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

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Engineering Technology Division

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

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CONTENTS

CONTENTS (continued)

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ABSTRACT

The Oak Ridge National Laboratory, under the auspices of the Department of Energy's Alternative Fuels Utilization Program, has managed the Federal Methanol Fleet Project since its inception in fiscal year 1985. This congressionally-mandated project directed the Department of Energy to introduce methanol-fueled vehicles into civilian government fleet operations. This interim report describes the first year of operation of a methanol fleet at Argonne National Laboratory in Argonne, Illinois. The fleet consists of five methanol-fueled 1986 Chevrolet S-10 pickup trucks along with five gasoline Chevrolet S-10s for comparison, as well as five methanol-fueled 1986 Ford Crown Victorias paired with four gasoline Fords. Data have been collected and tabulated on fuel consumption, maintenance records, oil sample analyses, and driver perceptions of vehicle operability. Energy efficiency for the methanol vehicles was slightly greater than that for the counterpart gasoline vehicles. Maintenance records reveal that the methanol vehicles required substantially more service than the gasoline vehicles, but a large proportion of the difference was due to methanol component replacements where improvements or upgrades were scheduled to be implemented after the vehicles were in service. Oil sample analyses revealed that engine wear rates were higher in the methanol vehicles. Drivers indicated that the methanol vehicles are quite acceptable, but they rated the gasoline vehicles higher. The Argonne fleet serves as the cold-weather site of the Federal Methanol Fleet and, as such, the methanol vehicles have been outfitted with special systems to aid in cold-starting and driveability. Drivers' ratings of ease of starting and driveability remained nearly unchanged during the cold winter weather at Argonne as compared to ratings during warm weather.

1. INTRODUCTION AND SUMMARY

1.1 Introduction

Argonne National Laboratory (ANL) has operated nineteen vehicles for a period of over one year 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 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. Previous ORNL reports (1,2)* detailed the results of the first and second years of operation of another of the activities of the Federal Methanol Fleet located at Lawrence Berkeley Laboratory, where the first methanol fleet was operated under the management of this project. Because much of the background and philosophy of this project has been described in those two reports as well as in other published reports (3,4,5), they will not be discussed at any length in this report. The reader is encouraged to refer to the previous reports for those details. This report will deal primarily with the description and characteristics of the methanol fleet operation at Argonne and the results from the first year of operation.

The fleet at ANL actually began operation in mid-1986 with the delivery of the gasoline vehicles that make up that portion of the fleet. The methanol vehicles arrived in late 1986 after they had been converted to methanol operation and had undergone tests for emissions and performance. The period of time for this report is the total time of operation through December 31, 1987, thus representing about one year for the methanol vehicles and about one and one-half years for the gasoline vehicles that are part of the study.

At Argonne ten of the vehicles are 1986 Chevrolet S-10 pickup trucks, five of which have been modified to operate on methanol, and nine of the vehicles are 1986 Ford Crown Victoria four-door sedans, five of which have been converted to methanol. All the methanol vehicles were converted to operate on methanol fuel by Alcohol Energy Systems, Inc. of Santa Clara, California. The methanol fuel at Argonne is nominally M85 (85% methanol and 15% regular unleaded gasoline). A separate underground storage tank for the methanol fuel was installed at Argonne along with fuel lines and a fuel dispensing pump.

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*Numbers in parentheses refer to references at the end of the report.

The Chevrolet S-10 trucks are assigned, mostly, to ANL maintenance personnel and are used for transportation around the site to work assignments. The Ford Crown Victorias are outfitted as security vehicles and are used by Argonne security force as patrol vehicles. The use of all of the methanol vehicles as well as their gasoline counterparts is generally confined to the ANL site except on rare occasions.

When the Congress of the United States instructed the Department of Energy to initiate this project it required that at least one of the operating fleets be located in a cold climate. Relatively poor cold-weather performance of methanol vehicles remained at that time as one of the technological barriers to the wide-spread use of methanol as a substitute for gasoline, and it is believed that Congress was mindful of that fact. The Argonne fleet satisfies that requirement since Argonne is located in the suburbs of Chicago, Illinois which experiences a relatively cold climate. For this service, the Argonne methanol vehicles have been equipped with special cold-starting systems to allow them to start and drive away at temperatures as low as -20°F (-29°C). The Chevrolets and Fords use different systems to accomplish this, as will be discussed later.

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

1.2 Summary

Argonne National Laboratory completed its first year of operation of nineteen vehicles for the Federal Methanol Fleet Project accumulating over 300,000 miles (480,000 km) on the nineteen project vehicles. Records show that nearly 26,000 trips were taken in the vehicles by

Argonne drivers and that nearly 27,000 gallons (102,000 liters) of fuel (methanol and gasoline) were used. The data for the first year of operation include records of 3192 refueling occasions.

Use of the nineteen vehicles was nearly equally divided between methanol and gasoline vehicles, and average trip lengths were quite short due to the nature of vehicle use at Argonne. The methanol vehicles attained slightly greater energy efficiency than their gasoline counterparts, most likely due to their higher-compression-ratio engines. Methanol vehicles required substantially more maintenance than the gasoline vehicles, but a large proportion of the difference was due to improvements and upgrades in methanol engine components, many of which were scheduled to be incorporated after the vehicles were in service. Analyses of oil samples taken regularly from the crankcases of each of the vehicles reveal that wear metals accumulation rates in the methanol vehicles are notably higher than those of the gasoline vehicles.

Drivers indicate very high acceptance of the methanol vehicles but not as high as for the gasoline vehicles, and their ratings of the vehicles do not appear to decline when the weather is cold.

2. ARGONNE NATIONAL LABORATORY FLEET

Argonne National Laboratory is located in the southwest suburbs of Chicago, Illinois on a campus-like site with nearly level terrain. Winters can be quite cold with numerous occurrences of below-freezing temperatures and several occasions of below-zero (Fahrenheit) temperatures each winter. Other seasons feature moderate-to-warm temperatures, sometimes in excess of ninety degrees in the summer. The laboratory site itself is located not far from major highways and has approximately 11 miles of roads on-site. Vehicles involved in the Federal Methanol Fleet Project are seldom used off-site; thus, average trip lengths for any of the nineteen participating vehicles is rather short.

2.1 ANL Fleet Description and Background

The ANL fleet consists of a total of nineteen vehicles with ten of them converted to operate on methanol. Of the nineteen vehicles, ten are 1986 model Chevrolet S-10 pickup trucks (five methanol and five gasoline), and nine are 1986 model Ford Crown Victoria 4-door sedans (five methanol and four gasoline). All nineteen vehicles used in the project at Argonne were purchased new by the United States General Services Administration (GSA) who also commissioned the conversions of ten of the vehicles to methanol. Those conversions were made by Alcohol Energy Systems, Inc. (AES) of Santa Clara, California in the period from summer to late fall of 1986. AES, in turn, commissioned various qualification tests of the vehicles as required by GSA, which tests included emissions before and after conversion to methanol. The results of those tests are provided later in this report.

A policy adopted by program management early in the project was that only "tried-and-proven" technologies would be utilized for conversions of vehicles to methanol. This would help to ensure reliability and, hopefully, reduce maintenance costs associated with the methanol vehicles. During the period of the project there have been few opportunities to purchase retrofitted vehicles with proven technology, but to the extent that technologies have been available, they have been purchased for the project. A slight deviation from this goal was required for the methanol Ford Crown Victorias for Argonne.

At one time it appeared that methanol Ford Crown Victorias were to be purchased for a taxi fleet in New York City, and it was anticipated that the DOE effort could "piggy-back" onto that experience and acquire vehicles for a federal fleet in that manner. However, the New York City methanol taxi fleet did not come to fruition, and it was necessary to proceed with the procuring of methanol Fords for Argonne without the prior experience having been gained by other parties. For this reason, it was anticipated that there could be some early shake-out problems with the Fords at Argonne. These were expected to be minimal, though, since much of the advance planning and some engineering for the methanol Fords had been done for the taxi fleet.

Figure 1 shows one of the methanol Chevrolet S-10 pickup trucks along with one of the methanol Fords at the Argonne site.

2.2 Methanol Vehicle Descriptions

2.2.1 Chevrolet S-10 Pickup Trucks

Conversions of five 1986 Chevrolet S-10 pickup trucks with 2.5 liter (151 cubic inches) 4-cylinder engines and with automatic transmissions were performed at Alcohol Energy Systems (AES) facilities and included replacement of many fuel system parts with methanol-compatible components; the on-board computer system which manages the engine operation was reprogrammed suitably for methanol operation. AES received backup support for the conversion effort on the Chevrolets from General Motors Corporation who supplied, among other things, the 20-gallon methanol vehicle fuel tank which has an epoxy-coated interior surface (applied over the stock terneplate of the standard gasoline tank) - a treatment which is said to be compatible with methanol. These vehicles in their standard gasoline version use a throttle-body fuel injection system, and that system was retained in large part for the methanol conversions. The central fuel injector was retained for the methanol application since its flow capacity was sufficiently large for the increased flow rates required by the methanol; the fuel pump was replaced with a one that is compatible with methanol.

ORNL–PHOTO 5689–88

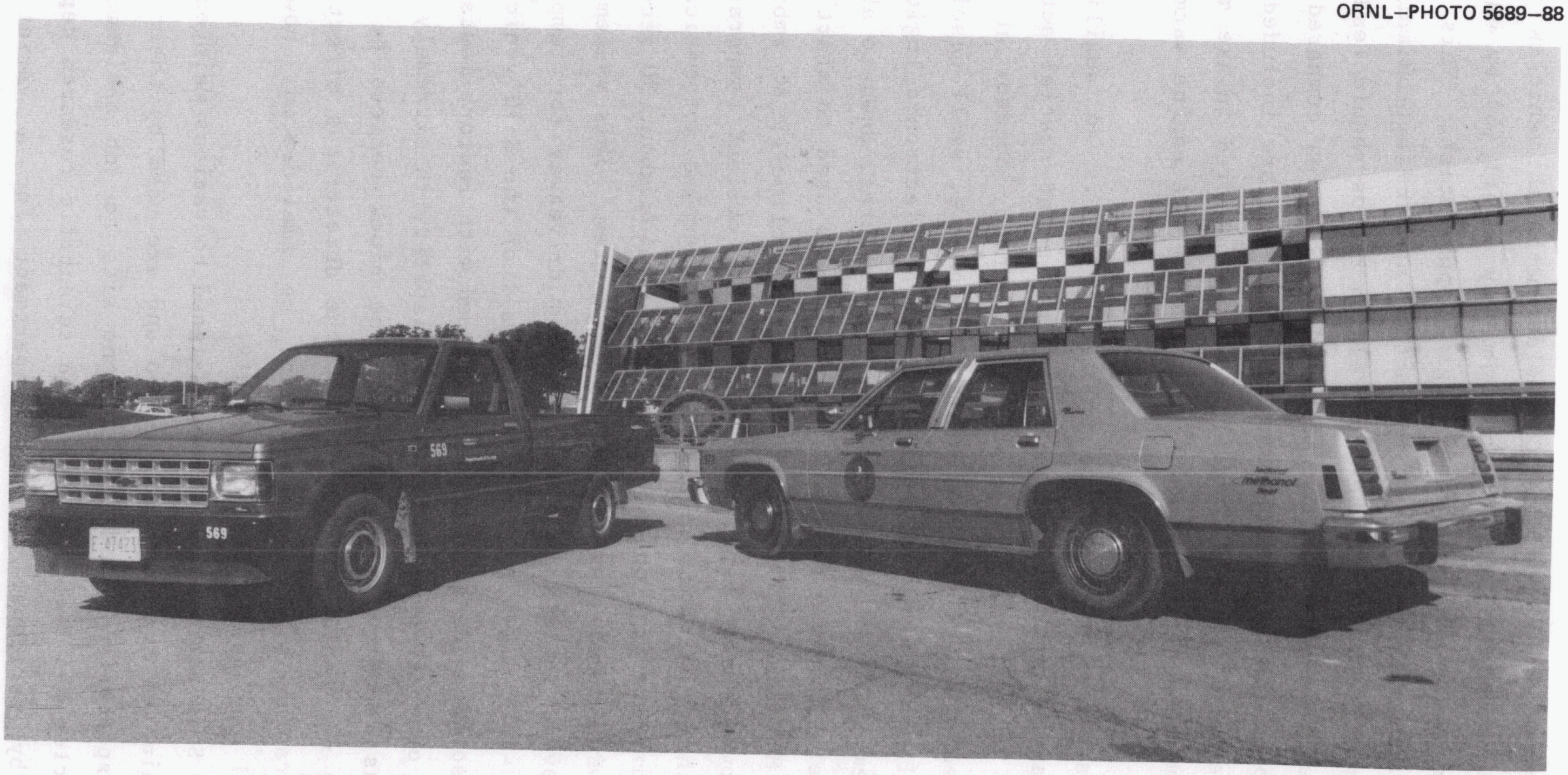

Fig. 1. Methanol Chevrolet S-10 and Ford Crown Victoria at Argonne National Laboratory.

The compression ratio for the Chevrolet methanol vehicles was increased from the standard 9.0:1 to approximately 10.5:1 (6) by using higher-compression pistons from another engine application. This was done to take advantage of the very high octane number (approximately 100) of the methanol fuel. The higher compression ratios should lead to slightly higher efficiencies for the methanol vehicles as compared to their gasoline counterparts. Colder-range spark plugs are included as part of the conversion, and the Chevrolets use a modified intake manifold to afford more fuel/air mixture heating during the engine warm-up period.

The cold-start system installed on the S-10s is an auxiliary gasoline system and is entirely automatic, requiring no special action by the driver. It includes a separate central fuel injector at the throttle body used just for the cold-start, a separate, small gasoline tank (a boat fuel tank) and fuel pump, and special electronic logic to control the system. For the warmer ambient temperatures, down to about the freezing level, the main methanol fuel system is used to start the engine with the M85 fuel (85% methanol and 15% gasoline). At ambient temperatures below freezing (specifically, when the coolant temperature is below 0°C), the gasoline cold-start system is invoked automatically and provides engine starting on the gasoline fuel plus about 30 seconds of warmup, then an automatic switch to the M85 system. This system was certified to provide satisfactory starting and driveaway for temperatures as low as -20°F (-29°C). In addition, all of the S-10 vehicles, including the gasoline models, have been equipped with factory-installed block heaters in order to provide for more reliability in extremely cold weather. It was recommended by AES that the block heaters be used routinely during very cold periods so that the deleterious effects of cold-engine operation with methanol might be ameliorated; however Argonne personnel use the heaters only rarely.

Nine of the S-10 vehicles have been assigned to various maintenance departments within the Argonne organization and are used by their personnel for transportation around the Argonne site to job assignments. One of the vehicles has been assigned to a scientific research department for use by personnel in that department for a variety of transportation needs. Average trip lengths for these kinds of duties are necessarily short and include a high proportion of idling or cold-engine operation.

2.2.2 Ford Crown Victoria Sedans

Conversions of five 1986 Ford Crown Victoria Sedans with 5 liter (302 cubic inches) V-8 engines and automatic transmissions were also made by Alcohol Energy Systems. These conversions included replacement of many fuel system components so as to make them compatible with methanol. The Fords have a sequentially-timed port fuel injection system; but, the standard gasoline injectors did not have flow capacity great enough to handle the extra flow demanded by a methanol system. Therefore, injectors with larger capacity (14 kg/hr capacity) were substituted for the standard units (7 kg/hr capacity) (6); no other changes in the injectors, themselves, were made, however. Both the original gasoline injectors as well as the larger-capacity injectors substituted in the methanol vehicles are manufactured by Bosch. Colder range spark plugs were substituted in the methanol Fords. In-tank fuel pumps, made by Walbro, with greater flow capacity which were said to be compatible with methanol, were also supplied with the conversion. Vehicle fuel tanks are the same as the stock gasoline tanks (18 gallon capacity) with the terneplate removed and with interior surfaces nickel-plated so as to be compatible with methanol. Appropriate changes to the vehicle's computer-control of the engine were made as necessary.

The compression ratio for the Ford methanol vehicles was increased from the standard 9.2:1 to approximately 11.2:1 (6) by use of special high-compression pistons which were made by the ECS (now ECS/Roush) Company originally for use in the methanol taxicab fleet of Fords for New York City.

The cold-start system for the Fords was supplied by the Ford Motor Company and is a proprietary system that uses only the methanol fuel. No auxiliary fuel is needed, and no special starting routines for cold weather are required; the system is entirely automatic. These systems, as installed on the Fords, were certified at AES to operate satisfactorily at the lowest required temperatures. Details of the operation of the systems are otherwise not known to the ORNL project management staff and cannot be reported herein.

The Fords have factory-installed block heaters on both the methanol and gasoline versions just as the Chevrolet S-10s to serve as emergency or back-up start systems. For the Fords it was also recommended that the block heaters be used when possible in order to minimize the severe effects of the cold weather on engine wear and performance. However, Argonne personnel have elected not to use the block heaters on a routine basis because of the inconvenience associated with the type of service in which the vehicles are assigned.

The nine Fords (five methanol and four gasoline) were placed into service at Argonne as security vehicles, and as such have been outfitted with usual police car equipment including lights, sirens, and special radios. They are used solely by the ANL security personnel in regular patrol of the ANL site. This type of service is characterized by relatively short trips and considerable engine idle time. The cars are operated on three work shifts per day and seven days per week; consequently, their mileage accumulation rate is quite high, with some vehicles accumulating close to 3000 miles (4800 km) per month.

2.2.3 Positive Crankcase Ventilation - Oil/Water Separator Bottles

For both the methanol Chevrolet S-10s and the methanol Ford Crown Victorias devices were incorporated by AES that were designed to reduce the amount of water dilution that may occur in the lubricating oil. Because much more water vapor is produced by combustion of methanol than by gasoline (for similar energy release) and because the higher-compression-ratio engines of the methanol vehicles may have more blowby, it was felt that considerable water dilution in the lubricating oil was likely and would present problems. So, AES installed a separator system within the positive crankcase ventilation (PCV) system of each of the methanol vehicles. This consisted of a bottle, of about one quart (one liter) volume, installed in the PCV system through which the oil vapors from the crankcase would normally pass. In the case of the methanol vehicles, the crankcase vapors might contain large quantities of water vapor which, it was thought, should be removed rather than recycling through the intake system along with the other vapors. The bottle was intended to allow some of the water vapor to separate/condense from the mixture while most of the oil vapor and mist would travel back to the intake system as is normal. A mechanism was included in the system so that the collected water/oil mixture could be drained periodically from the bottle, but it was necessary to open the hood for access to the drain.

2.3 Lubricating Oil, Oil Change and Sampling Intervals

Lubricating Oil for the methanol S-10 vehicles has been supplied by the Lubrizol Corporation and is a 10W-30 multi-grade oil with an additive developed by Lubrizol intended to reduce engine wear and corrosion that may be caused by the methanol fuel. The gasoline S-10s use a standard multi-grade lubricating oil recommended by General Motors for its vehicles and stocked by ANL.

Lubricating oil for the methanol Fords is the same Lubrizol 10W-30 oil as is used by the methanol Chevrolet S-10s, and that for the gasoline Fords is the same multi-grade oil as used by the gasoline S-10s.

Oil change interval for all nineteen vehicles in the project is set at 3000 miles, and the oil is sampled at 1000 mile intervals for laboratory analyses of wear metals, base number, fuel dilution, etc.

2.4 Methanol Refueling Facilities

Argonne has installed on its premises a complete methanol refueling facility including underground storage tank, fuel lines, and dispensing pump. The storage tank is fiberglass of approximately 6000 gallons (22,700 liters) capacity, manufactured by Dow-Corning (model number G 6000), and is installed underground. The tank along with its Dow 470 liner are certified to be compatible with 100% methanol. The dispensing pump is a Tokheim unit which was modified by the manufacturer to be compatible with methanol. The methanol refueling facility is located at the same site as the other refueling pumps at Argonne and has automated acquisition of refueling data. The fill tube for the underground methanol tank is located near the dispensing pump for the regular unleaded gasoline - a feature which has facilitated the mixing of the 85% methanol and 15% gasoline within the methanol tank since the gasoline can be taken from its dispensing pump and added directly into the methanol storage tank. All that is needed then is the proper quantity of methanol which is brought into the ANL site by tanker truck.

2.5 Data Requirements

Because Congress required that comparisons be made of operating costs, fuel consumption, and maintenance costs, certain data requirements are placed on Argonne. Copies of maintenance records for all nineteen vehicles, whether the maintenance is routine or non-routine, are sent to ORNL for inclusion in the Federal Methanol Fleet database. A complete repair history is maintained for each vehicle, including oil additions, oil changes, oil samples taken, and parts and labor required for other maintenance. Methanol and gasoline fuel-related maintenance is flagged in the database for special attention. Oil sample analyses are performed by a commercial laboratory located in Knoxville, Tennessee with the results sent directly to ORNL. Logs of all refueling transactions for the nineteen fleet vehicles are maintained.

Daily trip logs are maintained on which are recorded driver identification, beginning and ending odometer readings, time out, time in, and the drivers' estimate of the outdoor temperature. In order to assess the drivers' acceptance of the methanol vehicles, it was deemed appropriate to obtain their ratings of the "ease of starting" and "driveabilty" for each trip. Hence, the daily trip logs include columns in which the drivers, by making check marks, can rate the vehicles after each trip is completed. They may check either "Good," "Average," or "Poor," for both "ease of starting" and "driveability." No attempt has been made by project management staff to instruct Argonne personnel as to just what constitutes "Good," "Average," or "Poor." Rather, it is preferred that each driver make such a judgment based on his own personal experience. A specimen copy of the ANL daily trip log is included as Appendix A.

For the outdoor temperature estimates the drivers may put a check mark in one of three columns for the ambient temperature. They are: higher than 40°F; 6°F to 40°F; or less than 5°F (higher than 4°C; -14°C to 4°C; or less than -15°C). These temperature estimates help to correlate the drivers' ratings of ease of starting and driveability with temperature to reveal if the ratings suffer at lower temperatures.

3. RESULTS

3.1 Initial Emissions and Fuel Economy

Results from the exhaust emissions and fuel economy tests conducted by the Bay Area Emissions Laboratory in Hayward, California are presented in Tables 1 and 2, for the Chevrolet S-10s and Ford Crown Victorias respectively. Tests were performed according to the U.S. Federal Emissions Test Procedure (FTP), and appropriate adjustments for the methanol fuel were made in the course of the tests. Specifically, hydrocarbon emissions when methanol is the fuel are assumed to have the same ratio of methanol and gasoline as the fuel itself (85% methanol and 15% gasoline), and the methanol component values of hydrocarbon emissions have been corrected for the flame ionization detector (FID - the hydrocarbon emission analyzer) response factor of 0.855. Also noted in Tables 1 and 2 are the applicable 49-state Federal Emissions Standards, light-duty trucks for the Chevrolet S-10s and passenger cars for the Fords. Results are presented for the five vehicles of each type that were actually converted to methanol, with results being shown for each vehicle before and after conversion and for the average of the five vehicles. Fuel economy is determined from the FTP for both the city and highway cycles and is presented in both miles per gallon and kilometers per gigajoule so as to facilitate the comparison of fuel efficiencies between methanol and gasoline.

Table 1 shows that while emissions are slightly higher for the methanol Chevrolets over the gasoline versions, they still meet the Federal Standards by large margins. The reader should note that efforts have not been expended greatly to optimize or minimize the emissions from the methanol vehicles since such an undertaking would require considerable effort and would be beyond the scope of this project. Rather, the strategy has been to convert the vehicles to methanol and test for emissions without major adjustments. The more important comparison of emissions will be that which may be demonstrated in the future as the vehicles age and acquire miles. Another factor is that these emissions tests have been performed on new engines which have not been used or

Table 1. Exhaust emissions and fuel economy, from FTP tests at Bay Area Emissions Laboratory, before and after vehicle conversions to methanol

Chevrolet S-10 Pickup Trucks

Vehicle ID	Emissions (g/mile)			Fuel Economy[a]			
				City		Highway	
	HC	CO	NOx	mpg	km/GJ	mpg	km/GJ
ME-560							
(g)b	0.10	0.42	0.30	21.0	278	31.4	415
(m)c	0.29	1.39	0.62	13.6	317	19.0	443
ME-562							
(g)	0.19	0.53	0.20	20.2	267	29.7	393
(m)	0.17	0.74	0.51	13.6	317	19.4	453
ME-564							
(g)	0.14	0.45	0.36	21.4	283	29.0	383
(m)	0.33	1.36	0.71	13.5	315	20.0	467
ME-566							
(g)	0.13	0.34	0.26	25.2	333	31.8	420
(m)	0.28	1.44	0.44	13.0	303	19.6	457
ME-568							
(g)	0.16	0.32	0.59	25.5	337	32.5	430
(m)	0.27	1.39	0.43	1.35	315	20.5	478
5-Car Averages							
(g)	0.14	0.41	0.34	22.7	300	30.9	408
(m)	0.27	1.26	0.54	13.4	313	19.7	460
Applicable 49-State Federal Emission Standards							
	0.8	10.0	2.3				

[a]Fuel economy is from the Federal Test Procedure as conducted by the Bay Area Emissions Laboratory. The values of kilometers per gigajoule (km/GJ) are based, in part, on an assigned methanol heating value of 56,560 Btu/gal and a gasoline heating value of 115,400 Btu/gal. One Btu equals 1055 joules.

[b]Unleaded gasoline (per FTP requirements); before vehicle conversion to methanol.

[c]M85 consisting of 85% methanol and 15% unleaded gasoline; after vehicle conversion to methanol.

Table 2. Exhaust emissions and fuel economy, from FTP tests at Bay Area Emissions Laboratory, before and after vehicle conversions to methanol

Ford Crown Victorias

Vehicle ID	Emissions (g/mile)			Fuel Economy[a]			
				City		Highway	
	HC	CO	NOx	mpg	km/GJ	mpg	km/GJ
ME-570							
(g)b	0.17	0.43	0.40	16.3	215	24.3	321
(m)c	0.17	1.97	0.70	9.5	222	14.4	336
ME-572							
(g)	0.18	0.50	0.48	16.4	217	24.6	325
(m)	0.20	0.76	0.62	9.6	224	14.7	343
ME-574							
(g)	0.11	0.19	0.46	16.5	218	23.6	312
(m)	0.28	1.44	0.63	9.3	217	14.0	327
ME-576							
(g)	0.22	0.65	0.41	16.2	214	24.4	323
(m)	0.13	1.11	0.57	9.8	229	14.6	341
ME-578							
(g)	0.27	0.46	0.36	16.4	217	24.3	321
(m)	0.35	1.24	0.76	9.2	215	14.2	331
5-Car Averages							
(g)	0.19	0.45	0.42	16.4	216	24.2	320
(m)	0.23	1.10	0.64	9.5	222	14.4	336
Applicable 49-State Federal Emission Standards							
	0.41	3.4	1.0				

[a]Fuel economy is from the Federal Test Procedure as conducted by the Bay Area Emissions Laboratory. The values of kilometers per gigajoule (km/GJ) are based, in part, on an assigned methanol heating value of 56,560 Btu/gal and a gasoline heating value of 115,400 Btu/gal. One Btu equals 1055 joules.

[b]Unleaded gasoline (per FTP requirements); before vehicle conversion to methanol.

[c]M85 consisting of 85% methanol and 15% unleaded gasoline; after vehicle conversion to methanol.

even broken-in. This is different from the practice of the emissions certification procedure where vehicles are tested for emissions after they have accumulated 4000 miles.

The most measurable of the increases of emissions for the methanol vehicles was in the carbon monoxide, where the higher emissions suggest most likely less effective catalyst performance. Oxides of nitrogen might be expected to be slightly higher for the methanol vehicles, as they are shown to be, because those vehicles have higher compression ratios. Efficiency as indicated by kilometers per gigajoule is higher for the methanol vehicles in almost all cases shown and is probably also the result of the higher compression ratios for the methanol vehicles.

Results for the Fords, presented in Table 2, are very similar to the Chevrolets in character. Emissions are slightly higher for the methanol vehicles as compared to gasoline, but they still are well below the Federal Standards. Again, carbon monoxide is the constituent that is most increased for the methanol vehicles, and oxides of nitrogen are higher probably because of the higher compression ratios for the methanol vehicles. Efficiency is again slightly higher for the methanol vehicles probably due to the higher compression ratios.

Evaporative emissions as measured by the Sealed Housing Evaporative Determination (SHED) test by the Bay Area Emissions Laboratory are presented in Table 3 for both Chevrolet S-10s and Ford Crown Victorias, both before and after conversion to methanol. The Federal Standard for this test is 2 grams of hydrocarbons per test. All vehicles met the standard by large margins; but the methanol vehicles typically had slightly higher evaporative emissions.

3.2 Fleet Utilization and Fuel Consumption

Tables 4 and 5 summarize the fleet utilization (mileage accumulation) and fuel consumption results from the ANL fleet for its first year of operation; Table 4 reports results for the Chevrolet S-10s, and Table 5 is for the Ford Crown Victorias. Shown in the tables are data for total miles driven, average miles per trip, and average fuel economy for each of the nineteen vehicles as well as aggregate

Table 3. Evaporative emissions, from FTP Tests at Bay Area Emissions Laboratory, before and after vehicle conversions to methanol

Vehicle ID	Evaporative Emissions (grams)	
	Federal Standard = 2 grams	
	Before conversion (gasoline)	After conversion (methanol)
	Chevrolet S-10 Pickups	
ME-560	0.63	0.95
ME-562	0.62	0.58
ME-564	0.56	1.06
ME-566	0.52	0.55
ME-568	0.31	0.80
Five-car average	0.53	0.79
	Ford Crown Victorias	
ME-570	0.33	0.86
ME-572	0.42	0.48
ME-574	0.40	0.98
ME-576	0.34	0.63
ME-578	0.41	0.56
Five-car average	0.38	0.70

totals for the five vehicles of each type - methanol or gasoline (only four gasoline Fords). Almost 100,000 miles (160,000 km) of operation were accumulated on the Chevrolet S-10s and over 200,000 miles (320,000 km) on the Fords, indicating a high utilization factor for the vehicles. Gasoline vehicles of both makes have accumulated slightly more miles, but only because they were available for use sooner. Average miles per trip are quite evenly divided between methanol and gasoline vehicles, indicating that they are providing essentially equal service and experiencing essentially equal duty cycles. Trip lengths appear to be longer than might have been expected with the vehicles confined to on-site operation, but this results from the fact that multiple starts and stops are probably included in most "trips." Fuel economy in miles per gallon is not particularly good, probably another result of

Table 4. ANL Fleet utilization and fuel consumption data, through December 31, 1987

Chevrolet S-10 Pickup Trucks

Vehicle ID	Total Miles	Average miles/trip	Fuel economy	
			mpg	km/GJ[a]
		Methanol vehicles		
ME-560	16,446	15.4	9.8	229
ME-562	6,099	20.7	8.7	203
ME-564	7,266	22.4	9.5	222
ME-566	7,778	29.7	8.8	205
ME-568	5,446	7.1	11.2	261
TOTAL	43,035	15.8[b]	9.6[b]	224[b]
		Gasoline vehicles		
ME-561	14,862	11.0	16.6	219
ME-563	9,828	26.9	16.6	219
ME-565	6,410	15.9	18.5	245
ME-567	5,915	11.7	17.3	229
ME-569	9,411	25.2	16.7	221
TOTAL	46,426	15.5[b]	16.9[b]	219[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.

the short-trip duty that the vehicles are experiencing. For both Chevrolets and Fords, the average fuel economy, whether methanol or gasoline, is less than that which was attained in the city driving cycle of the Federal Test Procedure as reported in Tables 1 and 2. This is further evidence of rather strenuous duty that the vehicles experience at Argonne, indicating large proportions of time probably in the idle mode of engine operation.

One of the gasoline Fords (number ME-571) has been outfitted with two hour-meters installed inside the engine compartment to record the

Table 5. ANL Fleet utilization and fuel consumption data, through December 31, 1987

Ford Crown Victorias

Vehicle ID	Total Miles	Average miles/trip	Fuel economy	
			mpg	km/GJ[a]
		Methanol vehicles		
ME-570	15,180	10.1	6.3	147
ME-572	26,451	10.6	6.2	145
ME-574	19,864	10.9	6.2	145
ME-576	15,303	9.6	6.0	140
ME-578	20,591	11.6	6.0	140
TOTAL	97,389	10.6[b]	6.2[b]	145[b]
		Gasoline vehicles		
ME-571	19,548	8.7	10.2	135
ME-573	37,958	11.8	10.5	139
ME-575	21,087	8.8	10.2	135
ME-577	35,903	12.3	10.8	143
TOTAL	114,496	10.6[b]	10.5[b]	139[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.

amount of time that the engine runs as well as the amount of time that the transmission is engaged in a driving gear. This was done to provide additional information regarding the actual use-pattern of the Fords. A reading of the two meters shortly after the period covered by this report indicated 1347 total hours of engine running and 584 hours of transmission-engaged time. This indicates that the engine was running but without the transmission engaged (idling) for approximately 59% of the time, a result that is to be expected for police car service.

The on-road efficiencies as given by kilometers per gigajoule show that the methanol vehicles are slightly more efficient than the gasoline vehicles of the same type, thus verifying the trends that were demonstrated in the fuel economy tests reported in Tables 1 and 2 and resulting probably from the higher compression ratios of the methanol vehicles.

3.3 Comparison of Maintenance and Service - Methanol and Gasoline Vehicles

Tables 6 and 7 show the data for all maintenance performed at Argonne on the Chevrolets and Fords, with numbers of occasions of maintenance or service and total labor hours for each of the nineteen vehicles presented. "All maintenance," for the purposes of this report, includes any maintenance or service for which a vehicle service repair

Table 6. Maintenance Required by ANL Methanol Fleet Vehicles - Chevrolet S-10 Pickup Trucks

	Maintenance	
	Number of occasions	Labor hours
	Methanol Chevrolets	
ME-560	26	36.9
ME-562	17	34.8
ME-564	16	22.4
ME-566	19	33.0
ME-568	14	18.7
TOTAL	92	145.8
	Gasoline Chevrolets	
ME-561	16	8.4
ME-563	14	8.6
ME-565	8	4.9
ME-567	7	5.8
ME-569	13	10.4
TOTAL	58	38.1

Table 7. Maintenance Required by ANL Methanol Fleet Vehicles - Ford Crown Victorias

	Maintenance	
	Number of occasions	Labor hours
	Methanol Chevrolets	
ME-570	33	125.6
ME-572	43	82.6
ME-574	43	65.7
ME-576	36	77.5
ME-578	42	159.0
TOTAL	197	510.4
	Gasoline Chevrolets	
ME-571	35	64.1
ME-573	49	75.8
ME-575	29	43.0
ME-577	43	46.4
TOTAL	156	229.3

order was written by Argonne. This includes routine maintenance such as oil changes, tire changes, etc. as well as all vehicle preparation service such as installation of lights, radios, and decals.

Since routine maintenance and vehicle preparation have been performed on the equivalent schedules for all vehicles, and since the vehicles do not differ greatly in the amount and types of use that they experience, then a straightforward comparison of "all maintenance" between methanol and gasoline vehicles could reveal the differences in maintenance that are caused by the methanol fuel or the conversion technology. Such is not the case, however, because these data also include maintenance associated with component upgrades or improvements and some early corrective maintenance associated with methanol components. To include those occasions in the comparison is unfair to the assessment of methanol engine technology since, in some cases, it was known before the vehicles were delivered that certain improved components would be provided shortly after the fleet start-up that could have been included from the beginning if the start-up of the methanol operation could have been deferred.

Therefore, in the next section, the details of the various maintenance occasions that should not be included in the comparison between methanol and gasoline are discussed individually. Then, the data associated with those occasions (numbers of occasions and hours) will be deducted from the data of Tables 6 and 7, and the maintenance comparison will be made without counting the data from those circumstances.

3.3.1 Maintenance Associated with Methanol Component Upgrades/Improvements/Corrections - Chevrolet S-10 Pickup Trucks

Maintenance associated with methanol component upgrades, improvements, or corrections for the methanol Chevrolets is shown in Table 8 listed by vehicle. The total maintenance of this type represented 59.5 hours of labor on 18 occasions of maintenance. The components or systems involved in that amount are detailed below:

Separator Bottle: All of the methanol Chevrolets were delivered with the oil/water separator systems that were discussed in section 2.2.3 above. Users and drivers of these vehicles complained that the bottles were inconvenient because they required that the hoods be opened daily in order to check the liquid level in the bottle and, further, that many persons did not know how to empty the bottle. It was decided, after consultation with parties associated with the Argonne project, that the bottle on one of the vehicles, as an experiment, would be disconnected and that the PCV system in that vehicle would be routed in the normal fashion for a period of time during which the situation could be studied. During that period, the oil sample analyses were closely monitored to determine if that vehicle experienced higher than normal water dilution in the crankcase oil. Since water dilution was not elevated during the short study period, it was decided to disconnect the bottles of all of the vehicles. Prior to the disconnects, a few of the users requested maintenance for the purpose of emptying the bottles, and these data are included in Table 8.

Table 8. ANL Maintenance Involving Component Upgrades/Improvements/Corrections -

Chevrolet S-10 Pickup Trucks

	Occasions	Labor hours
ME-560:		
Separator Bottle	2	2.5
Gasoline Cold-Start System	1	8.0
Computer PROM	1	3.5
	4	14.0
ME-562:		
Gasoline Cold-Start System	1	8.5
Computer PROM	1	0.5
	2	9.0
ME-564:		
Separator Bottle	2	1.5
Gasoline Cold-Start System	1	8.0
Computer PROM	1	1.0
	4	10.5
ME-566:		
Separator Bottle	1	0.5
Gasoline Cold-Start System	1	9.0
Checkout Computer PROM	2	7.5
Computer PROM	1	0.5
	5	17.5
ME-568:		
Separator Bottle	1	0.5
Gasoline Cold-Start System	1	7.0
Computer PROM	1	1.0
	3	8.5
TOTAL	18	59.5

Gasoline Cold-Start System: The methanol Chevrolets were delivered initially to the ANL site without the auxiliary gasoline cold-start systems. Shortly afterwards, the systems were installed on the vehicles at ANL facilities. The maintenance records of these events also show up in the database and are accounted for in Table 8.

Computer Programmable-Read-Only-Memory (PROM): An improvement or correction was made to the computer memories (PROM) to incorporate a different calibration for air-fuel ratio during the engine warm-up period. There had been some occasions of what seemed to be rich fuel metering during the warm-up periods, and the result was rough-running engines. It was determined that an improvement to the programming or calibration of the computer's memory was the appropriate solution. The PROMs with the improved calibration were supplied, and the new units were installed on all of the methanol Chevrolets. Performance of the methanol vehicles during warm-up since the new PROMs were installed has been satisfactory.

3.3.2 Maintenance Associated with Methanol Component Upgrades/Improvements/Corrections - Ford Crown Victorias

Maintenance associated with methanol component upgrades, improvements, or corrections for the methanol Fords is shown in Table 9 listed by vehicle. The total maintenance of this type represented 273.5 hours of labor on 43 occasions of maintenance. The components or systems involved in that amount are detailed below:

Separator Bottle: The same phenomenon as for the Chevrolets regarding inconvenience was experienced with the Fords and led to the same result. That is, the bottles were disconnected and the PCV system routed in the normal fashion. No increase in water dilution in the crankcase oil was observed after the bottles were disconnected.

Temperature Sending Unit: A sensor which indicates cooling system temperature for the electronic engine controller of the Fords was replaced by a new unit which was said to be more reliable. There were no previous failures of the sensors at Argonne, but the improved sensors were provided and installed as a precaution.

Table 9. ANL Maintenance Involving Component Upgrades/Improvements/Corrections - Ford Crown Victorias

	Ocassions	Labor hours
ME-570:		
Separator Bottle	2	1.5
Temperature Sending Unit	1	1.5
Fuel Pump	1	12.0
Fuel Injectors	4	24.0
Fuel Filler Neck	1	1.0
Head Gasket	1	50.0
	10	90.0
ME-572:		
Separator Bottle	1	0.5
Temperature Sending Unit	1	1.5
Fuel Injectors	3	22.5
Fuel Filler Neck	1	1.0
Dipstick	1	0
	7	25.5
ME-574:		
Separator Bottle	1	0.5
Temperature Sending Unit	1	1.5
Fuel Injectors	4	25.0
Fuel Filler Neck	1	1.0
	7	28.0
ME-576:		
Temperature Sending Unit	1	1.5
Fuel Pump	1	1.5
Fuel Injectors	5	24.0
Fuel Filler Neck	1	1.0
Dipstick	1	0
	9	28.0
ME-578:		
Separator Bottle	2	1.0
Temperature Sending Unit	1	1.5
Fuel Pump	1	6.0
Fuel Injectors	3	18.5
Fuel Injectors - Engine Rebuild	1	74.0
Fuel Filler Neck	1	1.0
Dipstick	1	0
	10	102.0
TOTAL	43	273.53

Fuel Injectors: A considerable portion of the maintenance shown in Table 9 was associated with the replacing of fuel injectors. Those replacements were necessitated by two circumstances that were not indicators of the status of methanol engine technology but, rather, were situations that were greatly aggravated by the methanol fuel. Before the causes were positively identified, injectors were being changed quite frequently. Additionally, before it was known that injectors required changing, some engine damage was incurred by one of the Fords. These situations and circumstances are discussed below:

Fuel Filler Neck and Fuel Injectors: The fuel filler necks of the methanol Fords as delivered had the stock terneplate finish, and it was eventually stripped off by the corrosive effect of the methanol and went into the fuel system. The cars were performing quite poorly at this point, and symptoms pointed to lean combustion - as if fuel injectors were plugging. Indeed, they were being plugged with material that laboratory analyses identified as containing large amounts of lead. At that point, the fuel filler necks were the most likely source of the lead. They were replaced with filler necks that had the terneplate removed and were nickel-plated.

Before all of these phenomena could be fully characterized, one of the cars, number ME-578, suffered major engine damage from preignition and knock which were being caused by improper air-fuel ratios. One piston melted through, and another was damaged. The process of restoring the engine of ME-578 required 74 hours of service as indicated in Table 9. While the engine was disassembled, and on the advice of others associated with the Argonne activities, chrome piston rings were substituted for the molybdenum rings that were supplied with the car on its delivery to Argonne. This vehicle remains as the single one of the Fords to have chrome piston rings.

Dipsticks and Fuel Injectors: Subsequent to the problem with the fuel filler necks, the need for replacing fuel injectors reappeared, and while the symptoms were very similar to the previous case, the causes were not obvious. Laboratory analyses of fuel injector deposits revealed large amounts of organic materials on the injector tip. At about the same time, it was learned that the Fords were being routinely overfilled with oil each time the oil was changed. Typically, six quarts of oil were added during an oil change rather than the nominal five quarts. Oil is stored in drums at Argonne and measured out in bulk for an oil change, not by quarts, and the dipsticks are the guide for correct oil filling. There was, apparently, a discrepancy regarding the oil dipsticks which was misleading Argonne personnel about the proper oil level in the sump. So, all Argonne Ford dipsticks were gauged and marked accurately, and oil has been added since then according to the new markings on the dipstick.

Additionally, a fuel injector of an improved design that was recommended by Ford Motor Company as representing a solution to the continuing problem of injector fouling at Argonne was made available. The new injector, the 1.3C model from Bosch, replaced the pintle design which was thought to add to the injector fouling problems in conjunction with the other effects from the oil, etc. Injectors of the new design were installed in the Fords in the same time period that the corrections were being made to the dipsticks.

It has not been necessary to replace injectors in any of the Fords since the time that the new injectors were installed and the oil overfilling problem was corrected. The fact that the injector fouling problem appears to be resolved is thought to be a result primarily of having corrected the oil overfill problem rather than the result of the new injector design. This conclusion is further supported by the fact that one of the methanol Fords, number ME-572, still had the original injector style at the end of 1987, this after several thousand miles and several months since the oil overfill problem had been resolved. This Ford just did not generate the need for new injectors since its problems were corrected with the new dipstick markings.

Head Gasket: One of the Fords, number ME-570, suffered a blown head gasket probably as a result of the higher compression ratio for the methanol engines along with the poor combustion associated with injector fouling. On that occasion, a representative from Alcohol Energy Systems, Inc. traveled to Argonne to help with the diagnosis of the injector situation with the Fords in general. Vehicle ME-570 was used for the diagnostic examination since it needed repairs anyway, and the process required 50 hours labor for that vehicle.

Fuel Pump: Originally supplied fuel pumps for the methanol Fords were to be replaced by improved-design fuel pumps when they became available. This was done for three of the Fords during the time period covered by this report, and the associated maintenance data are shown in Table 9.

3.3.3 Comparison of Maintenance and Service - Methanol and Gasoline Vehicles - Deducting for Maintenance Associated with Component Upgrades/Improvements/Corrections

Tables 10 and 11 present the maintenance data for the Chevrolets and Fords, respectively, after deducting that associated with methanol

Table 10. Maintenance Required by ANL Methanol Fleet Vehicles; Deducting for Component Upgrades/Improvements/Corrections - Chevrolet S-10 Pickup Trucks

Vehicle ID	Maintenance: Occasions	Maintenance: Frequency (Occasions per 1000 mi.)	Maintenance: Labor hours	Maintenance: Intensity (hours per 1000 mi.)
		Methanol Chevrolets		
ME-560	22	1.3	22.9	1.4
ME-562	15	2.5	25.8	4.2
ME-564	12	1.6	11.9	1.6
ME-566	14	1.8	15.5	2.0
ME-568	11	2.0	10.2	1.9
TOTAL	74	1.7	86.3	2.0
		Gasoline Chevrolets		
ME-561	16	1.1	8.4	0.6
ME-563	14	1.4	8.6	0.9
ME-565	8	1.3	4.9	0.8
ME-567	7	1.2	5.8	1.0
ME-569	13	1.4	10.4	1.1
TOTAL	58	1.3	38.1	0.8

Table 11. Maintenance Required by ANL Methanol Fleet Vehicles; Deducting for Component Upgrades/Improvements/Corrections -

Ford Crown Victorias

Vehicle ID	Maintenance			
	Occasions	Frequency (Occasions per 1000 mi.)	Labor hours	Intensity (hours per 1000 mi.)
		Methanol Chevrolets		
ME-570	23	1.5	35.6	2.3
ME-572	36	1.4	57.1	2.2
ME-574	36	1.8	37.7	1.9
ME-576	27	1.8	49.5	3.2
ME-578	32	1.6	57.0	2.8
TOTAL	154	1.7	236.9	2.4
		Gasoline Chevrolets		
ME-571	35	1.8	64.1	3.3
ME-573	49	1.3	75.8	2.0
ME-575	29	1.4	43.0	2.0
ME-577	43	1.2	46.4	1.3
TOTAL	156	1.3	229.3	2.0

component upgrades, improvements, and corrections. These data, when presented in this fashion, represent a more accurate comparison of methanol engine technology with production gasoline engine technology. The tables include columns showing frequency of maintenance (occasions per 1000 miles) and labor intensity (hours per 1000 miles).

Table 10 for the Chevrolets shows that the methanol vehicles require more frequent maintenance and more intense labor than the gasoline vehicles. The difference in frequency is not large, but the labor intensity is twice as high for the methanol vehicles as compared to the gasoline vehicles. Additional time required for servicing the methanol vehicles is probably due, in part, to the fact that personnel at Argonne are somewhat unfamiliar with the systems of the methanol Chevrolets.

Note that methanol vehicle number ME-562 required, by far, the most maintenance of any of the Chevrolets, taking frequency and labor intensity together.

Table 11 shows only slight differences in frequency of maintenance and labor intensity between methanol and gasoline Fords. Furthermore, there are not great differences between individual vehicles in terms of the maintenance required.

3.4 Lubricating Oil Sample Analysis

Samples of the lubricating oil, drawn from the crankcase of each of the nineteen vehicles at approximately 1000 mile intervals, are analyzed for total base number, kinematic viscosity, and concentrations of iron, lead, copper, aluminum, chromium, sodium, and silicon. The data from these analyses are kept in the database at ORNL and will add considerable perspective to any reviews of this project's final results. Generally, a fleet operator uses information from oil sample analysis as a diagnostic tool to reveal needs for preventive or corrective maintenance. In this project, however, the information is not generally used to intervene in the natural processes that are progressing in the engines of the vehicles under study. Only in rare circumstances has the information been used to implement any vehicle service that would not have ordinarily occurred at a given point in time. No significant abnormal trends have been observed in either the total base number or the kinematic viscosity of the oil of any of the vehicles for the period of this report. Silicon enters the oil usually by contamination from dirt in the environment, and data regarding its concentration are not as enlightening as that of other contaminants vis-a-vis engine wear. Of iron, lead, and copper, iron is usually the largest contributor to lubricating oil contamination in both the methanol vehicles and the gasoline vehicles; aluminum is usually very small or negligible.

Results are presented below for wear metals accumulation rates in the lubricating oil. These data are found in a two-step procedure by (1) fitting linear regressions (least squares curve-fits) to the wear metals concentration data as a function of distance since oil change and

(2) determining the slopes of the regressions. Figure 2 is an example of this procedure where iron concentration data for the methanol and gasoline Chevrolet S-10s are shown on the same graph. The slopes of the lines representing the linear regressions are the wear metals accumulation rates, and these values are compared between methanol and gasoline vehicles to assess their relative engine wear conditions. Figure 3 shows the same comparison of iron accumulation rates for the methanol and gasoline Fords.

Tables 12 and 13 present the accumulation rates for iron, lead, copper, and aluminum in parts per million per 1000 miles for the Chevrolets and Fords, respectively. For the Chevrolets the accumulation rates of iron and lead were elevated over that of their comparable gasoline vehicles; the difference was more noticeable for the lead. For the Fords, only the iron accumulation was notably higher for the methanol vehicles: the other wear metals were of the same order between methanol and gasoline vehicles.

ORNL-DWG 88C-4432 ETD

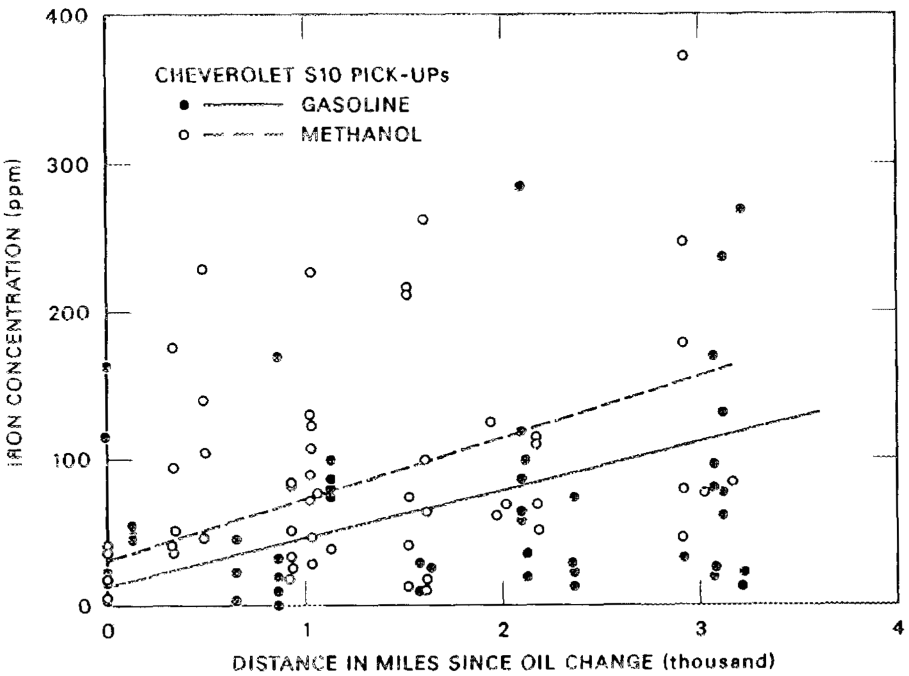

Fig. 2. Concentration of iron in lubricating oil — Chevrolets.

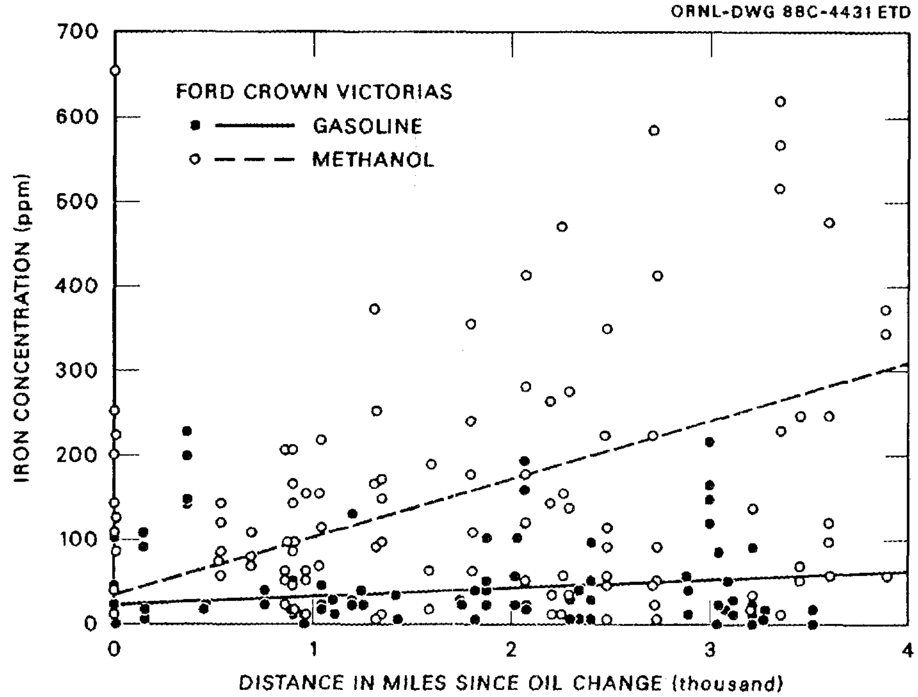

Fig. 3. Concentration of iron in lubricating oil — Ford.

Table 12. Wear metals accumulation rates
(in lubricating oil)
Argonne National Laboratory

Chevrolet S-10 Pickup Trucks

Average wear metals accumulated in
lubricating oil in parts per million
per 1000 miles of operation

Wear metal	ppm per 1000 miles	
	Methanol vehicles	Gasoline vehicles
Iron	42	32
Lead	64	17
Copper	4	5
Aluminum	6	2

Table 13. Wear metals accumulation rates (in lubricating oil) Argonne National Laboratory

Ford Crown Victorias

Average wear metals accumulated in lubricating oil in parts per million per 1000 miles of operation

Wear metal	ppm per 1000 miles	
	Methanol vehicles	Gasoline vehicles
Iron	67	10
Lead	10	13
Copper	3	7
Aluminum	6	2

It should be noted that while the rates of accumulation of some of the wear metals for the methanol vehicles are higher, the wear rates may still be tolerable. There are no strict guidelines as to just what should be expected to be "normal" wear rates for methanol engines. One would think that the gasoline vehicles should be considered to be the standard and, therefore, be the norm by which the methanol vehicles should be judged. However, indications are that methanol vehicles can operate (in moderate climates) at elevated levels of wear rates for long periods with no evidence of accelerated wear upon examination after over 100,000 miles (160,000 km) of use. (7)

3.5 Methanol Fuel Supply and Analyses

For the time period from the beginning of the project at Argonne through the end of 1987, methanol fuel had been procured by Argonne a total of six times. In all cases, except for one, fuel for the methanol vehicles (methanol and gasoline blended together), was procured separately and mixed in the storage tank simply by adding the two constituents together. For the single occasion when this was not the case, methanol fuel in the proper ratio, i.e. 85% methanol and 15% gasoline was received, already blended, from Amoco. Data regarding the fuel procurements and laboratory analyses of the fuel are contained in Appendix B.

3.6 Drivers' Perceptions of Vehicle Performance

During the period of time covered by this report, Argonne personnel recorded 5,720 trips in the Chevrolet S-10 pickup trucks of which 2,716 were in the methanol trucks and 3,004 were in the gasoline trucks. In the same time period, there were a total of 19,988 trips in the Ford Crown Victorias with 9,189 of them occurring in the methanol Fords and 10,799 in the gasoline Fords. Being that there are only four gasoline Fords, the rate of their use appears to have been considerably greater than that for the methanol Fords, but this is only because the gasoline Fords were available for use at Argonne for about six more months.

Approximately 180 Argonne personnel have driven one of the methanol Chevrolets at least once, while the comparable number for the gasoline Chevrolets is approximately 140. Given the manner in which the Chevrolets have been assigned for use, very few of the persons who have driven one of the methanol Chevrolets have also driven one of the gasoline Chevrolets. This situation is being remedied during the second year of operation by switching vehicle assignments so that the vehicles experience equal exposure. For the Fords, the situation is entirely different since all of the vehicles, both methanol and gasoline, are exposed in normal usage to nearly all of the ANL security personnel who would have any occasion to drive any of the security vehicles. Therefore, both the methanol and gasoline Fords have been exposed to approximately 150 different drivers on nearly an equal basis.

3.6.1 ANL Drivers' Ratings of Chevrolet S-10 Pickup Trucks

Tables 14, 15, and 16 show the ANL drivers' ratings of the Chevrolets "ease of starting" and "driveability" with Tables 14 and 15 showing the numbers of responses under the categories of "Good," "Average," and "Poor" and Table 16 showing the average response for the

Table 14. ANL Drivers' responses to "Ease of Starting" question, from daily trip logs, through December 31, 1987

Chevrolet S-10 Pickup Trucks

Vehicle ID	Number of responses				
	Good	Average	Poor	No response	Total
		Methanol Vehicles			
ME-560	1,034	21	9	3	
ME-562	135	148	6	6	
ME-564	268	50	5	1	
ME-566	260	0	1	1	
ME-568	663	82	15	8	
Subtotal	2,360	301	36	19	2,716
		Gasoline Vehicles			
ME-561	1,320	19	0	16	
ME-563	310	35	9	12	
ME-565	378	18	0	8	
ME-567	432	52	16	5	
ME-569	363	11	0	0	
Subtotal	2,803	135	25	31	3,004
TOTAL	5,163	436	61	60	5,720

Table 15. ANL Drivers' responses to "Driveability question, from daily trip logs, through December 31, 1987

Chevrolet S-10 Pickup Trucks

Vehicle ID	Number of responses				
	Good	Average	Poor	No response	Total
		Methanol Vehicles			
ME-560	872	105	83	7	
ME-562	124	159	6	6	
ME-564	224	98	1	1	
ME-566	245	4	1	12	
ME-568	595	151	8	14	
Subtotal	2,060	517	99	40	2,716
		Gasoline Vehicles			
ME-561	1,303	19	0	22	
ME-563	354	35	9	12	
ME-565	386	18	0	12	
ME-567	369	52	16	10	
ME-569	365	11	0	0	
Subtotal	2,765	135	25	56	3,004
TOTAL	4,825	436	61	696	5,720

Table 16. Averages of responses from the ANL daily trip logs for "Ease of starting" and "Driveability": data through December 31, 1987

Chevrolet S-10 Pickup Trucks

	Responses (%)			
	Good	Average	Poor	No Response
	Averages for vehicle types			
Ease of starting				
Methanol vehicles	87	11	1	1
Gasoline vehicles	93	4	1	2
Fleet average	90	8	1	1
Driveability				
Methanol vehicles	76	19	4	1
Gasoline vehicles	92	6	Nil	2
Fleet average	84	12	2	2

two groups of Chevrolets in percentages of total responses. These results are for all ambient temperatures. Data showing the ratings separated as a function of temperature are presented in the next section. For ease of starting the drivers rated the methanol vehicles only slightly lower than the gasoline vehicles, but both vehicle types performed quite well in the absolute sense in that category of ratings. Driveability of the methanol vehicles did not fare as well as ease of starting in the comparison with the gasoline vehicles, but, nevertheless was rated as "Good" for 76% of the time. Vehicle number ME-562 had the greatest number (and percentage) of ratings of "Average" and the smallest number of "Good" ratings of any of the Chevrolets for both ease of starting and driveability and was the only vehicle of the ten to be rated as "Average" more often than "Good" for both questions. This result correlates well with the maintenance data of Sect. 3.3 above where it was shown that vehicle number ME-562 required maintenance more frequently and with more effort than any other of the Chevrolets.

The Chevrolets, otherwise, were rated in the overwhelming majority of the time as "Good" for both ease of starting and driveability.

3.6.2 ANL Drivers' Ratings of Ford Crown Victorias

Similar results for the Fords are presented in Tables 17, 18, and 19, again representing results for all ambient temperatures. As a group, the Fords did not fare as well as the Chevrolets in either ease of starting or driveability. Percentages for the "Good" rating were lower than for the Chevrolets for both methanol and gasoline cars in both of the ratings categories, although for the gasoline cars the percentages were only slightly lower than the comparable results for the Chevrolets. In addition, the incidence of the "Average" rating was measurably higher for the Fords than for the Chevrolets. The comparison of methanol Fords to gasoline Fords shows that the drivers rate the gasoline cars substantially higher for both ease of starting and driveability. The most noticeable difference is in driveability where only

Table 17. ANL Drivers' responses to "Ease of Starting" question, from daily trip logs, through December 31, 1987

Ford Crown Victorias

Vehicle ID	Number of responses				
	Good	Average	Poor	No response	Total
	Methanol Vehicles				
ME-570	1,123	359	15	11	
ME-572	1,745	654	90	5	
ME-574	1,306	437	66	6	
ME-576	1,346	221	16	15	
ME-578	1,016	695	40	23	
Subtotal	2,060	2,366	227	60	9,189
	Gasoline Vehicles				
ME-571	2,033	184	15	13	
ME-573	2,657	543	3	24	
ME-575	2,347	42	0	10	
ME-577	2,391	508	14	15	
Subtotal	9,428	1,277	32	62	10,799
TOTAL	15,964	3,643	259	122	19,988

Table 18. ANL Drivers' responses to "Driveability question, from daily trip logs, through December 31, 1987

Ford Crown Victorias

Vehicle ID	Number of responses: Good	Average	Poor	No response	Total
Methanol Vehicles					
ME-570	906	492	96	14	
ME-572	1,302	935	251	6	
ME-574	1,097	547	160	11	
ME-576	970	477	128	23	
ME-578	880	676	190	28	
Subtotal	5,155	3,127	825	82	9,189
Gasoline Vehicles					
ME-571	2,012	204	15	14	
ME-573	2,451	737	11	28	
ME-575	2,327	57	2	13	
ME-577	2,207	688	12	21	
Subtotal	8,997	1,686	40	76	10,799
TOTAL	14,152	4,813	865	158	19.988

56% of the time did the drivers rate the methanol Fords as "Good" in driveability; this is probably a direct result of the injector problems that were discussed in section 3.3 above. (This still represents a good impression by the drivers of the methanol Fords since "Good" and "Average" received a total of 90% of the individual ratings of drive-ability.) Methanol cars received "Poor" ratings substantially more often than the gasoline cars.

Methanol Ford number ME-572 received the largest number of poor ratings in both ease of starting and driveability and also quite large numbers of "Average" ratings compared to the rest of the Fords. This finding is not reflected in the maintenance data above where vehicle

Table 19. Averages of responses from the ANL daily trip logs for "Ease of starting" and "Driveability": data through December 31, 1987

Ford Crown Victorias

	Responses (%)			
	Good	Average	Poor	No Response
	Averages for vehicle types			
Ease of starting				
Methanol vehicles	71	26	2	1
Gasoline vehicles	87	12	Nil	1
Fleet average	80	18	1	1
Driveability				
Methanol vehicles	56	34	9	1
Gasoline vehicles	83	16	Nil	1
Fleet average	71	24	4	1

number ME-572 was shown to be better than the average of the methanol vehicles in terms of frequency of maintenance and labor required.

3.6.3 ANL Drivers' Perceptions of Vehicles as Function of Ambient Temperature

Separating the data of Tables 14, 15, 17, and 8 and displaying it by ambient temperature is a good way to evaluate whether the drivers assess the performance of the vehicles any differently when the weather is cold. This is done in Tables 20 and 21 where the divisions of temperature correspond to those on the drivers' trip logs, i.e. greater than 40°F, 6 to 40°F, and 5°F or less. The drivers indicate on the trip logs only their own estimate of the outdoor temperature; it is not necessary that they try to indicate the precise temperature since it may be difficult for them to know the exact outdoor temperature.

The winter of 1986-87 and that small portion of the winter of 1987-88 that occurred during the period of this report were not extremely cold in the Argonne area. There were very few occurrences of

Table 20. ANL Drivers' responses to "Ease of starting" and Driveability", as influenced by ambient temperature; data through December 31, 1987

Chevrolet S-10 Pickup Trucks

	Responses in number and in (percentages)			
	Good	Average	Poor	Total
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
6 to 40°F				
Methanol vehicles	880 (88)	108 (11)	10 (1)	998
Gasoline vehicles	1,001 (95)	48 (5)	5 (0)	1,054
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
6 to 40°F				
Methanol vehicles	742 (76)	210 (21)	33 (3)	985
Gasoline vehicles	991 (94)	61 (6)	0 (0)	1,053
5°F or less				
Methanol vehicles	6 (32)	10 (53)	3 (15)	19
Gasoline vehicles	17 (100)	0 (0)	0 (0)	17

temperatures below 5°F, while there was a near normal frequency of moderately cold temperature of between 6°F and 40°F. Therefore, the period did not represent an outstandingly good test of the performance of the vehicles in extremely cold weather. Nevertheless, the data for the moderately cold weather are enough in number to begin to assess the acceptance of the cold-weather methanol vehicle technology by the Argonne drivers.

Table 21. ANL Drivers' responses to "Ease of starting" and Driveability", as influenced by ambient temperature; data through December 31, 1987

Ford Crown Victorias

	Responses in number and in (percentages)			
	Good	Average	Poor	Total
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
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
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
6 to 40°F				
Methanol vehicles	2,024 (65)	893 (28)	223 (7)	3,140
Gasoline vehicles	3,931 (87)	564 (13)	19 (0)	4,514
5°F or less				
Methanol vehicles	143 (99)	0 (0)	1 (1)	144
Gasoline vehicles	118 (98)	3 (2)	0 (0)	121

The differences in ratings of the Chevrolets between the various temperature ranges were almost imperceptible as shown in Table 20. Ratings for temperatures between 6 and 40°F were very nearly the same as those for temperatures greater than 40°F.

For the Fords the ratings of ease of starting shown in Table 21 were very nearly the same between the two higher temperature ranges. Responses for the coldest temperature range are probably not large enough in number to be statistically significant. For driveability the Fords were rated higher when weather in the temperature range of 6 to 40°F occurred than for that with temperatures of greater than 40°F, but this is probably because the maintenance problems that were described in section 3.3 earlier in this report all occurred in that part of the year with warmer temperatures, i.e. in the spring and summer of 1987. The evidence of the those problems with the vehicles should be expected to be manifest in the ratings of the vehicles by the drivers during that time period.

While the data for cold-weather performance of the Argonne vehicles are somewhat incomplete at this point, the trends in the data support the conclusion that the drivers perceive very little difference in performance of the methanol vehicles as the weather becomes cold.

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Sergeant Roger Roberts - Argonne Security

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APPENDICES

APPENDIX A - COPY OF TRIP LOG

federal methanol fleet

ARGONNE NATIONAL LABORATORY AUTOMOBILE REGISTER

(FOR METHANOL VEHICLES ONLY)

DATE	TIME OUT	DRIVER BADGE NUMBER	PLEASE CHECK (√)			ODOMETER		PLEASE CHECK (√)					
			OUTDOOR TEMPERATURE					EASE OF STARTING			DRIVEABILITY		
			$5^{\circ}F$ OR $<$	$6^{\circ}F$ TO $40^{\circ}F$	$> 40^{\circ}F$	OUT	IN	GOOD	AVG	POOR	GOOD	AVG	POOR

MAKE ______________ MODEL ______________________

M. E. NO. ______________________________________

Appendix A. Specimen copy of Argonne Trip Log.

APPENDIX B — FUEL PROCUREMENT AND LABORATORY ANALYSES

Fuel deliveries to Argonne are detailed below with the dates and amounts of methanol listed. The amounts given are only for the methanol except for delivery number 4 which was a delivery of M85. In the other cases, the appropriate amount of unleaded regular gasoline was added from Argonne supplies to the amount of methanol shown here in order to blend M85.

Table B.1. Details of methanol fuel deliveries

Fuel Delivery number	Date	Methanol amount (gal)
1	7-22-86	3,000
2	2-23-87	4,024
3	5-11-87	4,060
4	8-12-87	3,000*
5	9-22-87	4,710
6	12-7-87	4,112

*Delivery was pre-blended M85 fuel, not just methanol alone.

Laboratory analyses of the fuel, as taken from the dispensing pump at Argonne after the proper fuel mixtures have been implemented in the storage tank, have been performed routinely by AutoResearch Laboratories, Inc. The analyses include determinations of the Reid Vapor Pressure, the water content, the contamination by chlorides, and the distillation curve. Data are presented in Table B.2 for the results of those tests for Reid Vapor Pressure, water content, and chlorides contamination.

Table B.2. Results of laboratory analyses of methanol fuel at Argonne National Laboratory

Fuel delivery number	Reid vapor pressure (psi) (D-323 dry method)	Water (ppm) (D-4377)	Chlorides (ppm) (microcoulo.)
1	8.3	939*	1.3**
2	10.0	446	0.7**
3	10.05	392	<1
4	5.5	1226	<1
5	8.6	314	<1
6	7.0	605	<1

*D-1744

**Modified D-1317

ORNL/TM-10816

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