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Technical Report

Phase I Testing of Toyota Lean Combustion System (Methanol)

by

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Summary

The Toyota lean combustion system-methanol (T-LCS-M) is a lean burn combustion system utilizing methanol fuel that is designed to maximize 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 and M85 methanol fuels under transient driving and evaporative emissions test conditions. Total vehicle hydrocarbon (HC) emissions levels 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.

Background

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 to achieve improvements in fuel economy as well as comply with NOx 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 before 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 optimized and calibrated for operation on methanol fuel.

Toyota provided a Japanese-market-only vehicle, the Carina. Vehicle details are provided in Appendix A; this right-hand-drive automobile was not constructed to U.S. safety specifications and therefore is not able to be driven over the road in the U.S.

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

1. A calibration optimized for driveability;

2. A calibration enabling operation of the vehicle at its maximum lean limits; and

3. A calibration utilizing air/fuel ratios intermediate between the first two.

Toyota also provided a single M100 calibration, for maximum lean operation.

Several meetings between EPA and Toyota personnel through the spring of 1986 provided EPA personnel with technical details and updates not included in SAE Paper 860247,[2] a technical paper describing the development of the system.

Early in May of 1986, the LCS-M 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) cycle, utilizing M85 fuel. On May 9, 1986 the Carina LCS-M 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 found on the Toyota lean combustion system (T-LCS). Modifications to the fuel system included the substitution of parts resistant to methanol corrosion for stock parts.

The car may be operated on M100 neat methanol as well as M85 methanol/unleaded gasoline blend. Fuel changeover is accomplished by draining and flushing the fuel system and changing the electronic control unit (PROM, for programmed read only memory) to a unit compatible with the desired fuel. The exhaust catalyst is a close-coupled manifold catalyst. Details of the vehicle description 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 CVS used has a nominal capacity of 350 cfm.

Exhaust hydrocarbon emissions were measured by flame ionization detection (FID) from a Beckman Model 400. This FID was calibrated with propane; no attempt was made to adjust for FID response factor to methanol. No corrections were made for the difference in hydrocarbon composition due to the use of methanol rather than unleaded gasoline for fuel. NOx emissions were measured by chemiluminescent technique utilizing a Beckman Model 8501-5CA.

Exhaust formaldehyde was measured using a dinitrophenyl hydrazine (DNPH) technique.[3] 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). Quantization is accomplished by spectrophotometric analysis of the LC effluent stream.

Evaluation Process Description

Toyota has published emissions test results from the LCS-M system in SAE Paper 860247. Regulated pollutant levels over FTP, Federal Highway Fuel Economy (HWFE) and Japanese 10-mode cycles were presented in this paper, as well as aldehyde emissions data collected over the FTP cycle by a 2-4 DNPH method.

Phase I of the EPA evaluation sequence, the results of which are presented here, 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 conducted jointly by ECTD and Engineering Operations Division (EOD) personnel. This sequence consisted of a diurnal heat build conducted in an EOD sealed evaporative emissions test enclosure (SHED) followed by FTP and hot soak evaporative loss tests. Following completion of this set of tests, the vehicle was drained and refueled with M100 neat methanol and the PROM replaced with the M100 maximum lean limit PROM. The sequence of three evaporative emissions/FTP tests was then repeated for operation of the vehicle on M100 fuel. Following replacement of a fuel pump by Toyota, three additional FTP/HWFE 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 Testing

Upon its arrival at the Toyota Technical Center Ann Arbor, the Carina was tested for regulated emission levels over FTP and evaporative emissions cycles. The fuel used by Toyota for this testing was M85 fuel borrowed from the EPA laboratory, and the best driveability PROM was utilized. The results of this testing (Table 1) were given to EPA when the car was delivered for evaluation.

The vehicle fuel system was drained and a fresh fill of M85 was added following the receipt of the Carina by EPA. Three FTP/HWFE/idle, 10 and 30 mph steady-state tests were then conducted using the best driveability PROM. The results of this testing are presented in Tables 1 through 5.

A direct comparison of hydrocarbon levels would be difficult to make as Toyota does not state in SAE Paper 860247 their procedure for calibration of the FID or any adjustments made to the data for methanol operation. NOx emissions measured by EPA over the FTP cycle appeared high when compared to the .39 g/mi level reported by Toyota in SAE Paper 860247. Measured CO also appears high compared with .56 g/mi reported in the same paper. Pollutant levels other than aldehydes correlated fairly well between MVEL and the Toyota Technical Center testing. This engine/vehicle configuration appears to meet current regulated U.S. emissions standards with a substantial margin for error. Aldehyde levels over the FTP, an average 7.3 mg/mi, appear high when compared with the 3.3 mg/mi reported by Toyota.

HWFE test results at EPA are presented in Table 2. Test results from idle, 10 and 30 mph steady state testing are given in Tables 3, 4, and 5 respectively. Steady-state sampling is conducted over a 10-minute period of operation, and an 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 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 right-hand drive system of the vehicle.

The testing over the period May 21-23, 1986 was conducted using a flexible steel tube connection between the tailpipe of the vehicle and the CVS. The tests conducted from June 6-11, 1986 utilized an insulated stainless steel tube for the car to 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. Aldehyde levels did not appear to be significantly influenced by this change in test procedure.

This portion of Phase I was interrupted by the transfer of the methanol test capability from one test cell to another at MVEL. Testing resumed on September 10, 1986 with preparation of the vehicle for evaporative emissions/FTP cycle testing. No significant departures from gasoline car test procedures were allowed with respect to the evaporative emissions testing.

While no significant driving difficulties were noticed during the M85 phase of this testing, 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.

FTP test results are given in Tables 6 and 7 for M85 and M100 fuels, respectively. Evaporative emissions results are reported in Tables 8 and 9 for M85 and M100 fuels respectively. The results from an evaporative emission test conducted at Toyota, using M85 fuel are given in Table 8 for comparison. The evap HC losses were also obtained by FID and were not adjusted for FID response factor 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 cause the tube connection temperature to rise above 250°F during the test.

HC levels from the M85 FTP testing in September did not change significantly from the testing conducted previously. Consistently lower CO and NOx levels were noted during the September testing, however. M100 FTP HC levels are not consistent from test to test. The higher levels of the second and third FTP tests may have resulted from the start difficulties experienced. NOx levels should have been relatively unaffected by any start difficulties; the average level of .55 g/mi was a significant reduction from the M85 FTP NOx levels reported by EPA earlier.

M85 evaporative emissions from the vehicle appear low; it would appear that this vehicle would meet the gasoline vehicle evaporative emissions standards with a substantial safety margin. The M100 evaporative emissions levels were even lower, averaging only 0.27 g/test.

Following the conclusion of 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 attempt to test the vehicle over the FTP cycle was made. Serious driveability problems resulted, and on October 8, 1986, the vehicle was brought to the Toyota Technical Center for diagnosis of the fuel system problem. The problem was determined by Toyota to be related to the electrical lead to the tank fuel pump, and this pump was replaced. On December 2, 1986, the vehicle was returned by Toyota to MVEL.

Over the period December 9-11, 1986, the LCS-M was tested three times over FTP and HWFE cycles, utilizing M100 fuel and the M100 maximum lean PROM. Results from this testing are presented in Tables 10 and 11.

FTP HC levels from this phase of M100 testing were significantly lower than those measured during the September M100 testing. The high HC levels measured during September were probably caused by the start difficulties with the faulty fuel pump. The vehicle did not experience a start problem during December testing after the pump had been changed. CO levels from these 2 phases of testing were similar, but the NOx levels measured during December were approximately 40 percent higher than NOx levels measured during the September M100 testing.

As the M100 testing in December was unaffected by performance problems it would be particularly useful to compare these results with M85 test results from similar cycles. HC emissions from this phase of M100 testing are 10 to 15 percent lower than HC levels measured under M85 fuel operation. CO emission levels appear slightly lower under M100 conditions while NOx emissions appear relatively unaffected by the change in fuels. Aldehyde results have not yet been processed for this phase of M100 testing.

Total Vehicle HC Emissions Per Day

Another way to characterize a vehicle's HC emissions profile is to describe total vehicle emissions in grams of HC per vehicle per day. This recognizes the fact that HC emissions are a function of evaporative losses as well as exhaust emissions. This characterization may be particularly important in the case of vehicles whose powerplants differ only in the type of fuel used to power them.

One method [4] combines into a single equation the evaporative and running HC losses using diurnal and hot soak evaporative tests and the FTP driving cycle. Driving losses are recognized as having cold start and warm driving components. The cold start portion may be approximated as Bag 1 and Bag 2 emissions, the result multiplied by the number of cold starts in a driving day. The warm driving component may be approximated by the sum of Bag 2 and Bag 3 emissions divided by 7.5 miles (the number of miles driven over this portion of the cycle) and this entire quantity multiplied by the number of miles driven per day. Evaporative losses may be recognized as having separate diurnal and hot soak components. The diurnal component can be viewed as a once-a-day occurrence, and the hot soak losses multiplied by the number of trips taken per driving day.

The above may be condensed into the following equation:

g/car/day = NCS(Bag 1 HC - Bag 3 HC) + diurnal loss + TPD (Bag 2 HC + Bag 3 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:

g/car/day = 2 (Bag 1 HC - Bag 3 HC) + diurnal, + 4.7 (Bag 2 HC + Bag 3 HC) + 4.7 (hot soak)

Data from Tables 12 and 8, FTP by bag and evaporative emissions results from M85 testing have been used to calculate the g/vehicle/day data presented for M85 in Table 14. Data from Tables 13 and 9 were used to calculate the M100 figures presented in Table 14. The M100 results by bag from the December 9-11 FTP testing were used instead of the M100 FTP results from testing conducted on September 17-19. The September FTP test results may have been adversely impacted by the fuel pump problems experienced at that time.

M100 neat methanol appears to possess a substantially lower total HC emissions profile than M85 methanol blend by this approach. The lower M100 emissions profile is due to comparatively lower HC emissions in both exhaust and evaporative emissions. HC levels from M100 operation are lower in each FTP bag category than HC levels from M85 testing. Evaporative emissions for both the diurnal and hot soak tests for M100 are substantially below those obtained for M85 fuel. The LCS-M Carina then, would appear to offer lower HC emissions if the system was operated with M100, rather than M85 methanol fuel.

Fuel Economy Testing

Fuel economy data is published for all testing that was conducted using an FTP/HWFE test sequence on the same date. Both city and highway fuel economy numbers are calculated, enabling the computation of a composite city/highway fuel economy figure.

M85 fuel economy was calculated using an equation supplied by Toyota:

$$MPG_{M85} = \frac{1315 \text{ grams carbon/gallon of fuel}}{.4428\ (HC,\ g/mi) + .4288\ (CO\ g/mi) + .2729\ (CO_2\ g/mi)}$$

M100 fuel economy was calculated using the formula:

$$MPG_{M100} = \frac{1120.88 \text{ grams carbon/gallon}}{.375(HC,\ g/mi) + .429(CO,\ g/mi) + .273(CO,\ g/mi)}$$

The derivation of this equation appears in Appendix C, as well as the calculation of gasoline equivalency for M100 fuel. Fuel economy results are presented in Tables 15 and 16 for M85 and M100 fuels, respectively.

The composite city/highway MPG was calculated from the formula:

$$MPG = \frac{1}{\frac{.55}{\text{City MPG}} + \frac{.45}{\text{Highway MPG}}}$$

As expected, M100 city and highway fuel economies are lower than M85 fuel economies. After adjusting for heat value, average M85 gasoline equivalent composite mpg was 45.4, while average M100 gasoline equivalent composite mpg was 41.8.

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References

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2. "Development of Methanol Lean Burn System," Katoh, K., Y. Imamura and T. Inoue, SAE 860247, February 28, 1986.

3. Formaldehyde Measurement In Vehicle Exhaust At MVEL, Memo from R. L. Gilkey, OAR, OMS, EOD, Ann Arbor, MI, 1981.

4. Memo from Karl H. Hellman, OAR, OMS, ECTD, CTAB to Charles L. Gray, Jr., ECTD, November 20, 1986.

Table 1

Toyota LCS-M Carina, FTP Test Results
M85 Fuel, Best Driveability PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)	Comments
05/21/86	2200.	N/A	.128	1.17	220.	.82	Minor gear change error
05/22/86	2280.	7.92	.094	1.03	216.	.74	Bag 2 stall
05/23/86	2360.	N/A	.126	1.12	219.	.79	Bag 1 stall
06/06/86	2440.	5.83	.115	1.11	223.	.69	No problems noticed
06/10/86	2469.	6.76	.090	0.86	222.	.72	20-sec crank to start, Bag 1
06/11/86	2493.	8.77	.121	1.13	223.	.75	Gear change error, Bag 2
Averages		7.32	.112	1.07	221.	.75	
Std. Dev.		1.29	.016	0.11	.002	.05	

N/A signifies aldehyde levels not available due to technical problems.

LSC-M System FTP Cycle Results
Test Conducted At Toyota Technical Center (Ann Arbor)

Test Type	Aldehydes	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)
FTP	N/A	.121	.93	220.	.69

Table 2

Toyota LCS-M Carina, HWFE Test Results
M85 Fuel, Best Driveability PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)	Comments
05/21/86	2236.	N/A	.015	.08	160.	.54	
05/22/86	2315.	3.87	.015	.04	158.	.47	
05/23/86	2378.	N/A	.019	.03	160.	.53	
Averages		3.87	.016	.05	159.	.51	
Std. Dev.			.002	.026	1.2	.04	

N/A signifies aldehyde levels not available due to technical problems.

Table 3

Toyota LCS-M Carina, Idle Mode Test Results
M85 Fuel, Best Driveability PROM

Test Date	Odometer (km)	Aldehydes (mg/min)	HC (g/min)	CO (g/min)	CO_2 (g/min)	NOx (g/min)
05/21/86	2252.	N/A	.001	0.0	15.1.	.001
05/22/86	2350.	.81	.002	0.0	12.5	.011
05/23/86	2411.	N/A	.001	0.0	15.3	.011
Average		.81	.001	0.0	14.3	.011
Std. Dev.	--	--	--	1.6	--	

N/A signifies aldehyde levels not available due to technical problems.

Table 4

Toyota LCS-M Carina, 10 MPH Steady-State Cycle
M85 Fuel, Best Driveability PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)
05/21/86	2253.	N/A	.023	0.0	338.	.53
05/22/86	2375.	40.13	.012	0.0	337.	.48
05/23/86	2412.	N/A	.026	0.0	329.	.50
Average		40.13	.020	0.0	335.	.50
Std. Dev.		--	.007	--	4.9	.025

N/A signifies aldehyde levels not available due to technical problems.

Table 5

Toyota LCS-M Carina, 30 MPH Steady-State Cycle
M85 Fuel, Best Driveability PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)
05/21/86	2258.	N/A	.011	0.0	157.	.57
05/22/86	2390.	1.42	.004	0.0	153.	.63
05/23/86	2420.	N/A	.014	0.0	152.	.52
Average		1.42	.010	0.0	154.	.57
Std. Dev.		--	.005	--	2.6	.05

N/A signifies aldehyde levels not available due to technical problems.

Table 6

Toyota LCS-M Carina, FTP Test Results
M85 Fuel, Best Driveability PROM, Evap/FTP Sequence

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)	Comments
09/11/86	2528.	8.90	.105	.86	234.	.68	Stall in Bag 1
09/12/86	2565.	5.19	.115	.73	228.	.65	
09/16/86	2595.	4.56	.102	.80	226.	.67	
Averages		6.22	.107	.80	229.	.67	
Std. Dev.		2.35	.007	.065	4.2	.016	

Table 7

Toyota LCS-M Carina, FTP Test Results
M100 Fuel, Maximum Lean Limit PROM, Evap/FTP Sequence

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)	Comments
09/17/86	2626	6.01	.071	.76	222.	.56	
09/18/86	2655	6.45	.162	.79	212.	.53	Start probs, cold start
09/19/86	2685	7.28	.170	.75	222.	.55	Hot, cold start probs
Averages		6.58	.134	.77	219.	.55	
Std. Dev.		.64	.055	.02	5.8	.016	

Table 8

Evaporative Test Results, EPA Laboratory Toyota LCS-M Carina M85 Fuel

Test Date	Diurnal Loss (g)	Hot Soak (g)	Total (g)
09/11/86	.32	.20	.52
09/12/86	.49	.21	.70
09/16/86	.66	.25	.91
Average			.71

Evaporative Test Results, Toyota Technical Center Toyota LCS-M Carina M85 Fuel

Diurnal Loss (g)	Hot Soak Loss (g)	Total (g)
24	.47	.71

Table 9

Evaporative Test Results, EPA Laboratory Toyota LCS-M Carina M100 Fuel

Test Date	Diurnal Loss (g)	Hot Soak (g)	Total (g)
09/17/86	.13	.19	.32
09/18/86	.10	.16	.26
09/16/86	.09	.13	.22
Average			.27

Table 10

Toyota LCS-M Carina
FTP Testing, December 8-11, 1986
M100 Fuel, Maximum Lean Limit PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)
12/09/86	2767.	N/A	.080	.69	230.	.70
12/10/86	2830.	N/A	.089	.80	228.	.75
12/11/86	2893.	N/A	.110	.73	228.	.82
Average			.093	.74	229.	.76
Std. Dev.		--	.015	.056	1.2	.06

N/A indicates not available.

Table 11

Toyota LCS-M Carina
HWFE Testing, December 8-11, 1986
M100 Fuel, Maximum Lean Limit PROM

Test Date	Odometer (km)	Aldehydes (mg/mi)	HC (g/mi)	CO (g/mi)	CO_2 (g/mi)	NOx (g/mi)
12/09/86	2785.	N/A	.007	.01	161.	.37
12/10/86	2865.	N/A	.007	.00	161.	.42
12/11/86	2911.	N/A	.007	.04	157.	.56
Average			.007	.02	160.	.45
Std. Dev.			--	.02	2.3	.098

N/A indicates not available.

Table 12

FTP Test Results, HC By Bag
M85 Fuel, Best Driveability PROM

Test Date	Bag 1 HC (g/mi)	Bag 2 HC (g/mi)	Bag 3 HC (g/mi)	Test HC (g/mi)
09/11/86	.387	.027	.039	.105
09/12/86	.453	.027	.027	.115
09/16/86	.389	.027	.027	.102

Table 13

FTP Test Results, HC By Bag
M100 Fuel, Maximum Lean Limit PROM

Test Date	Bag 1 HC (g/mi)	Bag 2 HC (g/mi)	Bag 3 HC (g/mi)	Test HC (g/mi)
12/09/86	.330	.012	.022	.080
12/10/86	.389	.006	.021	.089
12/11/86	.330	.019	.116	.110

Table 14

Emissions Of g HC/Vehicle Day
Toyota LCS-M Carina

Test	M85 Fuel (g/veh day)	M100 Fuel (g/veh day)
1	2.27	1.80
2	2.58	1.71
3	2.81	1.76
Average	2.55	1.76
Std. Dev.	.27	.05

Table 15

Fuel Economy Results
M85 Fuel - Best Driveability PROM

Test Date	City MPG	Highway MPG	Composite MPG	Gasoline Equivalent MPG
05/21/86	21.7	30.1	24.8	45.1
05/22/86	22.1	30.5	25.2	45.9
05/23/86	21.8	30.1	24.9	45.3
Average, by category	21.9	30.2	25.0	45.4
Std. Dev. by category	.21	.3	.21	.42

Table 16

Fuel Economy Results
M100 Fuel - Maximum Lean Limit PROM

Test Date	City MPG	Highway MPG	Composite MPG	Gasoline Equivalent MPG
12/09/86	17.8	25.5	20.6	41.6
12/10/86	17.9	25.5	20.7	41.8
12/11/86	17.9	26.1	20.8	42.0
Average, by category	17.9	25.7	20.7	41.8
Std. Dev. by category	.07	.35	.10	.20

APPENDIX A

Description of Toyota LCS-M Test Vehicle

Vehicle Identification Number:	AT15102264700000
Curb weight	2015 lbs
Inertia weight	2250 lbs
Odometer reading at del.	1358 miles
Transmission	Manual, 5 speed
Shift speed code	15-25-40-45 mph
Dynamometer horsepower	8 HP
Engine:	
Fuel	M85 or M100 (see "Calibrations")
Number of cylinders	4, in-line
Displacement	97 cubic inches
Camshaft	Single, overhead camshaft
Compression ratio	11.5, pistons with flat heads are used
Combustion chamber	Wedge shape
Fuel Metering	Electronic port fuel injection
Bore	3.19 inches
Stroke	3.03 inches
Calibrations	Three separate calibrations (PROMs) are available for use with M85 fuel blend: 1) calibration optimized for performance and driveability; 2) calibration enabling the vehicle to run at the maximum lean limit of operation; and 3) a calibration intermediate between the first two. One PROM is available for use with M100 (neat methanol) fuel: a calibration enabling vehicle operation at the maximum lean limit.

Fuel tank	Stainless steel construction; capacity 14.5 gals.
Ignition	Spark ignition; spark plugs are ND W27ESR-U, gapped at .8 mm, torqued to 13 ft-lb. Toyota recommends changing spark plugs after 9,000 miles of vehicle operation.
Ignition timing	With check connector shorted, ignition timing should be set to 10°BTDC at idle. With check connector unshorted, ignition timing advance should be set to 15°BTDC at idle. Idle speed is approximately 550-700 rpm.
Engine oil	10W-30(SF). Toyota recommends oil change interval of 3,000 miles.
Fuel injectors	Fuel injectors (main and cold start) capable of high fuel flow rates are used. The fuel injector bodies have been nickel-plated, and the adjusting pipes constructed of stainless steel.
Fuel pump	In-tank electric fuel pump with brushless motor is installed to prevent brushes and commutators from corrosion. The body is nickel plated and its capacity to deliver fuel (flow rate) has been increased.
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 total volume, Pt:Rh loaded. Catalyst is close coupled to the exhaust manifold.

APPENDIX B

Specifications for M85 Test Fuel

Test	Min.	Max.	Result
Composition			
Methanol, vol. %			85.0
Unleaded base 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	8.8
Gravity, °API	48.3	49.1	48.7

APPENDIX C

Derivation of Fuel Economy Equation
M100 Neat Methanol Fuel

1 gallon of methanol weighs 2,989 grams

12.011, molecular weight of carbon

32.043, molecular weight of methanol (CH_3OH)

Weight percent of carbon in methanol:

$$\frac{12.011}{32.043} = .3748, \text{ 37.5 percent carbon}$$

$$2{,}989 \text{ grams } \frac{\text{methanol}}{\text{gallon}} \times (.375) = 1120.88 \text{ grams carbon/gallon methanol}$$

Assume:

Exhaust HC is methanol composition,
.429, weight fraction of carbon in CO.
.273, weight fraction of carbon in CO_2.

$$MPG = \frac{1120.88 \text{ grams carbon/gallon methanol}}{.375\ (HC,\ g/mi) + .429\ (CO,\ g/mi) + .273\ (CO_2,\ g/mi)}$$

Gasoline equivalency:

1 liter of gasoline = 32.16 MJ
1 liter of methanol = 15.90 MJ

$$\frac{32.16 \text{ MJ}}{15.90 \text{ MJ}} = 2.02,$$

factor by which M100 methanol fuel economy must be multiplied to obtain equivalent gasoline fuel economy on a heat energy basis.