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Technical Report

Evaluation of Toyota LCS-M Carina: Phase II

by

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I. Summary

Initial testing of the Toyota Lean Combustion (Methanol) Carina loaned to the U.S. EPA by the Toyota Motor Corporation involved the determination and comparison of fuel economy and pollutant emission profiles of the vehicle when operated on M100 and M85 methanol fuels. The results from this "Phase I" testing were summarized in SAE Paper 871090, "Fuel Economy and Emissions of a Toyota T-LCS-M Methanol Prototype Vehicle."

Testing subsequent to Phase I involved a number of short programs designed to further define the capabilities of this methanol lean burn system with regard to pollutant emissions and fuel economy. This testing was conducted using M100 neat methanol exclusively, and is referred to as "Phase II" testing. A summary of the results from these separate tests is presented below.

1. An improved version of the M100 best driveability calibration was tested and the results compared with those from testing with the PROM originally supplied with the vehicle. Toyota describes the improved best driveability calibration as 8 percent leaner at idle than the original best driveability calibration. NOx and CO emission levels over the FTP and HFET cycles rose when the improved calibration was used. Aldehydes and hydrocarbons remained at similar emisison levels regardless of calibration, however. (NOx, CO, and formaldehyde were emitted at rates of 1.25 and .93 grams per mile and 12.1 milligrams per mile respectively over the FTP with the improved calibration.) Composite gasoline equivalent fuel economy was 39.4 MPG for both calibrations.

2. The Carina was tested with an underfloor converter in addition to its original close-coupled manifold converter. Substantial increases in emission level efficiencies over manifold catalyst-only testing were obtained for HC, CO, and aldehydes over the FTP cycle. The two-catalyst system emitted only 5 milligrams per mile of formaldehyde over the FTP, but NOx emissions increased to 1.45 grams per mile over the same cycle. Gasoline equivalent composite fuel economy was 38.8 MPG with the two-catalyst system.

3. The Carina was tested over FTP/HFET cycles at an inertia weight of 2625 lbs, up from 2250 lbs inertia weight tested at previously. The additional weight was added to simulate operation of heavier vehicles equipped with engines of similar horsepower rating. CO levels over the FTP increased to 1.26 grams per mile, up from the .93 grams per mile measured at 2250 lbs test weight. Little change in other emission levels over the FTP or HFET cycle resulted from the additional test weight. City and highway fuel economy were reduced by .3 and .7 MPG respectively due to the increased weight.

4. The original equipment 165SR13 tires on the front drive wheels were replaced with higher aspect ratio 175/80R13 tires. The use of higher aspect ratio tires than those present on the vehicle as original equipment simulates the use of a larger chassis vehicle and increases the demand placed on the engine at constant speed.

Efficiencies decreased by 16 to 50 percent in each emissions category through the use of the higher tires. City fuel economy was also penalized approximately 5 percent for a city MPG of 16.2 through the use of the higher tires.

5. The vehicle was soaked and tested in the cold room to determine: a) the lowest temperature at which the vehicle would start and run on M100 fuel, and b) the emissions and fuel economy profiles of this vehicle at lower than 75°F conditions.

The lowest temperature at which the Carina would start and run reliably was 55°F. Emissions of carbon-containing pollutants generally increased as soak temperature decreased; emissions measured as HC increased from .09 to .19 grams per mile as temperature was decreased from 60° to 55°F, for example. Average NOx emissions, however, decreased over this same temperature range, from 1.25 to 1.18 grams per mile. Fuel economy gradually decreased with decreasing temperature. Average city MPG decreased to 16.34 MPG at 55°F from 16.79 MPG at 75°F.

6. The close-coupled manifold catalyst was removed and a non-catalyzed substrate substituted in its place to approximate engine-out, or baseline emissions. Three electronically controlled air/fuel ratio calibrations were utilized in this testing: a) a calibration optimized for driveability, b) a calibration similar to the first, yet 8 percent leaner at idle according to Toyota, and c) a calibration for operation at the maximum lean limit.

HC baseline levels from the Carina ranged from 7.2 to 7.7 grams per mile over the FTP; CO was emitted at a rate of 5.4 to 5.9 grams per mile over the same cycle. Average formaldehyde levels over the FTP varied from 312 milligrams per mile with the improved best driveability calibration to 573.1 milligrams per mile with the original best driveability calibration. The lowest HC, CO and formaldehyde levels over the FTP were emitted when the improved best driveability PROM was utilized. Higher levels of NOx, over those from the original best driveability and maximum lean limit calibrations, however were emitted when the improved best driveability calibration was used. Gasoline equivalent composite MPG was highest, 40.2 MPG, with the maximum lean limit calibration.

7. An air/fuel ratio measuring system, described in Appendix C was used to characterize the lean operating conditions of the Carina over several steady-state cycles.

Three separate air/fuel ratio calibrations were utilized, and pollutant emissions were also measured. Actual dynamometer horsepower of 8.0 and vehicle inertia test weight of 2250 lbs were used for this testing. The dummy catalyst substrate was used in place of the platinum/rhodium manifold close-coupled catalyst in order to provide an estimate of uncatalyzed engine-out emissions.

The air/fuel ratio measuring technique employed did not indicate that the improved best driveability PROM was 8 percent leaner at idle than the original best driveability PROM. Values of lambda (actual air/fuel ratio divided by stoichiometric air/fuel ratio) from both best driveability calibratins were similar over idle cycle testing. The best driveability calibrations ran at lambda values of 1.0 at idle, while the maximum lean limit PROM ran leaner, at approximately a lambda value of 1.14.

The two best driveability calibrations operated at lambda values of approximately 1.3 over the 10, 20, 30, 40 and 50 MPH steady-state cycles, which equates to an M100 air/fuel ratio of approximately 8.4 to 1. The maximum lean limit calibration operated at very near a lambda of 1.4 for these same cycles, which equates to an M100 air/fuel ratio of approximately 9.0 to 1. HC, NOx, and formaldehyde levels at idle were similar among the three PROMs; approximately 0.6 and 0.04 grams per minute and 50 to 80 milligrams per minute, respectively. CO emissions with the maximum lean limit PROM, 0.41 grams per minute, were less than 30 percent of the emission levels from the best driveability PROMs, however.

NOx levels at 10 MPH were 1.22 grams per mile with the lean limit PROM, approximately 30 percent below levels from the other PROMs. HC and CO levels were similar over all three calibrations. Aldehyde emissions approached an average 600 milligrams per mile with the improved best driveability calibration; the other two calibrations emitted at roughly twice this level. This difference in aldehyde levels, due solely to the air/fuel ratio calibration dissimilarities, is difficult to explain, particularly the difference between the two best driveability calibrations. Further analysis of the steady-state data is currently underway.

Average aldehyde values did not exceed 650 milligrams per mile for any calibration over the 20, 30, 40, and 50 MPH cycles, considerably lower levels than the emission rates reported at 10 MPH conditions. CO emissions did not exceed an average 2.5 grams per mile with any calibration over these cycles, and average CO emission rates generally decreased with increasing speed for each calibration. Emissions measured as HC also generally decreased as speed increased with each calibration over these cycles.

II. Introduction

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] to achieve improvements in fuel economy as well as comply with emission requirements under the Japanese 10-mode cycle:

A. A lean mixture sensor[3] was used in place of an oxygen sensor to control air/fuel ratio in the lean mixture range;

B. A swirl control valve[4] upstream of the intake valve was adopted to improve combustion by limiting torque fluctuation at increased air/fuel ratios; and

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

The Toyota Lean Combustion System Methanol (T-LCS-M) is similar to the T-LCS, but has been modified to maximize fuel economy and driving performance while minimizing pollutant emissions through the use of methanol fuel. SAE Paper 860247[5] described the development of the T-LCS-M system.

EPA became interested in this system because of its use of fuel methanol and Toyota provided EPA a T-LCS-M system in a Carina chassis. The Toyota Carina is a right-hand-drive vehicle sold in Japan. The vehicle provided to EPA was capable of operation on both M85 and M100 fuels by changing the onboard electronic control unit (PROM, for programmable read-only memory) to a system compatible with the fuel.

Initial testing of this vehicle at the EPA Motor Vehicle Emissions Laboratory involved the use of both M85 and M100 methanol fuels. This "Phase I" testing involved the determination and comparison of fuel economy and pollutant emission profiles of the vehicle when operated on each of these fuels. A summary of this testing was published in SAE Paper 871090.[6]

Testing subsequent to Phase I involved a number of separate issues concerned with various aspects of the T-LCS-M system. This testing was conducted using M100 neat methanol exclusively, and is referred to as "Phase II" testing. Some of these issues have been reported on in earlier memoranda.[7,8,9,10] A summary of these separate issues has been compiled, however, and is reported here.

III. 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. 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 PROM to a unit compatible with the desired fuel. The testing reported on here was conducted using M100 neat methanol exclusively, however. Details and specifications for the vehicle are given in Appendix A.

IV. Emission Analysis - Methods

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 [11] requires the reporting of methanol and organic material hydrocarbon equivalents (OMHCE). An explanation of the methanol data presented in this paper is given in Appendix B.

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.[12] Exhaust carbonyls including formaldehyde are bubbled through DNPH solution or drawn through DNPH-coated cartridges forming hydrazone derivatives. These derivatives are separated from the remaining unreacted DNPH by high performance liquid chromatography (HPLC). A spectrophotometer in the chromatograph effluent stream drives an integrator which determines formaldehyde derivative concentration.

V. Progam Design/Discussion of Test Results

A. Improved M100 Best Driveability Calibration

Toyota supplied EPA with two M100 electronic calibrations for the LCS-M Carina different that the calibration reported on in SAE Paper 871090.[6] The M100 electronic control unit mentioned in SAE Paper 871090 was calibrated for best driveability conditions, and is referred to as the "original" M100 best driveability PROM. The "improved" M100 best driveability calibration reported on here operated at an 8 percent leaner setting at idle than the "original" best driveability calibration; no other changes were made, however. The other recently provided M100 calibration, set to operate at maximum lean limit conditions, is referred to later in this report.

The Carina was tested several times over the Federal test procedure (FTP) and highway fuel economy test (HFET) cycles utilizing the original best driveability calibration. The PROM was then replaced with the improved calibration and the car was tested over the same cycles. The close-coupled manifold converter that the vehicle was originally equipped with was kept in the exhaust stream during this testing. Emissions and fuel economy test results from the improved calibration are presented in Tables 1, 2, and 3; results from the original calibration testing are also presented for comparison.

Average CO and NOx emissions increased 21 percent and 29 percent respectively over the FTP cycle when the improved calibration was used. No out-of-the-ordinary driving problems were noted during this testing, however. Aldehydes and emissions measured as hydrocarbons remained at similar levels over both calibrations. Emissions of aldehydes and NOx increased to 11.4 mg/mi and 0.97 g/mi over the HFET cycle, up from 8.5 mg/mi and 0.73 g/mi respectively with the original best driveability PROM. While emissions measured as HC and CO also increased with the leaner improved PROM, the reference levels obtained with the original best driveability PROM were very low.

Composite fuel economy was not appreciably aided by the leaner calibration. While a small gain in fuel economy under city driving conditions was noticed with the improved PROM, the original calibration had a slightly higher MPG under highway conditions. The result was a similar composite MPG and hence a similar gasoline equivalent MPG of 39.4 for both calibrations.

B. Two-Catalyst System

The LCS-M Carina arrived at the EPA Motor Vehicle Emissions Laboratory equipped with a close-coupled manifold catalytic converter. The exhaust system was modified to accept an underfloor converter in addition to the manifold catalyst. The underfloor converter was the "black box" converter from Engelhard Industries that was tested as part of the EPA low mileage methanol catalyst test program. This combination of manifold and underfloor converters tested simultaneously is referred to here as the "two-catalyst" system.

The "black box" converter is so named because its maker, Engelhard Industries, has not yet disclosed the catalytic formulation to protect patent rights. Engelhard representatives have stated, however, that this formulation may be particularly effective in an oxidation catalyst mode. Testing this configuration on a lean burn vehicle, therefore, would seem to be particularly appropriate.

The black box was installed in the exhaust stream approximately 1 foot downstream from the close-coupled manifold converter. The improved M100 best driveability PROM was used in this testing. The car was tested three times over FTP/HFET cycles. FTP results are presented in Table 4, together with recent results from vehicle testing with only a manifold catalyst. Efficiencies over manifold-catalyst-only

Table 1

Improved M100 Best Driveability PROM

FTP Cycle

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.06	.64	240.4	1.03	11.5	.007	.17	.09
2	.08	1.14	238.7	1.19	13.1	.010	.22	.11
3	.08	1.01	242.4	1.33	13.3	.010	.22	.11
4	.08	.91	240.2	1.46	10.4	.009	.20	.10
Average	.08	.93	240.4	1.25	12.1	.009	.20	.10

Original M100 Best Driveability PROM

FTP Cycle

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.07	.77	242.8	.97	12.4	.009	.20	.10

Emissions Efficiency of Improved Calibration Over The Original Calibration

FTP Cycle

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	(14.3)	(20.7)	(28.9)	(2.4)	(--)	(--)	(--)

* Calculated values per proposed rulemaking.

Table 2

Improved M100 Best Driveability PROM

HFET Cycle

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.005	.04	167.4	.89	10.2	.001	.01	.01
2	.005	.04	168.6	.87	11.6	.001	.01	.01
3	.006	.08	169.5	1.06	11.7	.001	.02	.01
4	.005	.04	171.7	1.06	12.2	.001	.01	.01
Average	.005	.05	169.3	.97	11.4	.001	.01	.01

Original M100 Best Driveability PROM

HFET Cycle

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.004	.02	167.8	.73	8.5	.001	.01	.01

Emissions Efficiency of Improved Calibration Over the Original Calibration

HFET Cycle

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	(25.0)	(150.)	(32.9)	(34.1)	(--)	(--)	(--)

* Calculated values per proposed rulemaking.

Table 3

Summary of Fuel Economy Test Results
Original/Improved M100 Calibrations

Testing Configuration	City MPG	Highway MPG	Composite MPG	Gasoline Equiv. Composite MPG
Improved M100 PROM Manifold Catalyst	17.0	24.3	19.6	39.4
Original M100 PROM Manifold Catalyst	16.8	24.5	19.6	39.4

Table 4

Two-Catalyst System Testing

FTP Cycle

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.06	.61	246.8	1.47	5.1	.008	.18	.09
2	.06	.64	243.1	1.46	5.6	.007	.16	.08
3	.06	.82	243.2	1.43	4.9	.008	.18	.09
Average	.06	.69	244.4	1.45	5.2	.008	.17	.09

Recent FTP Results, Manifold Catalyst Only

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.08	.93	240.4	1.25	12.1	.009	.20	.10

Efficiency of Two-Catalyst System Over Manifold Catalyst Only

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	25.0	25.8	(16.0)	57.4	11.1	15.0	10.0

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* Calculated values per proposed rulemaking.

testing have been calculated and are also included. HFET results are presented in similar format in Table 5. Fuel economy results for this testing are presented in Table 6.

Substantial increases in emission level efficiencies over manifold catalyst-only testing were obtained for HC, CO, and aldehydes over the FTP cycle. Particularly notable was the 57 percent decrease in aldehyde levels, from 12 to roughly 5 milligrams per mile. Though not presented here, an analysis of bag data revealed that all of the aldehydes measured here were collected in Bag 1--no aldehydes were detected in Bags 2 or 3. NOx levels, however, rose to an average 1.45 grams per mile, a 16 percent increase over the manifold-catalyst-only comparison level.

HFET results are presented in Table 5, together with results from manifold-catalyst-only testing for comparison. The overall trend is for emission levels to follow in direction, though of course not in magnitude, those from FTP testing.

Substantial increases in HC, CO and aldehyde conversion efficiency were attained through use of the black box converter over the HFET cycle. HC and CO levels from manifold-catalyst-only testing were very low, however, so the decrease in mass of emissions was not great. Aldehyde levels decreased from 11.4 to 0.0 milligrams per mile; this was a significant decrease. NOx levels however increased 14 percent over those from testing with the manifold-catalyst-only.

Fuel economy decreased over both city and highway cycle through the use of the two catalyst system compared to th close-coupled manifold catalyst system; the decrease i efficiency was not extreme, however. The decrease in city an highway M100 MPG was 0.3 and 0.4 respectively for a gasoline equivalent composite MPG of 38.8 with the dual-catalyst system.

C. Testing At Increased Inertia Weight

The LCS-M Carina had been previously evaluated at a test weight of 2250 lbs and at an actual dynamometer horsepower of 8.0. Toyota claimed that the engine horsepower of the 1.6-liter LCS-M engine is approximately 80 hp. The 1984 Test Car List was examined to determine average inertia weight and dynamometer horsepower ratings of vehicle systems with similar engine horsepower ratings. Considered cars also had to be comparably equipped in terms of transmissions and emission control equipment. The selected cars included Ford's Escort, GM 2000 Sunbird, Toyota's Camry, the Mazda 626, VW Jetta, and the Mitsubishi Cordia. A test weight of 2625 lbs at 8.0 actual dynamometer horsepower was selected as representative.

A 60/40 weight loading between front and rear wheels for this front-wheel-drive car was assumed, and the wall between the engine and front seat compartment was loaded with 233 lbs

Table 5

Two-Catalyst System Testing

HFET Cycle

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.003	0.00	177.0	1.23	0.0	.000	.008	.004
2	.004	0.01	170.1	1.04	0.0	.001	.013	.006
3	.003	0.00	169.9	1.05	0.0	.000	.008	.004
Average	.003	0.00	172.3	1.11	0.0	.000	.008	.004

Recent HFET Results, Manifold Catalyst Only

Test Average	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.005	.05	169.3	.97	11.4	.001	.01	.01

Efficiency of Two-Catalyst System
Over Manifold Catalyst Only

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	40.0	100.0	(14.4)	100.0	100.0	20.0	60.0

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* Calculated values per proposed rulemaking.

Table 6

Summary of Fuel Economy Test Results
Manifold Catalyst/Two-Catalyst System

Testing Configuration	City MPG	Highway MPG	Composite MPG	Gasoline Equiv. Composite MPG
Manifold Catalyst Only	17.0	24.3	19.6	39.4
Dual Catalyst System	16.7	23.9	19.3	38.8

of sandbags. This was the most practical way of loading the vehicle. The improved M100 best driveability calibration was used, and the car tested twice over FTP/HFET cycles. Emission test results are given in Tables 7 and 8, and fuel economy results are summarized in Table 9.

Little change in emission levels resulted from the additional loading of the vehicle and testing over the FTP cycle. NOx, aldehyde and HC levels were relatively unaffected by this testing. CO levels over the FTP, however, increased to 1.26 grams per mile, above the 0.93 grams per mile level at 2250 lbs test weight. The only notable difference in HFET test results was the decrease to 0.70 grams per mile NOx at 2625 lbs. The difference between the two individual NOx test results, 0.40 grams per mile, is high when compared to the average level of 0.70 grams per mile.

A degradation in fuel economy occurred with testing at the increased inertia weight. City and highway MPG were reduced by 0.3 and 0.7 MPG respectively due to the increased weight. Gasoline composite MPG was 38.6 at 2625 lbs. test weight.

D. Use of Higher Aspect Ratio Tires

The use of higher aspect ratio tires than those present on the vehicle as original equipment simulates the use of a larger chassis vehicle and increases the demand placed on the engine at constant speed. A degradation in emissions performance and fuel economy may be expected from this increased demand on engine output.

The original equipment tires (165SR13) on the front-drive wheels were replaced with the highest aspect ratio 13-inch tire that we could fit on the wheels (185/80R13). Larger tires would have interfered with the suspension struts which extended out over the front wheels. The vehicle was then tested over the FTP cycle. This testing was accomplished at 2250 lbs inertia weight, 8.0 actual dynamometer horsepower, and utilized the M100 improved best driveability calibration and close-coupled manifold converter. Test results are presented in Tables 10 and 11.

Emission levels increased in each category over those obtained with the lower aspect ratio tires. Emission efficiencies decreased by 16 to 50 percent in each emission category. Fuel economy over city driving conditions was also penalized, the penalty amounting to 0.8 MPG or roughly 5 percent from the reference figure presented in Table 11.

E. Cold Start/Emissions Testing

The Carina was soaked overnight in the cold room at successively lower temperatures, each soak followed by a cold start and test over the FTP cycle. The purpose of this testing was twofold: 1) to determine the lowest temperature at which

Table 7

Testing At 2625 Lbs. Inertia Weight

FTP Cycle

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.06	1.30	244.9	1.19	12.4	.008	.18	.09
2	.07	1.22	244.0	1.27	11.8	.009	.21	.11
Average	.07	1.26	244.5	1.23	12.1	.009	.20	.10

Testing at 2250 Lbs. Inertia Weight
FTP Cycle

Improved M100 Best Driveability Calibration

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.08	.93	240.4	1.25	12.1	.009	.20	.10

Emissions Efficiency At 2625 Lbs. Test Weight
Compared With 2550 Lbs. Test Weight

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	12.5	(35.5)	1.6	--	--	--	--

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* Calculated values per proposed rulemaking.

Table 8

Testing at 2625 Lbs. Inertia Weight

HFET Cycle

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.006	.05	175.7	.50	14.9	.001	.01	.01
2	.005	.07	172.3	.90	12.6	.001	.01	.01
Average	.005	.06	174.0	.70	13.8	.001	.01	.01

Testing At 2250 Lbs. Inertia Weight

HFET Cycle

Improved M100 Best Driveability Calibration

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.005	.05	169.3	.97	11.4	.001	.01	.01

Emissions Efficiency At 2625 Lbs. Test Weight Compared With 2250 Lbs. Test Weight

Efficency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	--	(20.0)	20.6	(21.0)	--	--	--

* Calculated values per proposed rulemaking.

Table 9

Summary of Fuel Economy Test Results
2625 Lbs Test Weight/2250 Lbs Test Weight

Testing Configuration	City MPG	Highway MPG	Composite MPG	Gasoline Equiv. Composite MPG
2250 pounds test weight	17.0	24.3	19.6	39.4
2625 pounds test weight	16.7	23.6	19.2	38.6

Table 10

Testing With Higher Aspect Ratio Tires
FTP Cycle, M100 Improved Best Driveability PROM

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.12	1.21	253.6	1.54	15.1	.014	.31	.15
2	.11	1.09	248.8	1.35	14.8	.012	.29	.14
Average	.12	1.15	251.2	1.45	15.0	.013	.30	.15

Recent Test Results, OEM Tires
FTP Cycle, M100 Improved Best Driveability PROM

Test Averages	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
Average	.08	.93	240.4	1.25	12.1	.009	.20	.10

Emissions Efficiency, Higher Aspect
Ratio Tires Over OEM Tires

Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	(50.0)	(23.7)	(16.0)	(24.0)	(44.4)	(50.0)	(50.0)

* Calculated values per proposed rulemaking.

Table 11

Summary of Fuel Economy Test Results
Higher Aspect Ratio Tires Versus OEM Tires

Testing Configuration	City MPG
OEM tires	17.0
Higher aspect ratio tires	16.2

the vehicle would start and run on M100 fuel; and 2) to determine the emissions and fuel economy profiles of this vehicle at lower than 75°F conditions. This testing was conducted using the original M100 best driveability calibration. The Carina was not equipped with any special cold start assist devices for this testing.

The vehicle was started and tested twice at 75°F. As expected, the vehicle experienced no significant driveability problems. No problems were experienced at 60°F conditions either. The car would not start at 50°F, however. Five-second cranking periods were followed by 10-second pause periods for this start attempt; this crank/pause cycle was repeated seven times before failure to start was declared. The car was then started and tested twice at 55°F conditions. An extended 15-second crank was necessary in order to start the engine at 55°F conditions. Emission results are presented in Table 12, while fuel economy results are given in Table 13.

Emissions of carbon-containing pollutants generally increased as soak temperatures decreased; emissions measured as HC increased from 0.09 to 0.19 grams per mile as temperature was decreased from 60° to 55°F, for example. Average NOx emissions, however, decreased over this same temperature range, from 1.25 to 1.18 grams per mile. Fuel economy gradually decreased with decreasing temperature. Average city MPG decreased to 16.34 MPG at 55°F from 16.79 MPG at 75°F.

F. Baseline Testing

In addition to the two PROMs calibrated for best driveability which were mentioned earlier in this paper, a third M100 PROM was supplied to EPA by Toyota. This PROM was calibrated for maximum lean operation, and is referred to here as the M100 maximum lean limit PROM. A dummy manifold catalyst substrate was also supplied to EPA, and this substrate replaced the original manifold catalyst for an effort to measure engine-out, or baseline emissions from the vehicle. Baseline as defined in this testing on the Carina includes the dummy substrate in the vehicle exhaust, rather than a "straight pipe" replacing the converter arrangement.

The Carina was tested several times over the FTP/HFET test cycles, utilizing each of the M100 PROM's. The dummy catalyst was used in place of the platinum/rhodium manifold catalyst during this testing. Emissions data is provided in Tables 14, 15, and 16 while a fuel economy summary is presented in Table 17.

Tests of an M100-fueled Volkswagen Rabbit equipped with a 1.6-liter engine indicated baseline HC emission levels of 0.96 grams per mile over the FTP.[13] This Volkswagen vehicle utilized a straight pipe rather than a dummy catalyst substrate for baseline testing, however. HC levels from the Carina presented here varied from 7.2 to 7.7 grams per mile. CO from this Volkswagen engine was measured at 6.54 grams per mile over

Table 12

Cold Room Testing

Original M100 Best Driveability Calibration--FTP Cycle

75°F Soak

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.08	.79	232.2	1.01	12.3	.010	.22	.11
2	.07	.92	255.1	1.20	9.6	.009	.20	.10
Average	.08	.86	243.7	1.11	11.0	.010	.21	.11

60°F Soak

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.08	.93	243.5	1.22	9.2	.009	.22	.11
2	.09	.96	246.3	1.28	N/A	.011	.25	.12
Average	.09	.95	244.9	1.25	9.2	.010	.24	.12

55°F Soak

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	.22	1.25	250.2	1.18	19.7	.020	.61	.30
2	.15	1.11	248.0	1.17	11.3	.020	.41	.20
Average	.19	1.18	249.1	1.18	15.5	.020	.51	.25

* Calculated per proposed rulemaking.
N/A signifies test results not available.

Table 13

Summary of Fuel Economy Test Results

Cold Room Testing

Testing Configuration	City MPG	Gasoline Equivalent MPG
75°F Soak	16.79	33.76
60°F Soak	16.65	33.47
55°F Soak	16.34	32.86

Table 14

Baseline Testing--FTP Cycle

Original M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	9.05	5.11	208.2	1.38	608.8	1.065	24.60	12.00
2	7.09	6.46	204.7	1.63	561.9	.834	19.26	9.43
3	7.01	6.12	203.0	1.52	548.7	.825	19.05	9.33
Average	7.72	5.90	205.3	1.51	573.1	.908	20.97	10.25

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	8.21	5.53	203.2	1.51	473.7	.966	22.31	10.85
2	6.87	4.74	206.2	1.52	232.7	.808	18.66	9.00
3	6.54	5.83	209.7	1.84	230.8	.770	17.78	8.58
Average	7.21	5.37	206.4	1.62	312.4	.848	19.58	9.48

M100 Maximum Lean Limit Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	8.52	5.70	198.3	1.14	500.0	1.002	23.15	11.26
2	7.54	5.42	197.8	1.01	454.1	.887	20.49	9.97
3	6.17	5.28	204.8	1.02	621.1	.726	16.77	8.28
4	7.04	5.36	198.4	0.87	597.0	.828	19.12	9.38
Average	7.32	5.44	199.8	1.01	543.1	.861	19.88	9.72

* Calculated values per proposed rulemaking.

Table 15

Baseline Testing--HFET Cycle

Original M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	4.99	1.91	151.1	1.21	155.6	.587	13.55	6.53
2	2.81	2.06	149.2	0.76	196.7	.330	7.62	3.72
Average	3.90	1.99	150.2	0.99	176.2	.459	10.59	5.13

Improved M100 Best Driveability Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	4.33	2.10	152.6	1.39	188.0	.509	11.76	5.69
2	4.34	1.95	148.9	1.05	98.6	.510	11.78	5.66
3	3.85	1.97	151.8	1.10	94.9	.452	10.45	5.02
Average	4.17	2.01	151.1	1.18	127.2	.490	11.33	5.46

M100 Maximum Lean Limit Calibration

Test Number	HC g/mi	CO g/mi	CO2 g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi
1	2.82	2.09	149.0	.52	286.6	.332	7.67	3.79
2	2.75	2.11	148.0	.51	258.5	.323	7.47	3.68
3	3.31	2.05	143.9	.50	278.4	.390	9.00	4.42
4	3.05	1.82	150.4	.57	229.1	.358	8.28	4.04
Average	2.98	2.02	147.8	.53	263.2	.351	8.11	3.98

Table 16

Emissions Efficiency of Two-Catalyst System Over Baseline Emissions

FTP Cycle--Improved M100 Best Driveability PROM

Emissions Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	99.2	87.2	10.5	98.3	99.1	99.1	99.1

Emissions Efficiency of Two-Catalyst System Over Baseline Emissions

HFET Cycle--Improved M100 Best Driveability PROM

Emissions Efficiency	HC	CO	NOx	Alde	HC*	CH3OH*	OMHCE*
Percent	99.9	100.	5.9	100.	100.	99.9	99.9

Table 17

Summary of Fuel Economy Test Results
Baseline Testing

Testing Configuration	City MPG	Highway MPG	Composite MPG	Gasoline Equiv. Composite MPG
Original best driveability calibration	16.6	24.3	19.4	39.0
Improved best driveability calibration	16.8	24.0	19.4	39.0
Maximum lean limit calibration	17.2	25.0	20.0	40.2

the FTP; a comparable 5.4 to 5.9 grams per mile was measured with the Carina. While NOx baseline emission levels were comparable between these vehicles when the best driveability Carina PROMS are considered, the Carina maximum lean limit PROM emitted only an average 1.01 grams per mile NOx over the FTP. This level was substantially below the 1.5 to 1.6 grams per mile NOx measured with the Carina best driveability PROMs. Formaldehyde emission levels from the Carina were also above those reported from this Volkswagen vehicle testing. The Carina original best driveability and maximum lean limit calibrations emitted formaldehyde emissions of 573 to 543 milligrams per mile over the FTP, respectively. These levels were more than twice as high as the average 252 milligrams per mile over the same cycle with the Volkswagen vehicle.

The efficiency of the catalyst system tested on this vehicle may be better appreciated by a comparison of emissions from the catalyst-equipped car versus the baseline levels presented here. Table 16 presents the emissions efficiency of the two-catalyst configuration referred to earlier in this report versus baseline levels over each pollutant measured.

All carbon-containing pollutant levels were greatly reduced by the two-catalyst system; efficiencies over both cycles exceeded 90 percent, with the exception of CO over the FTP cycle. NOx efficiencies were very low in comparison to those of the carbon-containing pollutants, however. The NOx improvement with the two-catalyst system was a mere 6 percent over the HFET cycle.

The fuel economy figures presented in Table 17 are similar to those presented in Tables 3 and 6, manifold catalyst and two-catalyst equipped testing respectively. A slight trend toward better fuel economy from the maximum lean limit PROM, however, is evident from the higher city and highway MPG figures obtained with this calibration, over the best driveability PROMs.

G. Air/Fuel Ratio Analysis

A measure of the how lean the vehicle may be operated may be taken by operating the vehicle at various steady-state modes and measuring air/fuel ratio requirements over these modes. The Micro Oxivision air/fuel ratio meter, Model MO-1000, is described by its manufacturer NGK Spark Plug Co., Ltd., as being able to perform this analysis quickly over a wide range of fuels, to include methanol. The testing described below made use of this meter to characterize air/fuel ratio requirements over several steady-state conditions with the Carina. Details of the operation of this meter and the exhaust gas sensor used are given in Appendix C.

All three M100 calibrations referred to earlier in this paper were used in this evaluation. The dummy catalyst substrate was used in place of the platinum/rhodium manifold close-coupled catalyst in order to provide an estimate of uncatalyzed engine-out emissions. The exhaust gas sensor was mounted in the exhaust pipe approximately 1 foot downstream of the manifold-mounted dummy catalyst. The vehicle was tested over idle, 10, 20, 30, 40 and 50 mile per hour steady-state conditions with the original and improved best driveability calibrations, as well as the maximum lean limit calibration. Lambda, which is defined as actual air/fuel ratio over stoichiometric air/fuel ratio, was measured to give an indication of engine leanness at these various steady-state conditions. Pollutant emissions were also measured during this testing. A summary of emissions data and air/fuel data in the form of lambda is given in Tables 18 through 23.

Toyota has claimed that the improved M100 best driveability calibration was 8 percent leaner at idle than the original best driveability calibration. The data in Table 18 indicate a slightly richer mixture at idle for the improved PROM, however. The mixture was approximately 10 percent leaner than best driveability PROM levels at idle when the maximum lean limit calibration was used. HC, NOx, and formaldehyde levels at idle were similar among the three PROMs; CO emissions with the maximum lean limit PROM were less than 30 percent of the emission levels from the best driveability PROMs.

An average lambda of 1.38 was measured with the maximum lean limit PROM at 10 MPH steady-state conditions, slightly leaner than the 1.31 measured with the improved best driveability calibration. NOx levels at 10 MPH were 1.22 grams per mile with the lean limit PROM, approximately 30 percent below levels from the other PROMs. HC and CO levels were similar over all three calibrations. Aldehyde emissions approached an average 600 milligrams per mile with the improved best driveability calibration; the other two calibrations emitted at roughly twice this level. This difference in aldehyde levels, due solely to the air/fuel ratio calibration dissimilarities, is difficult to explain, particularly the difference between the two best driveability calibrations.

Average lambda values over 20, 30, 40, and 50 MPH testing cycles exhibit a trend of roughly equivalent values between the two best driveability calibrations and a leaner value for the lean limit calibration at each testing cycle. The lean limit PROM lambda values approached 1.4 while the best driveability PROMs gave measured lambda values near 1.3 for this testing. Average aldehyde values did not exceed 650 milligrams per mile for any calibration over these cycles, considerably lower at levels than the emission rates reported at 10 MPH conditions. CO emissions did not exceed an average 2.5 grams per mile with any calibration over these cycles, and average CO emission rates generally decreased with increasing speed for each calibration. Emissions measured as HC also generally decreased with increasing speed with each calibration over these cycles.

VI. Conclusions

Conclusions from each aspect of Phase II testing are drawn below.

Table 18

Idle Cycle Testing

Original M100 Best Driveability PROM

Test Number	HC g/min	CO g/min	NOx g/min	Alde mg/min	HC* g/min	CH3OH* g/min	OMHCE* g/min	Lambda
1	1.00	1.46	.07	143.1	.117	2.70	1.35	1.10
2	.31	2.25	.02	40.3	.036	.84	.42	.94
3	.46	1.25	.03	49.4	.054	1.26	.62	1.06
Average	.59	1.65	.04	77.6	.069	1.60	.80	1.03

Improved M100 Best Driveability PROM

Test Number	HC g/min	CO g/min	NOx g/min	Alde mg/min	HC* g/min	CH3OH* g/min	OMHCE* g/min	Lambda
1	.35	2.49	.03	32.4	.041	.95	.47	.96
2	.70	1.78	.05	72.6	.082	1.90	.94	1.04
Average	.53	2.14	.04	52.5	.062	1.43	.71	1.00

M100 Maximum Lean Limit PROM

Test Number	HC g/min	CO g/min	NOx g/min	Alde mg/min	HC* g/min	CH3OH* g/min	OMHCE* g/min	Lambda
1	.40	.68	.03	44.7	.047	1.08	.54	1.08
2	.46	.48	.04	51.6	.054	1.24	.61	1.08
3	.37	.30	.05	60.9	.044	1.02	.51	1.12
4	.55	.34	.05	52.3	.065	1.49	.74	1.16
5	1.04	.25	.09	59.7	.122	2.82	1.37	1.26
Average	.56	.41	.05	53.8	.066	1.53	.75	1.14

* Calculated per proposed rulemaking.

Table 19

10 MPH Steady State Conditions

Original M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	23.07	3.94	1.90	1370.0	2.714	62.67	30.49	1.38
2	19.08	4.92	2.11	1149.0	2.245	51.85	25.23	1.30
Average	21.08	4.43	2.01	1259.5	2.480	57.26	27.86	1.34

Improved M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	17.15	3.63	1.69	624.9	2.017	46.58	22.48	1.32
2	17.32	3.61	1.90	540.8	2.038	47.05	22.66	1.30
Average	17.24	3.62	1.80	582.9	2.028	46.82	22.57	1.31

M100 Maximum Lean Limit PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	21.09	4.79	1.11	1077.5	2.481	57.29	27.79	1.36
2	15.53	5.04	1.08	1049.5	1.827	42.19	20.58	1.32
3	13.85	4.66	.96	1364.9	1.629	37.62	18.55	1.30
4	16.17	3.83	1.50	1174.6	1.903	43.94	21.47	1.56
5	16.75	3.76	1.45	1155.0	1.970	45.50	22.21	1.38
Average	16.68	4.42	1.22	1164.3	1.962	45.31	22.12	1.38

* Calculated per proposed rulemaking.

Table 20

20 MPH Steady-State Conditions

Original M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	13.41	2.09	1.90	229.4	1.578	36.44	17.46	1.36
2	11.20	2.15	1.08	515.7	1.318	30.44	14.74	1.30
3	10.17	2.76	2.09	820.8	1.197	27.64	13.55	1.30
Average	11.59	2.33	1.69	522.0	1.364	31.51	15.25	1.32

Improved M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	12.62	2.28	1.87	213.2	1.485	34.29	16.43	1.34
2	11.73	2.10	2.41	228.3	1.380	31.86	15.28	1.32
Average	12.18	2.19	2.14	220.8	1.433	33.08	15.85	1.33

M100 Maximum Lean Limit PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	10.92	3.03	1.18	836.5	1.285	29.67	14.52	1.36
2	8.71	2.83	1.09	712.3	1.025	23.66	11.60	1.32
3	12.85	2.61	1.08	455.5	1.512	34.92	16.85	1.38
4	11.49	2.05	.99	626.7	1.351	31.21	15.16	1.78
5	9.69	2.04	1.63	495.5	1.140	26.33	12.77	1.42
Average	10.73	2.51	1.19	625.3	1.263	29.16	14.18	1.45

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* Calculated per proposed rulemaking.

Table 21

30 MPH Steady-State Conditions

Original M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	8.82	1.53	2.31	371.7	1.038	23.97	11.59	1.30
2	6.35	2.09	N/A	451.2	.747	17.26	8.43	1.28
3	4.57	2.23	1.53	583.6	.538	12.42	6.18	1.32
Average	6.58	1.95	1.92	468.8	.774	17.88	8.73	1.30

Improved M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	7.22	1.90	1.98	130.3	.849	19.62	9.40	1.30
2	8.16	1.64	2.43	127.0	.961	22.18	10.62	1.32
Average	7.69	1.77	2.21	128.7	.905	20.90	10.01	1.31

M100 Maximum Lean Limit PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	2.90	2.08	1.23	482.3	.342	7.89	3.98	1.28
2	4.22	2.22	1.18	411.7	.497	11.47	5.65	1.30
3	4.07	2.11	1.13	250.4	.478	11.05	5.38	1.58
4	3.08	1.87	1.40	206.0	.362	8.37	4.08	1.38
Average	3.57	2.07	1.24	337.6	.420	9.70	4.77	1.39

* Calculated per proposed rulemaking.
N/A signifies not available.

Table 22

40 MPH Steady-State Conditions

Original M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	2.28	1.65	1.80	314.9	.269	6.21	3.10	1.24
2	2.71	1.78	1.37	377.0	.319	7.37	3.69	1.32
Average	2.50	1.72	1.59	346.0	.294	6.79	3.40	1.28

Improved M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	3.64	1.66	2.08	84.2	.429	9.90	4.76	1.28
2	3.51	1.75	2.07	95.8	.413	9.55	4.59	1.28
Average	3.58	1.71	2.08	90.0	.421	9.73	4.68	1.28

M100 Maximum Lean Limit PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	1.61	1.58	1.38	323.3	.189	4.37	2.23	1.28
2	1.53	1.62	1.58	153.3	.179	4.14	2.04	1.29
3	1.80	1.71	1.26	262.3	.212	4.89	2.45	1.58
4	5.48	2.07	1.37	110.0	.645	14.89	7.14	1.40
Average	2.61	1.75	1.40	212.2	.306	7.07	3.47	1.39

* Calculated per proposed rulemaking.

Table 23

50 MPH Steady State Conditions

Original M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	5.24	1.68	1.53	372.7	.616	14.23	6.95	1.28
2	1.24	1.48	1.44	245.8	.145	3.36	1.71	1.26
3	3.46	1.96	NA	388.4	.407	9.40	4.66	1.40
Average	3.31	1.71	1.49	335.6	.389	9.00	4.44	1.31

Improved M100 Best Driveability PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	2.14	1.60	1.75	62.8	.252	5.82	2.80	1.30
2	4.57	1.61	1.86	63.6	.537	12.41	5.94	1.30
Average	3.36	1.61	1.81	63.2	.395	9.12	4.37	1.30

M100 Maximum Lean Limit PROM

Test Number	HC g/mi	CO g/mi	NOx g/mi	Alde mg/mi	HC* g/mi	CH3OH* g/mi	OMHCE* g/mi	Lambda
1	.95	1.35	1.62	253.1	.112	2.58	1.35	1.30
2	1.17	1.48	1.14	243.6	.137	3.16	1.62	1.30
3	1.16	1.47	1.17	293.6	.137	3.16	1.64	1.32
4	1.58	1.75	1.11	211.1	.186	4.30	2.15	1.44
Average	1.22	1.51	1.26	250.4	.143	3.30	1.69	1.34

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* Calculated per proposed rulemaking.
NA signifies test results not available.

1. An improved version of the M100 best driveability calibration was tested and the results compared with those from testing with the PROM originally supplied with the vehicle. Toyota describes the improved best driveability calibration as 8 percent leaner at idle than the original best driveability calibration. NOx and CO emission levels over the FTP and HFET cycles rose when the improved calibration was used. Aldehydes and hydrocarbons remained at similar emission levels regardless of calibration, however. Composite gasoline equivalent fuel economy was 39.4 MPG for both calibrations.

2. The Carina was tested with an underfloor converter in addition to its original close-coupled manifold converter. Substantial increases in emission level efficiencies over manifold catalyst-only testing were obtained for HC, CO, and aldehydes over the FTP cycle. The two-catalyst system emitted only 5 milligrams per mile of formaldehyde over the FTP, but NOx emissions increased to 1.45 grams per mile over the same cycle. Gasoline equivalent composite fuel economy was 38.8 MPG with the two-catalyst system.

3. The Carina was tested over FTP/HFET cycles at an inertia weight of 2625 lbs, up from the 2250 lbs inertia weight tested at previously. CO levels over the FTP increased to 1.26 grams per mile, up from the 0.93 grams per mile emitted at 2250 lbs test weight. Little change in other emission levels over the FTP or HFET cycle resulted from the additional test weight. City and highway fuel economy were reduced by 0.3 and 0.7 MPG respectively due to the increased weight.

4. The original equipment 165SR13 tires on the front drive wheels were replaced with higher aspect ratio 175/80R13 tires. Efficiencies decreased by 16 to 50 percent in each emissions category through the use of the higher tires. City fuel economy was also penalized approximately 5 percent or 0.8 MPG by the use of the higher tires.

5. The vehicle was soaked and tested at colder than 75°F conditions to determine: a) the lowest temperature at which the vehicle would start and run on M100 fuel, and b) the emissions and fuel economy profiles of this vehicle at lower than 75°F conditions.

The lowest temperature at which the Carina would start and run reliably was 55°F. Emissions of carbon-containing pollutants generally increased as soak temperature decreased over the FTP cycle; average NOx emissions decreased over the same range, however. Fuel economy gradually decreased with decreasing soak temperature.

6. The close-coupled manifold catalyst was removed and a non-catalyzed substrate substituted in its place to approximate engine-out, or baseline emissions. Three electronically controlled air/fuel ratio calibrations were utilized in this testing: a) a calibration optimized for driveability, b) a calibration similar to the first, yet 8 percent leaner at idle according to Toyota, and c) a calibration for operation at the maximum lean limit.

HC baseline levels from the Carina ranged from 7.2 to 7.7 grams per mile over the FTP; CO was emitted at a rate of 5.4 to 5.9 grams per mile over the same cycle. Average formaldehyde levels over the FTP varied from 312 milligrams per mile with the improved best driveability calibration to 573.1 milligrams per mile with the original best driveability calibration. The lowest HC, CO and formaldehyde levels over the FTP were emitted when the improved best driveability PROM was utilized. Higher levels of NOx, over those from the original best driveability and maximum lean limit calibrations, however were emitted when the improved best driveability calibration was used. Gasoline equivalent composite MPG was highest, 40.2 MPG, with the maximum lean limit calibration.

7. An air/fuel ratio measuring system, described in Appendix C was used to characterize the lean operating conditions of the Carina over several steady-state cycles. Three separate air/fuel ratio calibrations were utilized, and pollutant emissions were also measured. Actual dynamometer horsepower of 8.0 and vehicle inertia test weight of 2250 lbs were used for this testing.

The air/fuel ratio measuring technique employed did not indicate that the improved best driveability PROM was 8 percent leaner at idle than the original best driveability PROM. Values of lambda (actual air/fuel ratio divided by stoichiometric air/fuel ratio) from each calibration were similar over idle cycle testing. The original and improved best driveability calibrations ran at lambda values of 1.0 at idle, while the maximum lean limit PROM ran leaner, at approximately 1.14.

The two best driveability calibrations operated at lambda values of approximately 1.3 over the 10, 20, 30, 40 and 50 MPH steady-state cycles, which equates to an M100 air/fuel ratio of approximately 8.4 to 1. The maximum lean limit calibration operated at very near a lambda of 1.4 for these same cycles, which equates to an M100 air/fuel ratio of approximately 9.0 to 1.

HC, NOx, and formaldehyde levels at idle were similar among the three PROMs: approximately 0.6 and 0.4 grams per minute and 50 to 80 milligrams per minute, respectively. CO emissions with the maximum lean limit PROM, 0.41 grams per minute, were less than 30 percent of the emission levels from the best driveability PROMs, however.

NOx levels at 10 MPH were 1.22 grams per mile with the lean limit PROM, approximately 30 percent below levels from the other PROMs. HC and CO levels were similar over all three calibrations. Aldehyde emissions approached an average 600 milligrams per mile with the improved best driveability calibration; the other two calibrations emitted at roughly twice this level. This difference in aldehyde levels, due solely to the air/fuel ratio calibration dissimilarities, is difficult to explain, particularly the difference between the two best driveability calibrations.

Average aldehyde values did not exceed 650 milligrams per mile for any calibration over the 20, 30, 40, and 50 MPH cycles, considerably lower levels than the emission rates reported at 10 MPH conditions. CO emissions did not exceed an average 2.5 grams per mile with any calibration over these cycles, and average CO emission rates generally decreased as speed increased with each calibration. Emissions measured as HC also generally decreased as speed increased with each calibration over these cycles.

Future work in this area should include an effort at mapping excess air ratio (lambda) over at least two additional parameters: intake manifold pressure and engine speed. Air/fuel ratio analysis presented in the literature typically involves mapping over these parameters. A direct comparison of data gathered by the method described in Appendix C with other published data is difficult in the absence of this format.

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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

CALCULATION OF HC, METHANOL AND HCHO

As proposed, the regulations in reference 7 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 in this paper 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.

APPENDIX C

NTK MICRO OXIVISION AIR/FUEL RATIO METER

The MICRO OXIVISION MO-1000 is an air/fuel ratio meter designed specifically for use with the NTK Universal Exhaust Gas Oxygen Sensor.

The detecting section of the sensor is made of two ZrO_2 substrate elements: 1) an O_2 pumping cell, and 2) an O_2 detecting cell, both heated by ceramic heaters. ZrO_2 has two interesting properties with respect to its use as a sensor. First, a galvanic potential is caused by different O_2 partial pressures on either side of a ZrO_2 element. Second, an oxygen ion may be moved by applying voltage to the ZrO_2 element.

The detecting cell contains two chambers. The first, or reference cavity contains a high concentration of oxygen. The othe side of the detector is exposed to exhaust gas, and is referred to as the detecting gas cavity. The separation of these two cells by a ZrO_2 element generates a galvanic potential voltage in the same fashion as a conventional oxygen sensor. The galvanic potential is approximately 100mV at very lean conditions and may rise to 900 mV under rich conditions.

The pumping cell can control the partial O_2 pressure in the gas detecting cavity by pumping O_2; therefore, it may also control galvanic potential. This potential may be held at 450 mV in any exhaust condition by controlling current to the pumping cell, and therefore the pumping current corresponds to the air/fuel ratio of the exhaust gas.

Further information concerning the operation of the sensor is available from the U.S. distributor of this product, NGK Spark Plugs (U.S.A.), Inc.

APPENDIX C (cont'd)

NTK MICRO OXIVISION AIR/FUEL RATIO METER

Specifications

Sensor Specification (MB-100):

Measurement Range:

Lambda	0.7 - 2.2
Air/Fuel Ratio	10-30 A/F
O_2 Partial Pressure	0-25%

Accuracy and Repeatability:

Lambda

Measurement Range	Accuracy	Repeatability
$.9<\lambda<1.1$	$\pm 0.02\ \lambda$	$\pm 0.002\ \lambda$
other	$\pm 0.03\ \lambda$	$\pm 0.003\ \lambda$

Air Fuel Ratio:

Measurement Range	Accuracy	Repeatability
13<A/F<16	±0.2 A/F	±0.02 A/F
other	±0.3 A/F	±0.03 A/F

O2 Partial Pressure:

Measurement Range	Accuracy	Repeatability
$0.0<O_2\%<2.0$	$\pm 0.2\%\ O_2$	$\pm 0.02\%O_2$
other	$\pm 0.3\%\ O_2$	$\pm 0.03\%O_2$

Response Time:

0.1 sec (0-90% of reaction time)

Variable Conditions:

Exhaust Gas Temperature	0 - 800°C
Exhaust Gas Pressure	0.8 - 1.3 atm.
Tightening Torque	4 ± 0.5 Kg m
Vibration	up to 30 G
Wiring Temperature	-20°C - 130°C
Wiring Tensile Strength	10 Kg. f
Thread Size	M 18 - P 1.5
Heater Supply Voltage	10.5 ± 0.5 V/DC

Specifications (cont'd)

Meter Specifications (MO-1000):

Sensor Operation System:

Icp Current	25 ± 3 micro A
Vs Voltage	450 mV
Limit of pumping current	- 12.5 - 12.5 mA
Heater supplied voltage	10.5 ± 0.5V DC

Data Processing System:

Sample Period	10 msec
Measurement for Pumping Current of Sensor	12 Bit A/D

Readout Equipment Details:

4 digit LED

	Indication Range	Resolution
Lambda	0.500-2.290 λ	0.001 λ
Air Fuel Ratio	4.00-33.30 A/F	0.01 A/F
O_2%	0.00-22.00%O_2	0.01%O_2
Function	Running Average: 0.5 sec.; 2.0 sec.; 10.0 sec.; and HOLD	

Analog Output Voltage:

Connector:	BNC connector (0.5V)
Display:	Same as readout
Function:	Real time, the running average between 2.0 and 10.0 sec. The readout gain of A/F can be selected corresponding to 0 - 5V

Range of Usage:

Sensor Gain	000-999
Hydrogen/Carbon Ratio of Fuel	0.00-9.99
Oxygen/Carbon Ratio of Fuel	0.00-9.99

Power Source:

AC 90 - 126V	2A
(op. AC 180 - 260V	1A)
DC12 - 16V	5A

DC Power Cord

White Wire	Positive (+)
Black Wire	Negative (-) or ground

Connector:

Power line connector	IEA spec.
Sensor harness connector	NANA BOSHI NJC 20A alpha - 7

Environmental Operating Conditions:

Temperature	5 - 45°C
Humidity	15 - 80% R.H. (non-condensing)

Physical Size:

250mm W x 100mm H x 300mm D
Weight 4.6 Kg