EPA/AA/CTAB/87-02

Technical Report

Phase I Testing of Toyota Lean Combustion System (Methanol)

by

Gregory K. Piotrowski
J. Dillard Murrell

January 1987

NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources
Emission Control Technology Division
Control Technology and Applications Branch
2565 Plymouth Road
Ann Arbor, Michigan 48105

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ANN ARBOR, MICHIGAN 48105

OFFICE OF
AIR AND RADIATION

June 4, 1987

MEMORANDUM

SUBJECT: Exemption From Peer and Administrative Review

FROM: Karl H. Hellman, Chief KH
Control Technology and Applications Branch

TO: Charles L. Gray, Jr., Director
Emission Control Technology Division

The attached report entitled, "Phase I Testing of Toyota Lean Combustion System (Methanol)," (EPA-AA-CTAB-87-02) describes characterization testing comprised of transient driving and evaporative emission tests conducted on both M100 and M85 methanol fuels.

Since this report is concerned only with the presentation of data and its analysis and does not involve matters of policy or regulations, your concurrence is requested to waive administrative review according to the policy outlined in your directive of April 22, 1982.

Approved: ______________________ Date: ____________
Charles L. Gray, Jr., Dir., ECTD

Attachment

Note

This report has been published, substantially as it appears here, as SAE Paper 871090, "Fuel Economy and Emissions of a Toyota T-LCS-M methanol Prototype Vehicle," May 1985.

Background

The Toyota lean combustion system methanol (T-LCS-M) is a lean burn methanol combustion system designed to max- imize fuel economy and driving performance while minimizing pollutant emissions. Testing at the EPA Motor Vehicle Emissions Laboratory (MVEL) indicates that this system allows relatively low emissions of regulated pollutants and aldehydes when operated on either M100 or M85 methanol fuels under transient driving and evaporative emissions test conditions. Total vehicle hydrocarbon emissions appear lower when the vehicle is operated on M100 rather than M85 fuel. Fuel economy is slightly improved when the system is operated on M85 rather than M100 fuel.

THE TOYOTA LEAN COMBUSTION SYSTEM (T-LCS) was described in a paper appearing in the Japanese Society of Automotive Engineering Review for July, 1984.[1]* This lean burn system made use of three particular technologies[2]-[5] to achieve improvements in fuel economy as well as comply with emission levels under the Japanese 10-mode cycle:

1. A lean mixture sensor was used in place of an oxygen sensor to control air/fuel ratio in the lean mixture range;

2. A swirl control valve upstream of the intake valve was adopted to improve combustion by limiting torque fluctuation at increased air/fuel ratios; and

3. Sequential fuel injection with optimized injection timing was used to complement the operation of the swirl control valve.

EPA became interested in this system with regard to its potential use with methanol fuel, and requested that Toyota provide a T-LCS system calibrated for operation on methanol fuel.

Toyota provided a T-LCS-M system in a Carina chassis, a right-hand-drive vehicle sold in Japan.

---

* Numbers in brackets denote references listed at the end of the paper.

Toyota equipped the engine for M85 methanol/unleaded gasoline blend operation with three calibrations:

1. A calibration optimized for driveability;

2. A calibration for operation at the engine's maximum lean limit; and

3. A calibration intermediate between the first two.

Toyota also provided a single M100 calibration optimized for best driveability.

M85 testing described in this paper was accomplished utilizing only the M85 best-driveability calibration for direct comparability to the test results from the M100 best-driveability calibration. Testing of the M85 intermediate and maximum lean limit calibrations will be conducted as a future effort.

SAE Paper 860247[5] describes the development of the T-LCS-M system; additional technical details beyond those in [5] were provided to EPA by Toyota prior to vehicle delivery.

Early in May of 1986, the T-LCS-M Carina vehicle arrived at the Toyota Technical Center in Ann Arbor. While at the Toyota facility the vehicle was tested for evaporative emissions and over the Federal Test Procedure (FTP) driving cycle, utilizing M85 fuel. On May 9, 1986 the vehicle was delivered to the EPA Motor Vehicle Emissions Laboratory for evaluation.

Vehicle Description

The test vehicle is a 1986 Toyota Carina, a vehicle sold in Japan but currently not exported to the United States. The power plant is a 1587 cc displacement, 4-cylinder, single overhead camshaft engine. The engine has been modified for operation on methanol in a lean burn mode, incorporating the lean mixture sensor, swirl control valve and timed sequential fuel injection of the Toyota lean combustion system (T-LCS). Modifications to the fuel system included the substitution of parts resistant to methanol corrosion.

The car can be operated on M100 neat methanol as well as M85 methanol/gasoline blend. Fuel changeover is accomplished by draining and flushing the fuel system and changing the electronic control unit (PROM, for programmable read only memory) to a unit compatible with the desired fuel. The exhaust catalyst is a closecoupled manifold catalyst. Details of the vehicle are provided in Appendix A and fuel specifications for the M85 blend are given in Appendix B.

Test Facilities and Equipment

Emissions testing at EPA was conducted on a Clayton Model ECE-50 double-roll chassis dynamometer, using a direct-drive variable inertia flywheel unit and road load power control unit. The Philco Ford constant volume sampler has a nominal capacity of 350 cfm.

Exhaust hydrocarbon emissions were measured by flame ionization detection (FID) using a Beckman Model 400 calibrated with propane; no attempt was made to adjust for FID response to methanol. No corrections were made for the difference in hydrocarbon composition due to the use of methanol rather than unleaded gasoline. An alternate method which has been proposed[6] is discussed in Appendix E, which calculates the methanol emissions and organic material hydrocarbon equivalents required by [6].

NOx emissions were measured by the chemiluminescent technique utilizing a Beckman Model 951A NOx analyzer. CO was measured using a Bendix Model 8501-5CA infrared CO analyzer.

Exhaust formaldehyde was measured using a dinitrophenylhydrazine (DNPH) technique.[7] Exhaust carbonyls including formaldehyde are bubbled through DNPH solution forming hydrazone derivatives. These derivatives are separated from the remaining unreacted solution by high performance liquid chromatography (HPLC). A spectrophotometer in the chromatograph effluent stream drives an integrator which determines formaldehyde derivative concentration.

Evaluation Process

Toyota published emissions test results from the LCS-M system in SAE Paper 860247. Regulated pollutant levels over the FTP, highway fuel economy (HFET) and Japanese 10-mode cycles were presented in that paper, as well as aldehyde emissions data collected over the FTP cycle by the DNPH method.

This Phase I EPA evaluation sought to confirm Toyota's results over the FTP sequence and provide emissions performance data over several unreported parameters. Phase I testing began with a series of six FTP tests utilizing M85 test fuel supplied by Howell Hydrocarbons of San Antonio, Texas. The M85 best-driveability PROM was used in this series of tests. These tests were followed by three evaporative emissions/FTP tests. This sequence consisted of a diurnal heat build conducted in a sealed evaporative emissions determination (SHED) enclosure followed by FTP and hot soak evaporative loss tests. After this set of tests, the vehicle was drained and refueled with M100 neat methanol and the PROM replaced with the M100 PROM. Three evaporative emissions/FTP tests were then repeated on M100 fuel. Following replacement of the fuel pump by Toyota, three additional FTP/HFET tests were completed on the vehicle, also using M100 fuel.

Phase II will consist of more extensive evaluation techniques as well as attempts to further reduce pollutant emissions by means of advanced technology.

Vehicle Emissions

Upon its arrival at the Toyota Technical Center in Ann Arbor, the Carina was tested for regulated exhaust and evaporative emission levels. The fuel used by Toyota for this testing was M85 fuel borrowed from the EPA laboratory, and the M85 best-driveability PROM was utilized. The results of this testing were given to EPA when the car was delivered for evaluation.

Following the receipt of the Carina by EPA, the vehicle fuel system was drained and a fresh fill of M85 was added. Three FTP/HFET/idle/10 mph/30 mph tests were then conducted using the M85 bestdriveability PROM. The results of this testing are presented in Tables 1 through 3. (All testing presented in this report was conducted at the EPA Motor Vehicle Emissions Laboratory unless otherwise noted.)

As shown in Table 1, the delivered Carina's FTP emissions did not exactly replicate the values reported in SAE Paper 860247 for the earlier T-LCS-M vehicle: the delivered car has lower HC emissions and higher CO, NOx, and aldehyde emissions. The EPA FTP results and Ann Arbor Toyota FTP results did correlate quite well, however.

HFET test results are presented in Table 2. Test results from idle, 10 mph and 30 mph steady-state testing are given in Table 3. Steady-state sampling was conducted over a 10-minute period of operation, and the average during that time period is reported. These data provide a more complete characterization of the emissions profile of the vehicle during various modes of operation.

Vehicle driveability on M85 fuel and the M85 best-driveability PROM was excellent. Only relatively minor driving problems occurred during this initial testing and none were serious enough to invalidate a test. Most of these problems were related to driver unfamiliarity with the vehicle's right-hand drive, left-hand shift system.

The testing in late May 1986 was conducted using a flexible steel tube connection between the tailpipe of the vehicle and the CVS. The tests conducted in June 1986 utilized an insulated stainless steel tube for the CVS connection. The insulating cover was fitted with a heat blanket but during this portion of testing, power was not supplied to the heating element. The primary purpose of the blanketed tube is to prevent the condensation of aldehydes in the exhaust. The blanket/insulation made no difference in emission levels of aldehydes, nor any of the other pollutants.

Table 1

FTP Test Results, M85 Fuel [a]

Test Site	Date	No.of Tests	HC g/mi	CO g/mi	NOx g/mi	Alde. mg/mi	Meth MPG
Toyota-Japan[b]	1985		0.21	0.56	0.39	3.2 [c]	23.1
Toyota-Ann Arbor[d]	May 1986	1	0.12	0.93	0.69	--	21.7
EPA-Ann Arbor[d]	May-June 1986	6	0.11	1.07	0.75	7.3 [c]	21.7
EPA	Sep. 1986	3	0.11	0.80	0.67	6.2 [c]	20.9

[a] Results of individual tests are given in Appendix C.
[b] 10.6 compression ratio, lean burn (SAE 860247).
[c] 1.0-liter Pt-Rh catalyst.
[d] 11.5 compression ratio.

Table 2

HFET Test Results, M85 Fuel

Test Site	Date	No.of Tests	HC g/mi	CO g/mi	NOx g/mi	Alde. mg/mi	Meth MPG
Toyota-Japan	1985	---------not reported----------					32.0
EPA	May-June 1986	3	0.02	0.05	0.51	3.9	30.2

Table 3

Steady Speed Test Results, M85 Fuel
(EPA, May 1986)

Speed	No.of Tests	HC g/mi	CO g/mi	NOx g/mi	Alde. mg/mi	Meth MPG
Idle	3	0.00[a]	0.0[a]	0.01[a]	0.8[b]	.297[c]
10 MPH	3	0.02	0.0	0.50	40.1	14.4
30 MPH	3	0.01	0.0	0.57	1.4	31.4

[a] Grams per minute.
[b] Milligrams per minute.
[c] Indicates gallons per minute on idle test.

Table 4

EPA Test Results, M100 Fuel

Date	Cycle	No.of Tests	HC g/mi	CO g/mi	NOx g/mi	Alde. mg/mi	Meth MPG
Sep. 1986	FTP	3	0.13	0.77	0.55	6.6	18.7
Dec. 1986	FTP	3	0.09	0.74	0.76	11.3	17.9
Dec. 1986	HFET	3	0.01	0.02	0.45	5.7	25.7

At this point Phase I testing was interrupted by the relocation of the methanol test capability from one test cell to another at EPA. Testing resumed in September 1986 with evaporative emissions/FTP cycle testing, using standard gasoline car evaporative emissions test procedures.

No significant driving difficulties were noticed during the M85 phase of this testing, but vehicle performance problems were experienced shortly after the car was configured to operate on M100 fuel. An extended crank period, 60 to 70 seconds over four attempts, was necessary to start the vehicle on September 18, 1986. This long crank period probably accounted for the more than doubling of HC emissions from the FTP conducted the previous day. The start problems continued during the following day, during both the cold and hot start portions of the FTP. Upon completion of the hot soak evaporative loss test that day the driver was unable to restart the vehicle, and it had to be manually pushed out of the evaporative test enclosure.

Test results from the Fall of 1986 are given in Table 4 for M85 and M100 fuels. Evaporative emissions results are reported in Table 5 for M85 and M100 fuels. As was done for tailpipe HC emissions, the evaporative HC losses were obtained by FID and were not adjusted for FID response to methanol nor for use of methanol rather than unleaded gasoline.

The only procedural change from the FTP testing conducted previously was that during the September testing the vehicle-to-CVS connection was heated to 250°F before the start of testing. (This is a minimum temperature maintained throughout the test; exhaust gas heating may have caused the tube connection temperature to rise above 250°F during the test.)

Comparison, M85 Vs. M100

HC levels from the M85 FTP testing in September did not change significantly from the earlier M85 testing. Consistently lower CO and NOx levels on M85 were noted in September, however.

M100 FTP HC levels were not consistent from test to test. The higher HC levels in some of the FTP tests may have resulted from the start difficulties experienced. NOx levels should have been relatively unaffected by the start difficulties; the average level of .55 g/mi was a significant reduction from the M85 FTP NOx levels achieved at EPA earlier.

M85 evaporative emissions were low; it would appear that this vehicle would meet gasoline vehicle evaporative standards with a substantial safety margin. The M100 evaporative emissions were even lower.

Table 5

Evaporative Test Results

Site	Date	Fuel	No. of Tests	Diurnal (grams)	Hot Soak (grams)	Total (grams)
Toyota-Ann Arbor	May 1986	M85	1	0.24	0.47	0.71
EPA	Sep. 1986	M85	3	0.49	0.22	0.71
EPA	Sep. 1986	M100	3	0.11	0.16	0.27

Table 6

Bag-by-Bag FTP HC Emissions

Date	Fuel	Bag 1 g/mi	Bag 2 g/mi	Bag 3 g/mi
Sep. 1986	M85	0.410	0.027	0.031
Dec. 1986	M100	0.350	0.012	0.053

After the M100 evap tests the vehicle was drained, flushed and refilled with M85. The PROM was changed to the M85 best-driveability unit and an FTP was attempted. Serious driveability problems resulted, and on October 8, 1986, the vehicle was brought to the Toyota Technical Center for diagnosis of the problem. The problem was determined by Toyota to be related to the tank fuel pump's electrical lead, and the pump was replaced. On December 2, 1986, the vehicle was returned by Toyota to MVEL.

In December 1986, the T-LCS-M was tested three times over the FTP and HFET utilizing M100 fuel (Table 4).

The vehicle experienced no start problems in the December testing, after the pump had been replaced. FTP HC levels from this phase of M100 testing were lower than those measured during the September M100 testing. The high HC levels in September were probably caused by the start difficulties. FTP CO levels from these two phases of testing were similar, but the M100 NOx levels measured during December were higher than in September.

As the December M100 testing was unaffected by performance problems, these test results are the ones which should be compared to the M85 data in Table 1. HC emissions from this phase of M100 testing are lower than HC levels measured under M85 fuel operation. The M100 CO emission levels appear slightly lower, while NOx emissions are about the same for either fuel.

M100 aldehyde levels measured during December are not consistent with those of the September M100 testing. Two of the three FTP tests conducted in December produced aldehyde levels twice as large as other M100 FTP tests.

Total Vehicle HC Emissions Per Day

A useful measure of a vehicle's HC emissions is total vehicle HC emissions per day. This includes evaporative HC losses as well as exhaust HC emissions. This characterization may be particularly important in the case of vehicles whose powerplants differ as to the type of fuel used.

One method[8] combines into a single equation the evaporative and running HC losses using data from diurnal and hot soak evaporative tests and the FTP driving cycle. Evaporative losses have separate diurnal and hot soak components. The diurnal component is treated as a once-a-day occurrence, and the hot soak losses are multiplied by the number of trips per driving day. Running losses are recognized as having cold start and warm driving components. The cold start contribution is represented by the difference between Bag 1 and Bag 3 emissions multiplied by the number of cold starts per day. The warm driving component is represented by the sum of Bag 2 and Bag 3 emissions, divided by 7.5 miles, and multiplied by the number of miles driven per day.

The above combine into:

grams/day = NCS(Bag1 HC Bag3 HC)
+ diurnal loss +
TPD(Bag2 HC + Bag3 HC)
+ TPD(hot soak losses)

Where:

NCS = The number of cold starts per day

TPD = The number of trips per day

Two cold starts per day are assumed here, as well as 4.7 trips per day of 7.5 miles each. The equation above therefore reduces to:

grams/day = 2(Bag1 HC Bag3 HC) + diurnal +
4.7(Bag2 HC + Bag3 HC) + 4.7(hot soak)

Data from Tables 5 and 6, evaporative emissions and FTP bag results, have been used to calculate the g/vehicle/day for M85 and M100. Table 7 shows that the LCS-M Carina emits less "daily HC" with M100 than with M85. Tailpipe HC levels from M100 operation are lower in each FTP bag than HC levels from M85 testing, and M100 evaporative emissions (both diurnal and hot soak) are also lower.

Fuel Economy

Fuel economy data are shown in Table 8 for all testing which included both a FTP and a HFET test on the same date. (The fuel economy calculation method used in this paper is detailed in Appendix D.) M100 city and highway fuel economies are lower than M85 fuel economies.

T-LCS-M Compared to Gasoline Cars

Table 9 shows a comparison between the emissions and gasoline equivalent fuel economies of the T-LCS-M Carina and similar gasoline-fueled 1984-85 Toyota vehicles.[9] While differences in some parameters exist between the vehicles, they are slight.

Both M85 and M100 gasoline equivalent fuel economies were higher than that of the heavier gasoline vehicles. The Tercel vehicle tested at 2,250 lbs and 7.3 dynamometer horsepower achieved a composite fuel economy very similar to the methanol-fueled vehicle. Overall, the T-LCS-M vehicle, when fueled with either M85 or M100, demonstrated gasoline equivalent fuel economies very comparable to similar gasoline-fueled vehicles.

Table 7

Total HC Per Day
(from Tables 5 and 6)

M85 fuel:	2.55 grams/day
M100 fuel:	1.76 grams/day

Table 8

Fuel Economy Summary

Fuel	No. of Tests	City MPG	Hwy MPG	Combined MPG	Gas. Equiv. Comb. MPG
M85	3 (May 1986)	21.9	30.2	25.0	43.6
M100	3 (Dec 1986)	17.9	25.7	20.7	41.6

Table 9

Comparison of T-LCS-M Versus
"Equivalent" Toyota Gasoline Cars
(All testing done at EPA laboratory.)

A. Vehicle Specifications

Vehicle	Engine	Drive	Trans-mission	Dyno HP	Test Weight
Carina LCS-M	97 CI, FI, 11.5 CR	FWD	M5	8.0	2250
1984/5 Tercel	89 CI, 2 bbl, 9.0 CR	FWD	M4	7.3	2250
1984/5 Tercel	89 CI, 2 bbl, 9.0 CR	FWD	M5	7.8	2375
1984/5 Corolla	97 CI, 2 bbl, 9.0 CR	FWD	M5	7.7	2500

B. Fuel Economy and FTP Emissions

	Gasoline Equivalent MPG			HC	CO	NOx
Vehicle	City	Hwy	Comb.	g/mi	g/mi	g/mi
Carina-M85	37.5	52.7	43.1	.11	0.98	0.72
Carina-M100	36.8	51.6	42.3	.11	0.76	0.66
Tercel M4	38.7	49.8	43.0	.21	1.02	0.63
Tercel M5	34.4	48.2	39.5	.20	1.19	0.36
Corolla	33.5	47.2	38.5	.18	0.93	0.43

HC emissions of the gasoline vehicles were almost twice as high as the Carina's HC levels on either methanol fuel. CO levels from the methanol vehicle were slightly lower than those from the gasoline cars, except for the gasoline Corolla. The M100 CO level of .76 g/mi was significantly lower than all other configurations compared here. The lower NOx levels from the heavier Tercel and Corolla gasoline vehicles compare favorably to those from the 4-speed gasoline Tercel and methanol Carina vehicles. NOx emissions of .36 g/mi from the 5-speed Tercel were half as large as the .72 g/mi average from the M85 configuration tested. The .66 g/mi NOx level from M100 testing was roughly equivalent to the levels measured from the 2250 lb gasoline Tercel.

No attempt is made here to analyze the cause of the emission level differences between the gasoline and methanol vehicle configurations (e.g., vehicle test weight, catalytic converters present, etc.). These differences in individual cases may be significant. Overall, however, the T-LCS-M vehicle, fueled with either M100 or M85, demonstrated similar regulated pollutant levels to comparably configured gasoline vehicles.

Acknowledgements

The authors gratefully acknowledge the efforts of James Garvey and Ernestine Bulifant of the Test and Evaluation Branch, Emission Control Technology Division, who conducted the driving cycle tests, and the efforts of Lottie Parker of the Engineering Operations Division, who conducted the evaporative emissions testing.

Conclusions

1. NOx emissions over the FTP cycle on M85 fuel, an average of .72 grams per mile, were higher than the .39 grams per mile reported for this car's predecessor in SAE Paper 860247. NOx measured during M100 operation over the FTP cycle averaged .66 grams per mile.

2. CO emissions from both M85 and M100 testing were well below current light-duty vehicle standards. CO levels with M100 were lower than with M85.

3. Aldehyde emission levels were approximately the same for M100 and M85 operation.

4. Evaporative emissions were very low. Average total loss per SHED test was .27 grams with M100 fuel, while use of M85 emitted an average .71 grams per test. (These tests were conducted using a FID calibrated with propane.)

5. Total grams of HC emitted per vehicle/day were calculated to be 1.76 and 2.55 grams, from M100 and M85 operation respectively. This calculation accounts for both evaporative and transient emissions, for a particular operating cycle.

6. Gasoline equivalent fuel economy for both methanol fuels was comparable to similar non-lean burn gasoline vehicles.

7. Regulated emission levels from the M100 or M85 fueled T-LCS-M were similar to those from comparably configured gasoline vehicles.

References

1. N. Kobayashi, et al., "Development of Toyota Lean Combustion System," Japan Society of Automotive Engineering Review, July 1984, pp. 106-111.

2. Y. Kimbara, K. Shinoda, H. Koide and N. Kobayashi, "NOx Reduction Is Compatible With Fuel Economy Through Toyota's Lean Combustion System," SAE Paper 851210, October 1985.

3. T. Kamo, Y. Chujo, T. Akatsuka, J. Nakano and M. Suzuki, "Lean Mixture Sensor," SAE Paper 850380, February 1985.

4. S. Matsushita, T. Inoue, K. Nakanishi, T. Okumura and K. Isogai, "Effects of Helical Port With Swirl Control Valve On the Combustion and Performane of S.I. Engine," SAE Paper 850046, February 1985.

5. K. Katoh, Y. Imamura and T. Inoue, "Development of Methanol Lean Burn System," SAE Paper 860247, February 1986.

6. "Proposed Emission Standards and Test Procedures for Methanol-Fueled Vehicles, Draft Regulation," U.S. Environmental Protection Agency, Federal Register, Vol. 51, No. 168, August 29, 1986.

7. "Formaldehyde Measurement In Vehicle Exhaust At MVEL," R. L. Gilkey, EPA, Ann Arbor, MI, 1981.

8. "M100 vs. M85," Memo from Karl H. Hellman, EPA to Charles L. Gray, Jr., November 20, 1986.

9. "V.I. Report" and "Tests Report" (Test Car Lists) for 1984 and 1985, EPA, Ann Arbor, MI.

APPENDIX A

DESCRIPTION OF TOYOTA LCS-M TEST VEHICLE

Vehicle	2015 lbs
Transmission	Manual, 5 speed
Shift speed code	15-25-40-45 mph
Fuel	M85 or M100
Number of cylinders	Four, in-line
Displacement	97 cubic inches
Camshaft	Single, overhead camshaft
Compression ratio	11.5, flat head pistons
Combustion chamber	Wedge shape
Fuel Metering	Electronic port fuel injection
Bore and Stroke	3.19 inches x, 3.03 inches
Ignition	Spark ignition; spark plugs are ND W27ESR-U, gapped at .8 mm, torqued to 13 ft-lb.
Ignition timing	With check connecter shorted, ignition timing should be set to 10°BTDC at idle. With check connecter unshorted, ignition timing advance should be set to 15°BTDC at idle. Idle speed is approximately 550-700 rpm.
Fuel injectors	Main and cold start fuel injectors capable of high fuel flow rates. The fuel injector bodies have been nickel-plated, and the adjusting pipes are stainless steel.
Fuel pump	In-tank electric fuel pump with brushless motor to prevent corrosion. The body is nickel plated and its fuel delivery flow rate capacity has been increased.

APPENDIX A (cont'd)

DESCRIPTION OF TOYOTA LCS-M TEST VEHICLE

Fuel tank	Stainless steel construction; capacity 14.5 gals.
Fuel lines and filter	The tube running from the fuel tank to the fuel filter has been nickel plated. The fuel filter, located in the engine compartment, has also been nickel plated. The fuel delivery rail has been plated with nickel-phosphorus.
Catalytic converter	1 liter volume, Pt:Rh loaded, close coupled to the exhaust manifold.

APPENDIX B

SPECIFICATIONS FOR M85 TEST FUEL

Test	Min.	Max.	Result
Composition			
Methanol, vol. %			85.0
Unleaded gasoline, vol.%			15.0
Distillation, °F			
IBP	103	117	103
10 percent	133	143	139
50 percent	140	149	148
90 percent	140	150	148
End point			152
Reid vapor pressure, psi	9.0	9.2	9.2
Gravity, °API	48.3	49.1	48.7

APPENDIX C

INDIVIDUAL TEST RESULTS AT EPA

A. Tailpipe Emissions

Test Type	Date	Fuel	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Alde. (mg/mi)	Meth. MPG
FTP	05/21/86	M85	.13	1.17	.82	N/A	21.7
HFET	05/21/86	M85	.02	.08	.54	N/A	30.1
Idle	05/21/86	M85	.00[a]	.00[a]	.01[a]	N/A	.316[c]
10 MPH	05/21/86	M85	.02	.00	.53	N/A	14.3
30 MPH	05/21/86	M85	.01	.00	.57	N/A	30.8
FTP	05/22/86	M85	.09	1.03	.74	7.9	22.1
HFET	05/22/86	M85	.02	.04	.47	3.9	30.5
Idle	05/22/86	M85	.00[a]	.00[a]	.00[a]	0.8[b]	.258[c]
10 MPH	05/22/86	M85	.01	.00	.48	40.1	14.3
30 MPH	05/22/86	M85	.00	.00	.63	1.4	31.6
FTP	05/23/86	M85	.12	1.12	.79	N/A	21.8
HFET	05/23/86	M85	.02	.03	.53	N/A	30.1
Idle	05/23/86	M85	.00[a]	.00[a]	.01[a]	N/A	.317[c]
10 MPH	05/23/86	M85	.03	.00	.50	N/A	14.6
30 MPH	05/23/86	M85	.01	.00	.52	N/A	31.7
FTP	06/06/86	M85	.12	1.11	.69	5.8	21.4
FTP	06/10/86	M85	.09	.86	.72	6.8	21.6
FTP	06/11/86	M85	.12	1.13	.75	8.8	21.4
FTP	09/11/86	M85	.11	.86	.68	8.9	20.5
FTP	09/12/86	M85	.12	.73	.65	5.2	21.0
FTP	09/16/86	M85	.10	.80	.67	4.5	21.2
FTP	09/17/86	M100	.07	.76	.56	6.0	18.4
FTP	09/18/86	M100	.16	.79	.53	6.5	19.2
FTP	09/19/86	M100	.17	.75	.55	7.3	18.4
FTP	12/09/86	M100	.08	.69	.70	13.7	17.8
HFET	12/09/86	M100	.01	.01	.37	7.1	25.5
FTP	12/10/86	M100	.09	.80	.75	7.2	17.9
HFET	12/10/86	M100	.01	.00	.42	6.4	25.5
FTP	12/11/86	M100	.11	.73	.82	12.9	17.9
HFET	12/11/86	M100	.01	.04	.56	3.7	26.1

[a] Idle test results in grams per minute.
[b] Idle test results in milligrams per minute.
[c] Idle test results in gallons per minute.
N/A signifies not available.

APPENDIX C (cont'd)

INDIVIDUAL TEST RESULTS AT EPA

B. Evaporative Emissions

Date	Fuel	Diurnal (gms)	Hot Soak (gms)	Total (gms)
09/11/86	M85	.32	.20	.52
09/12/86	M85	.49	.21	.70
09/16/86	M85	.66	.25	.91
09/17/86	M100	.13	.19	.32
09/18/86	M100	.10	.16	.26
09/19/86	M100	.09	.13	.22

APPENDIX D

The fuel economy calculations used in this report are an application of the general carbon balance equation:

$$\text{miles/gal} = \frac{\text{grams carbon/gallons fuel}}{\text{grams carbon/mile}} = \frac{N}{D}$$

$$N = (.866)(2799)(\%G)+(.375)(2994)\%M,$$

Where:

.866	=	carbon fraction of gasoline,
.375	=	carbon fraction of methanol,
2799	=	grams gasoline/gallon,
2994	=	grams methanol/gallon,
%G	=	% gasoline/100, and,
%M	=	% methanol/100

The nominal values for gasoline were determined by EPA (50 FR 27127) and are based on a specific gravity of 0.739 and 8.345 lbs H_2O/gal, yielding 6.17 lb/gal. The values for methanol are based on a specific gravity of 0.791, giving 6.60 lb/gal for methanol.

$$D = 0.866\ HC + 0.429\ CO + 0.273\ CO_2 + 0.375\ CH_3OH + 0.400\ HCHO$$

Where:

The coefficients are the carbon weight fractions of the carbon-containing compounds, and the compounds have units of grams per mile.

The gasoline equivalent fuel economy values are based on adjusting for the energy content difference between gasoline and methanol. The EPA rulemaking established the nominal energy content of gasoline at 18,507 BTU/lb yielding 114,132 BTU/gallon. Similarly, methanol at 8,600 BTU/lb is 56,768 BTU/gallon. The adjustment, based on fuel energy is:

$$\text{Gasoline equivalent adjustment} = \frac{\text{Energy of gasoline}}{(\text{Energy of gasoline})\%G + (\text{Energy of methanol})\%M}$$

Dividing by the energy of gasoline:

$$\text{Gasoline equivalent adjustment} = \frac{1}{\%G + 0.4974\ \%M}$$

Which = 2.01 for M100 and 1.75 for M85.

APPENDIX E

CALCULATION OF HC, METHANOL AND HCHO

As proposed, the regulations in reference 6 require the measurement of methanol (CH_3OH) and formaldehyde (HCHO). Methanol emissions are especially important since the dilution factor equation includes CH_3OH emissions. At the time the test results reported here were made, the EPA lab did not measure CH_3OH. Therefore, the results shown here were computed with an assumed FID response factor of 0.75 and an assumed HC ppm to methanol ppm factor of xx/.85, where xx is the fraction of methanol in a methanol gasoline blend. HC, methanol and organic material hydrocarbon equivalents computed using these procedures, as called for in reference 6, are given below.

APPENDIX E (cont'd)

CALCULATED METHANOL, HC AND ORGANIC MATERIAL HYDROCARBON EQUIVALENTS

Test Date	Test Type	Test Fuel	Methanol (g/mi)	HC (g/mi)	OMHCE (g/mi)
05/21/86	FTP	M85	.295	.032	.160
05/21/86	HFET	M85	.036	.004	.019
05/21/86	Idle	M85	.003 [a]	.000 [a]	.002 [a]
05/21/86	10 MPH	M85	.053	.006	.029
05/21/86	30 MPH	M85	.026	.003	.014
05/22/86	FTP	M85	.217	.024	.121
05/22/86	HFET	M85	.034	.004	.020
05/22/86	Idle	M85	.004 [a]	.000 [a]	.002 [a]
05/22/86	10 MPH	M85	.028	.003	.033
05/22/86	30 MPH	M85	.010	.001	.005
05/23/86	FTP	M85	.291	.031	.157
05/23/86	HFET	M85	.043	.005	.023
05/23/86	Idle	M85	.003 [a]	.000 [a]	.002 [a]
05/23/86	10 MPH	M85	.060	.007	.033
05/23/86	30 MPH	M85	.032	.003	.017
06/06/86	FTP	M85	.266	.029	.147
06/10/86	FTP	M85	.207	.022	.115
06/11/86	FTP	M85	.280	.030	.155
09/11/86	FTP	M85	.243	.026	.135
09/12/86	FTP	M85	.267	.029	.147
09/16/86	FTP	M85	.235	.025	.129
09/17/86	FTP	M100	.195	.008	.098
09/18/86	FTP	M100	.440	.019	.213
09/19/86	FTP	M100	.463	.020	.224
12/09/86	FTP	M100	.219	.009	.110
12/09/86	HFET	M100	.019	.001	.009
12/10/86	FTP	M100	.242	.010	.118
12/10/86	HFET	M100	.018	.001	.009
12/11/86	FTP	M100	.300	.013	.149
12/11/86	HFET	M100	.019	.001	.011

[a] Grams per minute.