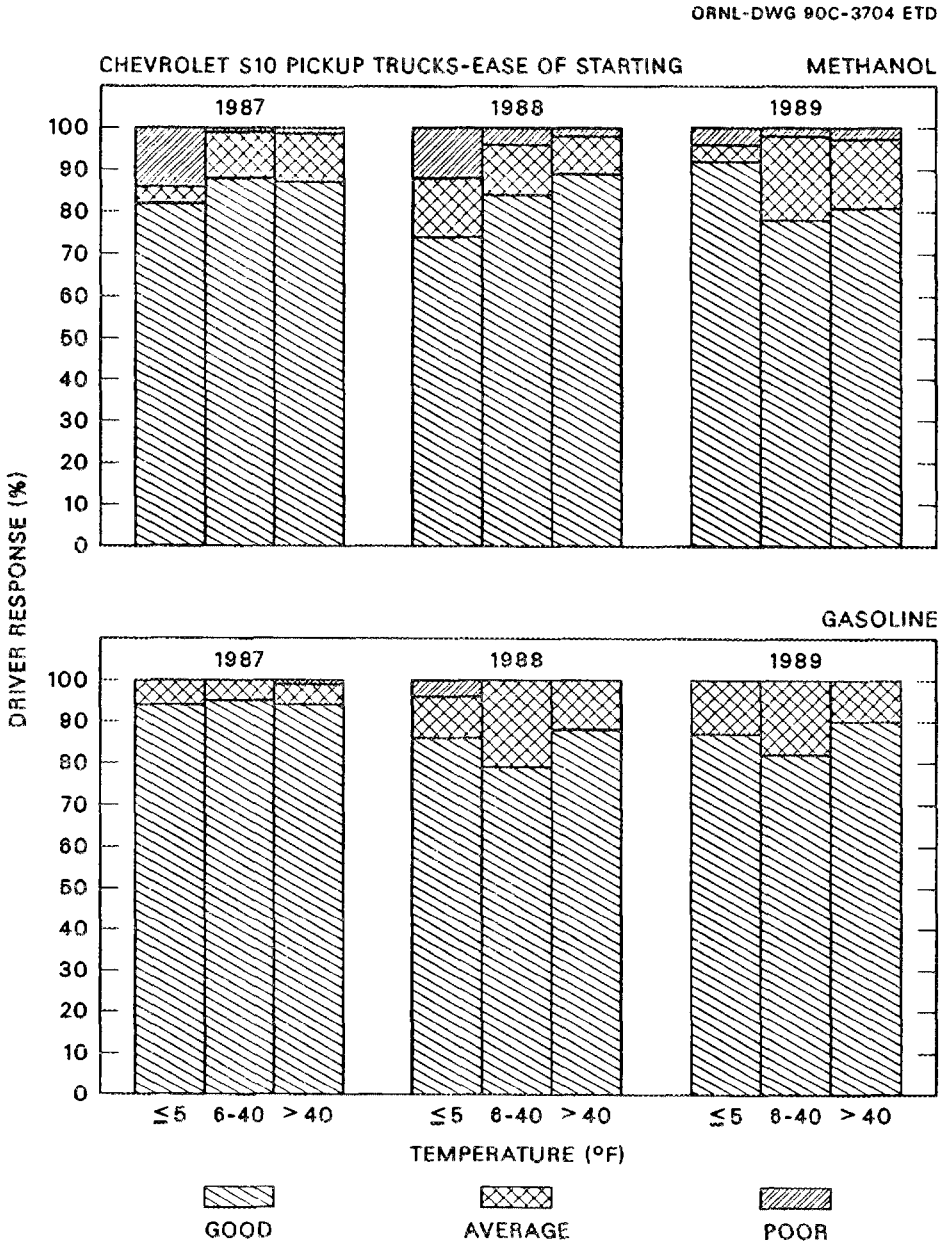

Fig. 16. Driver ratings of ease of starting for Chevrolet S10 Pickup Trucks as a function of estimated ambient temperature.

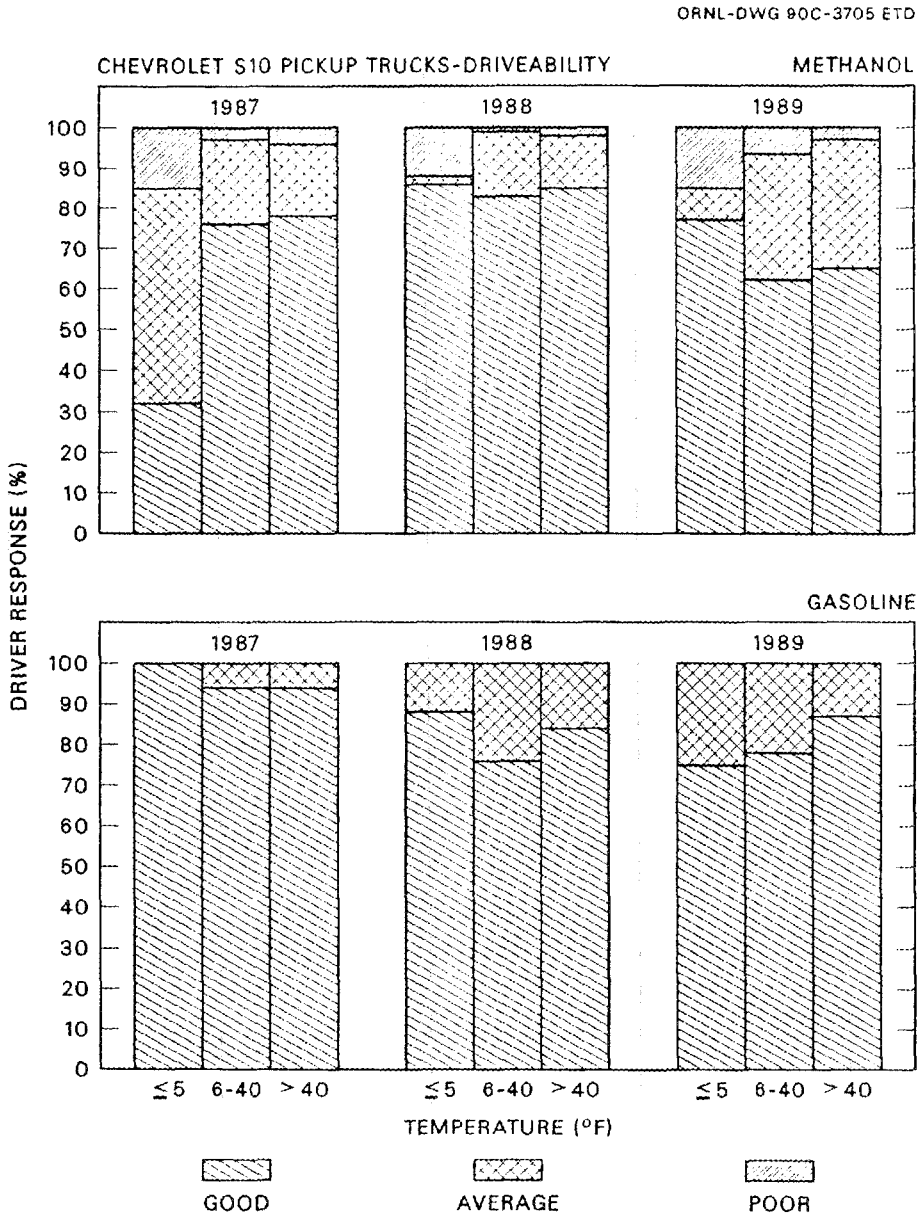

Fig. 17. Driver ratings of driveability for Chevrolet S10 Pickup Trucks as a function of estimated ambient temperature.

that the gasoline cold start systems on the methanol vehicles were performing satisfactorily. The number of good responses does not necessarily increase with increasing ambient temperature, as one might expect, but as shown in Table 10, the frequency of temperatures below 5°F is small, and again, the methanol Chevrolets have a gasoline cold start system. In Fig. 17 it appears that many more drivers rated the driveability of the methanol Chevrolets as average or poor when the weather was cold in 1987. Also, a sizeable number of drivers

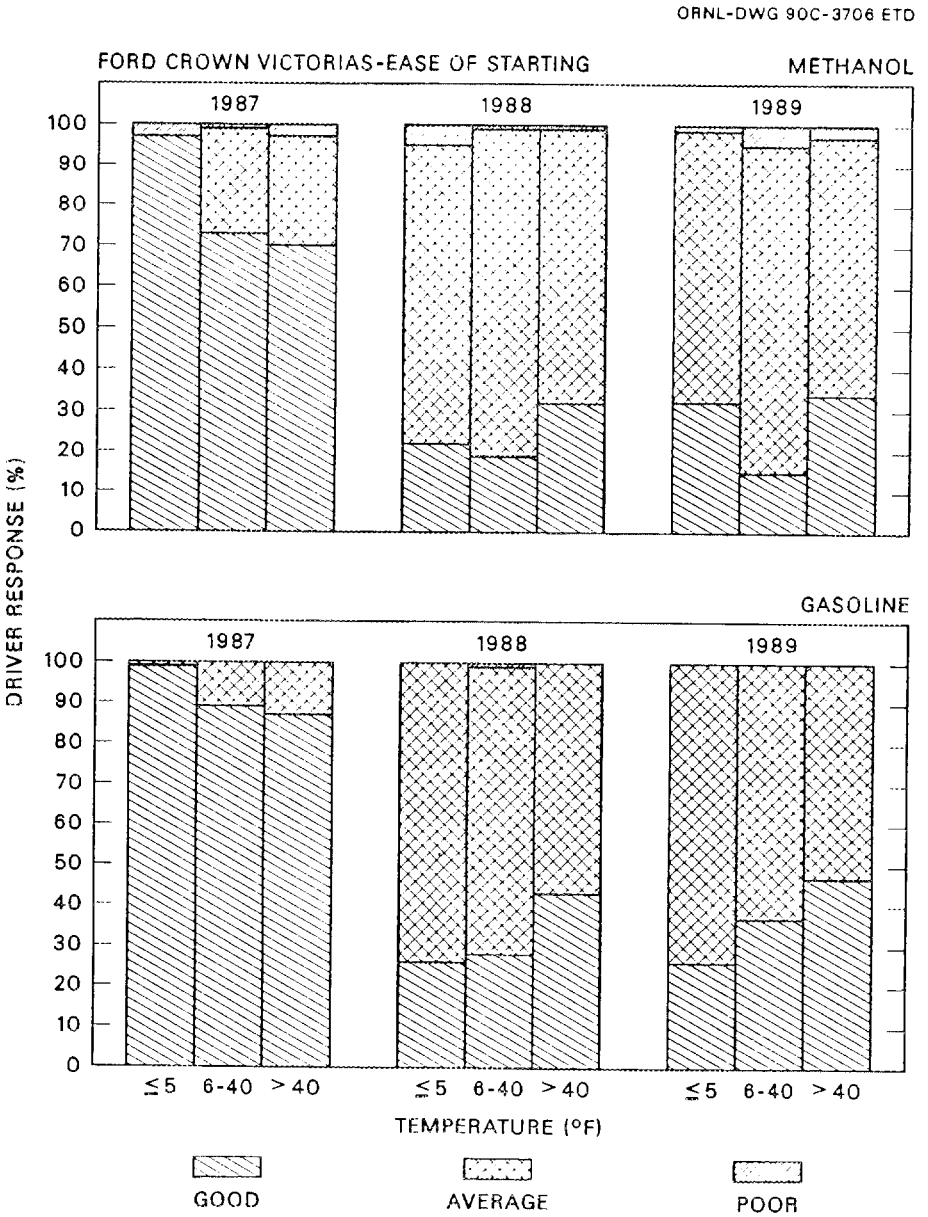

Fig. 18. Driver ratings of ease of starting for Ford Crown Victorias as a function of estimated ambient temperature.

gave average responses in the warmer weather of 1989. Except for these occurrences, the number of good responses is overwhelmingly high.

The decline in good responses for the Fords which was evident for the second year in Figs. 14 and 15, is also quite evident in Figs. 18 and 19. Note in Fig. 18 the high percentage of good ease of starting responses in 1987, especially during cold weather. Both

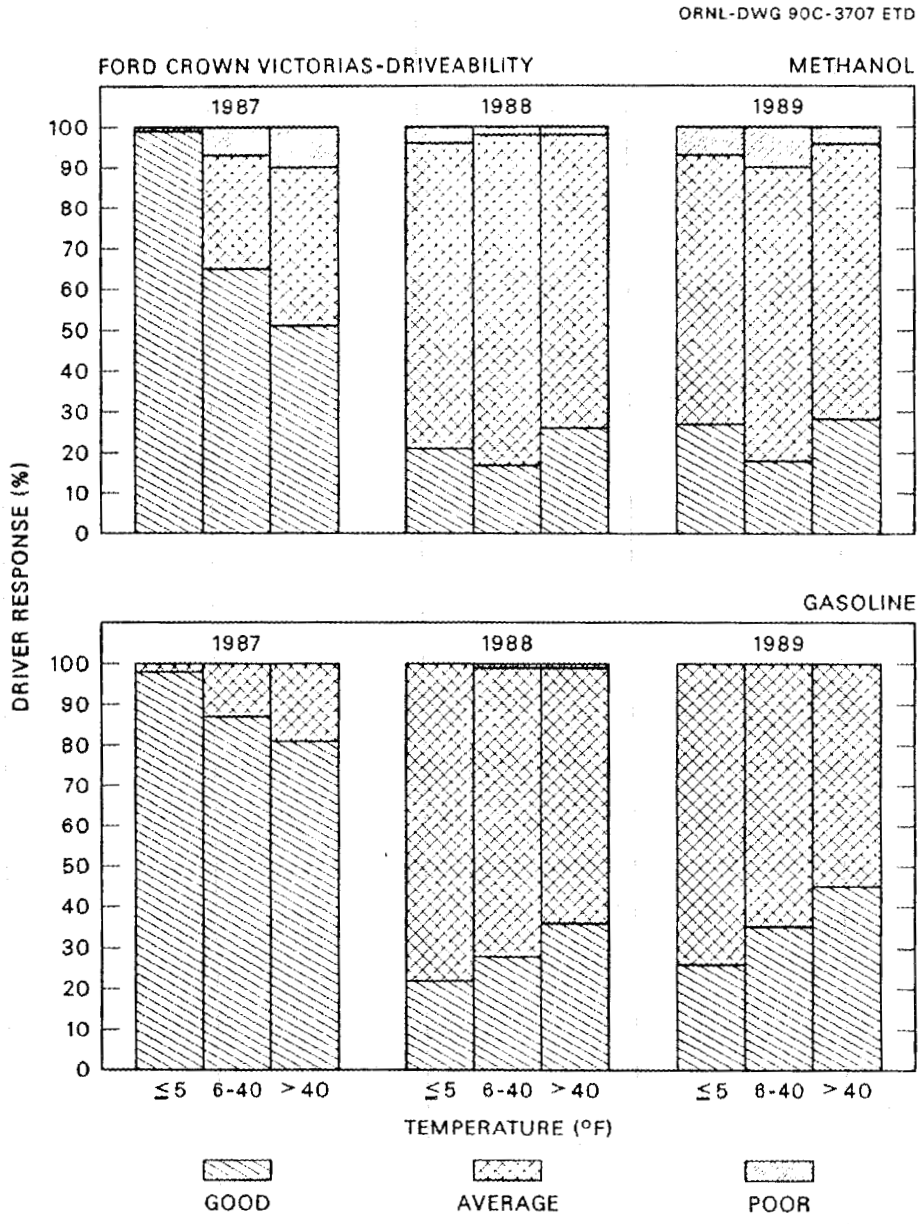

Fig. 19. Driver ratings of driveability for Ford Crown Victorias as a function of estimated ambient temperature.

vehicle types suffered a decline in number of good ratings from 1987 to 1988, and both have the highest number of good responses in the warmer weather for 1988 and 1989. The response to driveability in Fig. 19 shows increasing numbers of good responses with increasing temperature for the gasoline Fords in 1988 and 1989. The good responses have been offset almost entirely by average responses, for both ease of starting and driveability.

Table 10. Drivers' estimates of temperatures
(percent of responses)

	Greater than 40°F	6-40°F	5°F or less
1st year	62	35	3
2nd year	55	40	5
3rd year	61	38	1

While the drivers' ratings do vary with the apparent ambient temperature, the data do not entirely indicate that colder weather produces more difficult starting or worse driveability. The fact that the vehicles have cold start systems (except for the Fords in the latter half of 1989) certainly has the potential to alter any expected trends. To further examine how drivers' opinions of the vehicles' ease of starting change with weather, the data have been viewed in yet another way. The first rating of ease of starting each day has been extracted from the rest of the data, assuming that the first start of each day would be with a cold engine (as the vehicle has had several hours of "soaking" at the ambient temperature). This, of course, may not always be true for the Fords, which experience a large amount of around-the-clock use. Numbers were assigned to ratings of good, average, and poor, so that numerical averages could be calculated to generate Figs. 20 and 21. Figure 20 shows the monthly average of the first daily rating of ease of starting, for the Chevrolets. For methanol vehicles with no cold start system, one would expect to see the highest ratings in the warmer months, and lower ratings in colder months. Note that except for a dip in the fall of 1989 for the methanol Chevrolets, the curves are all relatively flat and ratings are generally good. A similar curve for the methanol Buicks at ORNL,[10] which have no cold start system, was more "classically" shaped, trailing off to average and poor in the cooler months, as expected.

Figure 21 shows the first start data for the Fords. Note that in 1987 both vehicle types were rated good until late summer/early fall, when the methanol vehicles' ratings began to decline. The data for 1988 and 1989 show the general decline in driver ratings for both vehicle types, which was discussed previously. The bottom two curves are for the methanol vehicles in 1988 and 1989. Note the dip to average in the fall/winter for both of these curves. It is interesting to note that the 1989 data does not seem to indicate any lesser degree of driver satisfaction than 1988, even though the cold-start systems were not in operation in the latter half of 1989. As mentioned above, the Fords are security vehicles and are used around the clock, so the possibility certainly exists that on many of the "first" starts of a calendar day,

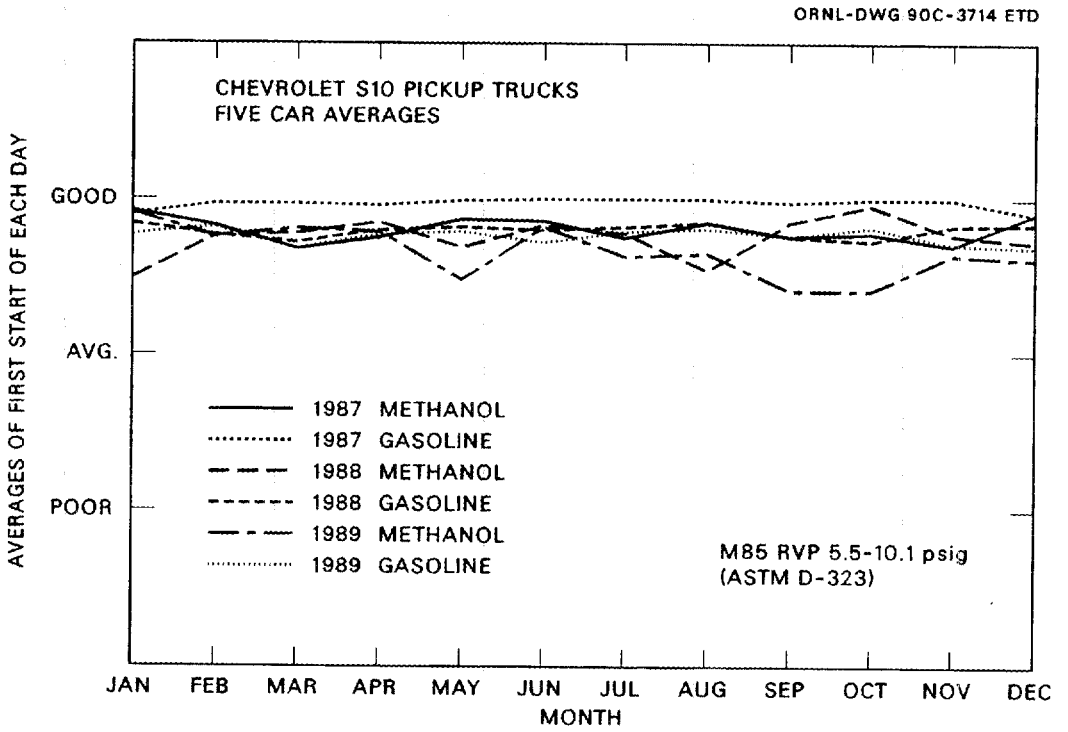

Fig. 20. Average rating of ease of starting for first daily starts as a function of month for Chevrolet S10 Pickup Trucks.

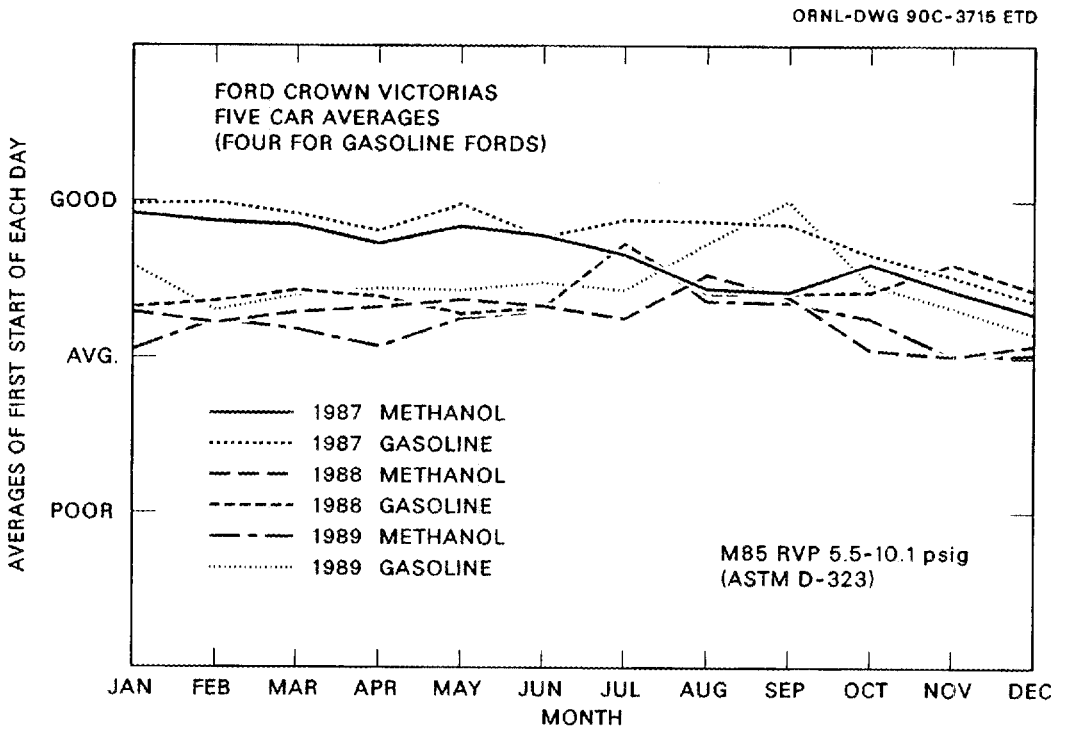

Fig. 21. Average rating of ease of starting for first daily starts as a function of month for Ford Crown Victorias.

the vehicle may not have been "cold." Also, the vehicles are equipped with electric block heaters. There is no data on when the heaters are used, but it is likely that they *are* used in very cold weather.

The data presented suggest that successful cold start systems can be engineered to provide reliable starting for methanol vehicles. While the drivers' ratings of the gasoline vehicles is generally a little higher than that of the methanol vehicles, the methanol vehicles' ratings are nonetheless acceptable. The cold start systems on the ANL vehicles can be thought of as "first generation" systems. Original equipment manufacturers are doing research in the area of cold start for methanol (or flex fuel) vehicles, and it is likely that systems available on OEM cars will be as reliable as the gasoline vehicles to which the consumer has grown accustomed.

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Appendix A

FURTHER DISCUSSION OF EMISSIONS TESTING

The data from which Figs. 1-6 were generated are summarized in Table A.1. Shown are vehicle mileage at each test, and OMHCE, CO, and NO_x emissions in grams/mile, as well as aldehyde emissions (HCOH) for the most recent tests. Tests with duplicate mileage indicate a repeat of the test (rounds 3A and 3B).

Table A.1. Summary of emissions tests results

Vehicle I.D.	Round	Odometer (miles)	OMHCE[a]	CO	NO_x	HCOH
			(grams/mile)			
		Chevrolet S10s				
Gasoline	1	14	0.18	0.32	0.24	nm[b]
565	2	10,400	0.21	1.93	0.51	nm
	3	27,300	0.39	2.71	0.55	0.011
Methanol	1	381	0.16	0.74	0.51	nm
562	2	7,600	0.72	8.27	0.67	nm
	3A	17,900	0.32	6.30	0.53	0.065
	3B	17,900	0.34	6.27	0.60	0.059
568	1	288	0.25	1.39	0.43	nm
	2	8,700	0.44	6.36	0.85	nm
	3	29,600	0.38	5.59	1.02	0.071
		Ford Crown Victorias				
Gasoline	1	85	0.20	0.40	0.43	nm
575	2	23,400	0.67	0.77	1.07	nm
	3	48,600	0.81	3.09	0.73	0.009
Methanol	1	793	0.18	0.76	0.62	nm
572	2	32,800	0.70	2.23	0.79	nm
	3A	53,300	0.63	2.39	0.45	0.312
	3B	53,300	0.66	2.35	0.43	0.299
574	1	418	0.23	1.44	0.63	nm
	2	26,900	0.65	3.16	0.71	nm
	3	53,800	2.46	9.36	0.84	0.522

[a]By ORNL Protocol

[b]Not measured

The highest emissions appear to be the CO emissions from methanol Chevrolets 562 and 568; and, in the last round of testing, from methanol Ford 574. These relatively high CO emissions are accompanied by high OMHCE emissions in vehicles 562 and 574. No explanation for this result is available at this time, although some insight can be gained from examining the results from the various phases (bags) during the test. Table A.2 shows the CO mass emitted during the three test phases from each of the vehicles during the last two rounds of testing. Note in Table A.2 that there is clearly a problem with the fueling of vehicles 562 and 568 during the cold transient portion of the test, as their bag 1 CO emissions are about three times that of the other vehicles, while their bags 2 and 3 appear more reasonable. It is probable that whatever caused these high emissions is the same problem that

Table A.2. Vehicle CO emissions by test phase (grams)

		Test Phase		
Vehicle I.D	Round	Cold Transient (bag 1)	Cold Stabilized (bag 2)	Hot Transient (bag 3)
		Chevrolet S10s		
Gasoline				
565	2	15.5	3.8	7.1
	3	22.0	6.4	8.3
Methanol				
562	2	118	6.10	9.10
	3A	96.3	3.30	4.83
	3B	92.8	3.56	6.29
568	2	64.0	10.6	16.8
	3	81.2	4.0	6.01
		Ford Crown Victorias		
Gasoline				
575	2	8.91	0.75	2.07
	3	26.7	6.80	9.26
Methanol				
572	2	25.8	0.60	8.90
	3A	31.0	1.05	6.25
	3B	31.3	1.20	5.27
574	2	38.8	1.0	10.7
	3	64.2	26.5	28.2

existed during the second round of testing. Vehicle 574 shows high values of CO during all phases of round 3 testing, but did not exhibit this behavior during round 2 testing. Obviously, something has changed on this vehicle and caused the high CO emissions during the entire FTP cycle in round 3.

A comparison of formaldehyde levels from the gasoline vehicles with those of the methanol vehicles in Table A.1 shows the typically higher values associated with methanol fuel. The formaldehyde values of about 10 mg/mile are typical of gasoline-fueled vehicles equipped with modern emission control systems (three-way catalyst, oxygen sensor feedback control). It should be noted, however, that no steps were taken during the conversion process to address the formaldehyde emissions. Newer technology has resulted in the availability of catalysts formulated especially for methanol-based fuels and these could be very effective in reducing formaldehyde emissions to the levels associated with gasoline-fueled vehicles.[A1,A2] Results from long-term durability tests, however, are just now becoming available.

The most recent round of testing allowed the computation of emissions more in keeping with the EPA protocol.[11] The emissions data supplied by Amoco Research Laboratories were manipulated to yield values for the NOHC and OMHCE as shown in Table A.3.

Table A.3 shows that the FID (flame ionization detector) is measuring mostly methanol, and the amounts of non-oxygenated hydrocarbons (NOHC) emitted by these M85-fueled engines are, with the exception of vehicle 574, less than those emitted by the gasoline-fueled vehicles. Of course, the gasoline-fueled vehicles emit no methanol and significantly less formaldehyde than the M85-fueled vehicles.

The latest data also provide an opportunity to evaluate the effectiveness of the "ORNL Protocol" in estimating the OMHCE. Table A.4 lists the OMHCE as determined from the measured data and from the ORNL Protocol. The agreement is good enough to make the comparisons (between rounds) in Table A.1 valid.

Table A.3. Round 3 methanol vehicle organics emissions

Vehicle I.D.	Odometer (miles)	THC[a]	MeOH[b]	NOHC[c]	OMHCE[c]
		(grams/mile)			
		Chevrolet S-10s			
562	17,900	0.26	0.55	0.07	0.31
	17,900	0.27	0.52	0.09	0.32
568	29,600	0.31	0.42	0.16	0.34
		Ford Crown Victorias			
572	53,300	0.48	1.05	0.12	0.58
	53,300	0.51	1.05	0.15	0.60
574	53,800	2.07	2.95	1.06	2.33

[a]Calculated using FID directly with no methanol corrections.

[b]Measured directly using impingers.

[c]Calculated using measured methanol values. FID methanol response factor = 0.79. Neglects methanols levels in dilution air.

Table A.4. Round 3 comparison of OMHCE values

Vehicle I.D.	OMHCE (gm/mile) (1)	(2)	(3)
	Chevrolet S-10s		
562	0.31	0.32	0.01
	0.32	0.34	0.02
568	0.34	0.38	0.04
	Ford Crown Victorias		
572	0.58	0.63	0.05
	0.60	0.66	0.06
574	2.33	2.46	0.13

Notes: (1) Calculated using measured methanol values.
(2) Calculated using ORNL Protocol.
(3) Difference (2)-(1).

Appendix A. REFERENCES

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APPENDIX B

Data used to generate the bar graphs in Figs. 7-19 is presented here in tabular form. Maintenance data for the Chevrolets and Fords is in Tables B.1 and B.2, respectively. The metals accumulation rates per season for Figs. 9-11 are given in Tables B.3 and B.4. Driver responses for ease of starting and driveability of the Chevrolets are shown for the third year in Table B.5, for the second year in Table B.6, and for the first year in Table B.7. Similar data for the Fords is given in Tables B.8-B.10. The driver response data as a function of

Table B.1. Maintenance frequency and intensity — Chevrolet S10 Pickup Trucks

	Frequency (occasions of maintenance per 1000 miles)		
	First year	Second year	Third year
All Maintenance			
Methanol	1.7	1.9	2.0
Gasoline	1.3	1.1	1.3
Fuel-Related Maintenance			
Methanol	0.2	0.3	0.4
Gasoline	0.0	0.0	0.0
	Intensity (hours of maintenance per 1000 miles)		
	First year	Second year	Third year
All Maintenance			
Methanol	2.0	4.1	7.2
Gasoline	0.8	0.9	1.3
Fuel-Related Maintenance			
Methanol	0.4	1.4	2.2
Gasoline	0.0	0.0	2.2

drivers' estimates of ambient temperature is shown in Tables B.11-B.16. Tables B.11-B.13 provide the data for the Chevrolets for third, second, and first years of operation, respectively. Tables B.14-B.16 provide similar data for the Fords.

Table B.2. Maintenance frequency and intensity — Ford Crown Victorias

	Frequency (occasions of maintenance per 1000 miles)		
	First year	Second year	Third year
All Maintenance			
Methanol	1.6	1.7	1.9
Gasoline	1.4	1.5	1.4
Fuel-Related Maintenance			
Methanol	0.2	0.2	0.2
Gasoline	0.03	0.02	0.0
	Intensity (hours of maintenance per 1000 miles)		
	First year	Second year	Third year
All Maintenance			
Methanol	2.4	3.8	5.9
Gasoline	2.0	3.1	3.6
Fuel-Related Maintenance			
Methanol	0.1	0.3	0.7
Gasoline	0.05	0.1	0.0

Table B.3. Metals accumulation rates as a function of season — Chevrolet S10 Pickup Trucks

Season	Accumulation rate (ppm/1000 mi)					
	Iron			Lead		
	1987	1988	1989	1987	1988	1989
	Methanol Vehicles					
Spring[a]	41	174	35	98	123	153
Summer[b]	23	60	60	134	132	92
Fall[c]	95	38	49	125	43	54
Winter[d]	109	116	27	156	155	77
	Gasoline Vehicles					
Spring[a]	51	23	27	16	29	72
Summer[b]	60	18	24	17	23	6
Fall[c]	6	20	14	14	27	3
Winter[d]	16	3	48	23	4	10

[a]March 16 through June 15.

[b]June 16 through August 15.

[c]August 16 through November 15.

[d]Winter season for a given year includes 2.5 months of subsequent year, except for winter of 1989, which includes only partial 1990 data (November 16 through March 15).

Table B.4. Iron accumulation rate as a function of season — Ford Crown Victorias

Season	Accumulation rate (ppm/1000 mi)		
	Iron		
	1987	1988	1989
Methanol Vehicles			
Spring[a]	40	65	56
Summer[b]	55	27	93
Fall[c]	60	50	17
Winter[d]	120	72	47
Gasoline Vehicles			
Spring[a]	8	17	55
Summer[b]	11	21	16
Fall[c]	6	9	12
Winter[d]	9	34	0

[a]March 16 through June 15.

[b]June 16 through August 15.

[c]August 16 through November 15.

[d]Winter season for a given year includes 2.5 months of subsequent year, except for winter of 1989, which includes only partial 1990 data (November 16 through March 15).

Table B.5. Driver responses from daily trip logs.
Third Year — January 1, 1989 to December 31, 1989

Chevrolet S-10 Pickup Trucks

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	1532	338	47	11
Gasoline	2089	302	5	11
	Percent of Total			
Methanol	79	18	2	1
Gasoline	87	13	0[a]	0[a]
	Numbers of Responses			
Driveability				
Methanol	1222	603	90	13
Gasoline	2004	385	0	18
	Percent of Total			
Methanol	63	31	5	1
Gasoline	83	16	0[a]	1

[a]Less than 0.5%.

Table B.6. Driver responses from daily trip logs.
Second Year — January 1, 1989 to December 31, 1989

Chevrolet S-10 Pickup Trucks

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	1366	158	45	11
Gasoline	1697	294	4	7
	Percent of Total			
Methanol	86	10	3	1
Gasoline	85	15	0	0
	Numbers of Responses			
Driveability				
Methanol	1331	213	27	9
Gasoline	1625	362	4	11
	Percent of Total			
Methanol	84	13	2	1
Gasoline	81	18	0	1

Table B.7. Driver responses from daily trip logs.
First Year — January 1, 1989 to December 31, 1989

Chevrolet S-10 Pickup Trucks

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	2360	301	36	19
Gasoline	2803	135	25	41
	Percent of Total			
Methanol	87	11	1	1
Gasoline	93	4	1	2
	Numbers of Responses			
Driveability				
Methanol	2060	517	99	40
Gasoline	2788	135	25	56
	Percent of Total			
Methanol	76	19	4	1
Gasoline	92	6	0	2

Table B.8. Driver responses from daily trip logs.
Third Year — January 1, 1989 to December 31, 1989

Ford Crown Victorias

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	596	1532	86	12
Gasoline	590	801	3	13
	Percent of Total			
Methanol[b]	27	69	4	1
Gasoline	42	57	0[a]	1
	Numbers of Responses			
Driveability				
Methanol	540	1523	141	22
Gasoline	562	828	2	15
	Percent of Total			
Methanol[b]	24	68	6	1
Gasoline	40	59	0[a]	1

[a]Less than 0.5%.

[b]Percentages do not add up to 100% due to rounding.

Table B.9. Driver responses from daily trip logs.
Second Year — January 1, 1989 to December 31, 1989

Ford Crown Victorias

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	691	2017	40	12
Gasoline	822	1480	5	7
	Percent of Total			
Methanol	25	73	2	0
Gasoline	36	64	0	0
	Numbers of Responses			
Driveability				
Methanol	597	2089	56	18
Gasoline	782	1505	20	7
	Percent of Total			
Methanol	21	76	2	1
Gasoline	34	65	1	0

Table B.10. Driver responses from daily trip logs.
First Year — January 1, 1989 to December 31, 1989

Ford Crown Victorias

	Responses			
	Good	Average	Poor	No Response
	Number of Responses			
Ease of Starting				
Methanol	6536	2366	227	60
Gasoline	9428	1277	32	62
	Percent of Total			
Methanol	71	26	2	1
Gasoline	87	12	0	1
	Numbers of Responses			
Driveability				
Methanol	5155	3127	825	82
Gasoline	8997	1686	40	76
	Percent of Total			
Methanol	56	.34	9	1
Gasoline	83	16	0	1

Table B.11. Driver response as a function of estimated temperature

Third Year — January 1, 1989 — December 31, 1989

Chevrolet S-10 Pickup Trucks

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	952 (81)	195 (17)	32 (3)	1,179
Gasoline vehicles	1,411 (90)	159 (10)	2 (0)	1,602
Temperature: 6 to 40°F				
Methanol vehicles	554 (78)	142 (20)	14 (2)	710
Gasoline vehicles	592 (82)	128 (18)	3 (0)	723
Temperature: 5°F or less				
Methanol vehicles	24 (92)	1 (4)	1 (4)	26
Gasoline vehicles	52 (87)	8 (13)	1 (0)	60
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	760 (65)	378 (32)	40 (3)	1,178
Gasoline vehicles	1,389 (87)	208 (13)	0 (0)	1,597
Temperature: 6 to 40°F				
Methanol vehicles	441 (62)	222 (31)	46 (6)	709
Gasoline vehicles	566 (78)	155 (22)	0 (0)	721
Temperature: 5°F or less				
Methanol vehicles	20 (77)	2 (8)	4 (15)	26
Gasoline vehicles	45 (75)	15 (25)	0 (0)	60

Table B.12. Driver response as a function of estimated temperature

Second Year — January 1, 1989 — December 31, 1989

Chevrolet S-10 Pickup Trucks

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	842 (89)	86 (9)	19 (2)	947
Gasoline vehicles	1,083 (88)	146 (12)	1 (0)	1,230
Temperature: 6 to 40°F				
Methanol vehicles	481 (84)	66 (12)	21 (4)	568
Gasoline vehicles	536 (79)	139 (21)	0 (0)	675
Temperature: 5°F or less				
Methanol vehicles	32 (74)	6 (14)	5 (12)	43
Gasoline vehicles	74 (86)	9 (10)	3 (4)	86
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	809 (85)	124 (13)	15 (2)	948
Gasoline vehicles	1,035 (84)	190 (16)	4 (0)	1,229
Temperature: 6 to 40°F				
Methanol vehicles	475 (83)	88 (16)	7 (1)	570
Gasoline vehicles	512 (76)	161 (24)	0 (0)	673
Temperature: 5°F or less				
Methanol vehicles	36 (86)	1 (2)	5 (12)	42
Gasoline vehicles	75 (88)	10 (12)	0 (0)	85

Table B.13. Driver response as a function of estimated temperature

First Year — January 1, 1989 — December 31, 1989

Chevrolet S-10 Pickup Trucks

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	1,462 (87)	192 (11)	23 (1)	1,677
Gasoline vehicles	1,786 (94)	86 (5)	20 (1)	1,892
Temperature: 6 to 40°F				
Methanol vehicles	880 (88)	108 (11)	10 (1)	998
Gasoline vehicles	1,001 (95)	48 (5)	5 (0)	1,054
Temperature: 5°F or less				
Methanol vehicles	18 (82)	1 (4)	3 (14)	22
Gasoline vehicles	16 (94)	1 (6)	0 (0)	17
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	1,312 (78)	297 (18)	63 (4)	1,672
Gasoline vehicles	1,757 (94)	121 (6)	0 (0)	1,878
Temperature: 6 to 40°F				
Methanol vehicles	742 (76)	210 (21)	33 (3)	985
Gasoline vehicles	991 (94)	61 (6)	0 (0)	1,052
Temperature: 5°F or less				
Methanol vehicles	6 (32)	10 (53)	3 (15)	19
Gasoline vehicles	17 (100)	0 (0)	0 (0)	17

Table B.14. Driver response as a function of estimated temperature

Third Year — January 1, 1989 — December 31, 1989

Ford Crown Victorias

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	452 (34)	828 (63)	43 (3)	1,323
Gasoline vehicles	387 (47)	434 (53)	1 (0)	822
Temperature: 6 to 40°F				
Methanol vehicles	122 (15)	657 (80)	42 (5)	821
Gasoline vehicles	180 (37)	310 (63)	2 (0)	492
Temperature: 5°F or less				
Methanol vehicles	22 (32)	45 (66)	1 (1)	68
Gasoline vehicles	19 (26)	53 (74)	0 (0)	72
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	372 (28)	887 (67)	56 (4)	1,315
Gasoline vehicles	367 (45)	454 (55)	0 (0)	821
Temperature: 6 to 40°F				
Methanol vehicles	150 (18)	590 (72)	80 (10)	820
Gasoline vehicles	173 (35)	317 (64)	2 (0)	492
Temperature: 5°F or less				
Methanol vehicles	18 (27)	44 (66)	5 (7)	67
Gasoline vehicles	19 (26)	53 (74)	0 (0)	72

Table B.15. Driver response as a function of estimated temperature

Second Year — January 1, 1989 — December 31, 1989

Ford Crown Victorias

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	417 (32)	881 (67)	7 (1)	1,305
Gasoline vehicles	512 (43)	690 (57)	1 (0)	1,203
Temperature: 6 to 40°F				
Methanol vehicles	230 (19)	986 (80)	19 (1)	1,235
Gasoline vehicles	263 (28)	658 (71)	4 (1)	925
Temperature: 5°F or less				
Methanol vehicles	43 (22)	142 (73)	9 (5)	194
Gasoline vehicles	45 (26)	131 (74)	0 (0)	176
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	345 (26)	937 (72)	21 (2)	1,303
Gasoline vehicles	427 (36)	762 (63)	13 (1)	1,202
Temperature: 6 to 40°F				
Methanol vehicles	211 (17)	993 (81)	27 (2)	1,231
Gasoline vehicles	256 (28)	658 (71)	10 (1)	924
Temperature: 5°F or less				
Methanol vehicles	41 (21)	146 (75)	7 (4)	194
Gasoline vehicles	39 (22)	137 (78)	0 (0)	176

Table B.16. Driver response as a function of estimated temperature

First Year — January 1, 1989 — December 31, 1989

Ford Crown Victorias

	Number of response (percentage)			
	Good	Average	Poor	Total Responses
	Ease of starting			
Temperature: Greater than 40°F				
Methanol vehicles	4,089 (70)	1,562 (27)	185 (3)	5,836
Gasoline vehicles	5,310 (87)	774 (13)	14 (0)	6,098
Temperature: 6 to 40°F				
Methanol vehicles	2,307 (73)	804 (26)	38 (1)	3,149
Gasoline vehicles	3,998 (89)	502 (11)	18 (0)	4,518
Temperature: 5°F or less				
Methanol vehicles	140 (97)	0 (0)	4 (3)	144
Gasoline vehicles	120 (99)	1 (1)	0 (0)	121
	Driveability			
Temperature: Greater than 40°F				
Methanol vehicles	2,988 (51)	2,234 (39)	601 (10)	5,823
Gasoline vehicles	4,948 (81)	1,119 (19)	21 (0)	6,088
Temperature: 6 to 40°F				
Methanol vehicles	2,988 (65)	893 (28)	223 (7)	3,140
Gasoline vehicles	3,931 (87)	564 (13)	19 (0)	4,514
Temperature: 5°F or less				
Methanol vehicles	143 (99)	0 (0)	1 (1)	144
Gasoline vehicles	118 (98)	3 (2)	0 (0)	121

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