State of California
California Environmental Protection Agency

AIR RESOURCES BOARD

TECHNICAL SUPPORT DOCUMENT

PUBLIC HEARING TO CONSIDER ADOPTION OF NEW CERTIFICATION TESTS AND STANDARDS TO CONTROL EXHAUST EMISSIONS FROM AGGRESSIVE DRIVING AND AIR-CONDITIONER USAGE FOR PASSENGER CARS, LIGHT-DUTY TRUCKS, AND MEDIUM-DUTY VEHICLES UNDER 8,501 POUNDS GROSS VEHICLE WEIGHT RATING

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I. INTRODUCTION

As summarized in the Staff Report, the ARB staff is proposing standards and test procedures aimed at reducing off-cycle emissions from on-road motor vehicles. These test procedures, known collectively as the Supplemental Federal Test Procedures (SFTP), were developed cooperatively by the United States Environmental Protection Agency (U.S. EPA) and the ARB, with substantial contributions from the motor vehicle manufacturers. Vehicles in the passenger car, light-duty truck, and medium-duty vehicle classes up to 8501 pounds gross vehicle weight rating would be affected. The regulations proposed by staff would take effect for passenger cars and light-duty trucks beginning in the 2001 model-year with a 25 percent phase-in. The remainder of the phase-in is 50 - 85 - 100 percent, ending in model-year 2004. The applicability of these regulations to medium-duty vehicles begins in the 2003 model-year with a 25 - 50 - 100 percent phase-in, ending in model-year 2005.

These regulations would apply both to high-speed, high-load driving as contained in the new US06 test cycle, and driving with the air-conditioner on represented by a 10-minute hot start test known as the SC03 test. Staff projects that these regulations will result in 2020 statewide emission reductions of 133 tons per day non-methane hydrocarbon plus oxides of nitrogen. The best estimate of the projected costs is $28.80 to $38.60 per vehicle, as described in the Staff Report. The estimated cost-effectiveness of these regulations is $0.44 to $0.60 per pound.

The proposed standards applicable to California low-emission vehicles have been selected to be approximately equal in stringency to current Federal Test Procedure (FTP) standards for low-emission vehicles. This means that most vehicles will not require significant hardware modifications in order to comply with these requirements. Staff currently expects approximately 70 percent of future vehicles to comply with the proposed standards employing only calibration changes and minor exhaust-gas recirculation system upgrades, with an additional 30 percent requiring catalyst loading and/or volume changes. Standards have been chosen with the low-emission vehicle category in mind. Ultra-low-emission vehicles and super-ultra-low-emission vehicles certified to the proposed requirements would need to meet the same standards. The proposed standards have been agreed-upon by the automotive industry after extensive discussions with the ARB staff prior to the proposal of these regulations.

II. CALIFORNIA LOW-EMISSION VEHICLE PROGRAM

The proposed regulations would apply to vehicles in the California Low-Emission Vehicle program. The Low-Emission Vehicle program established FTP emission standards for the following categories of vehicles: transitional-low-emission vehicle (TLEV), low-emission vehicle (LEV), and ultra-low-emission vehicle (ULEV). The FTP emission standards for the passenger cars and light-duty trucks under 3751 pounds loaded vehicle weight are shown in Table 1. These standards are applicable at 50,000 miles, with correspondingly higher standards at 100,000 miles.

Table 1. 50,000-Mile FTP Exhaust Emission Standards for Low-Emission Vehicle Categories

	NMOG (g/mi)	CO (g/mi)	NOx (g/mi)
TLEV	0.125	3.4	0.4
LEV	0.075	3.4	0.2
ULEV	0.040	1.7	0.2

Manufacturers are required to meet an annual non-methane organic gases (NMOG) fleet average requirement for passenger cars and light-duty trucks under 3751 pounds loaded vehicle weight produced and delivered for sale in California. These fleet average requirements do not apply for the heavier light-duty truck and medium-duty vehicle classes. For passenger cars and light-duty trucks under 3751 pounds loaded vehicle weight, the fleet average requirement, as shown in Table 2, began in 1994 and declines each year through 2003. By the 2001 model year when the SFTP requirements are phased-in, the majority of the vehicle fleet will be LEVs.

Table 2. Annual NMOG Fleet Average Requirement for Passenger Cars and Light-Duty Trucks Under 3751 Pounds

Model Year	Fleet Average NMOG Emissions (g/mi)
1994	0.25
1995	0.231
1996	0.225
1997	0.202
1998	0.157
1999	0.113
2000	0.073
2001	0.070
2002	0.068
2003 and subsequent	0.062

In an ARB biennial review of the Low-Emission Vehicle and Zero-Emission Vehicle Program, various technologies were identified that may be used by automotive manufacturers to reduce vehicle emissions in achieving the LEV emission standards.[1] A combination of these technologies may be used depending upon the vehicle and the emission reductions needed to meet the LEV and ULEV FTP standards. These technologies are divided into four general categories of improvements: fuel control, fuel atomization and delivery, the reduction of engine-out emissions, and exhaust gas aftertreatment. Table 3 lists the technologies discussed in the report. Certain technologies are expected to be utilized in all LEV and ULEV applications, such as adaptive fuel control systems, heat-optimized exhaust pipes, improvements to the catalytic system, leak-free exhaust systems, and electronic exhaust gas recirculation. Other technologies are expected to be incorporated only in a certain percentage of the LEVs and ULEVs. Staff expects that for LEVs the typical catalyst sizing compared to the engine displacement would be approximately 1 liter of catalyst per liter of engine displacement. No significant extensions of the above technology are expected to be required in order to meet the proposed off-cycle emission standards; existing LEV technology will generally be utilized, with occasional modifications and upgrades to this technology, as necessary.

Table 3. Potential Emission Control Technologies for LEVs

Dual Oxygen Sensors	Heat-Optimized Exhaust Pipes
Universal Exhaust Gas Oxygen Sensors	Engine Calibration Techniques
Individual Cylinder Air-Fuel Control	Leak-Free Exhaust Systems
Adaptive Fuel Control Systems	Increased Catalyst Loading
Electronic Throttle Control Systems	Improved High-Temperature Washcoats
Reduced Combustion Chamber Crevice Volumes	Electrically-Heated Catalysts
Sequential Multi-Point Fuel Injection	Electric Air Injection
Air-Assisted Fuel Injectors	Full Electronic Exhaust Gas Recirculation
Improved Induction Systems	Hydrocarbon Absorber Systems
Close-Coupled Catalyst	Engine Designs to Reduce Oil Consumption

Staff expects that recent improvements in catalytic converter technology will be the most significant development which will enable manufacturers to produce LEVs and ULEVs at a relatively low cost. Recent advances include improvements to the washcoat, ceria, and precious

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[1] California Air Resources Board. Mail-out #96-28: Staff Report for the Low-Emission Vehicle and Zero-Emission Vehicle Program Review. El Monte, California. November 1996.

metal processing techniques. Palladium-only and tri-metal three-way catalyst technologies have improved stoichiometric conversion efficiency, light-off performance, and high temperature durability compared to traditional (platinum and rhodium) three-way catalysts. These improved catalysts are currently being used in some production vehicles by several vehicle manufacturers.

Reducing a vehicle's FTP emissions to meet the more stringent LEV and ULEV exhaust emission standards will likely reduce SFTP emissions. Although it is difficult to quantify the decrease in SFTP emissions as a vehicle's FTP emissions are reduced to LEV and ULEV levels, in general, emission control strategies that will reduce warmed-up FTP emissions will also reduce US06 and air-conditioner emissions. Approximately 30 percent of the vehicles tested in the ARB standard-setting test programs were not LEV-representative. (The test programs are described in detail in Section VI.) As manufacturers modify these vehicles to comply with the LEV FTP emission standards, the SFTP emissions will likely be reduced.

Test results from two vehicles provide an indication of the US06 NMHC plus NOx emission differences between a TLEV and an LEV. A 1994 model-year TLEV Honda Civic and a 1996 model-year LEV Civic were tested. The 1996 model-year Civic model was the first gasoline-powered vehicle to be certified in the LEV category. Compared to its predecessor, the LEV Civic uses a more accurate electronic control of the air-fuel ratio, a close-coupled catalytic converter, and a new "tumble port" cylinder head design which produces better mixing of the air and fuel throughout the compression and ignition phase. As shown in Table 4, the US06 NMHC plus NOx emissions from the LEV Civic were 44 percent of the emissions from the TLEV Civic. Including a compliance margin (the emission headroom manufacturers typically allow for compliance with an emission standard to account for variability), NMHC plus NOx emissions from the LEV Civic would not exceed the proposed US06 4,000 mile standard for passenger cars. These data should not be interpreted as the typical expectation of US06 emission reductions from a TLEV to an LEV, as baseline US06 levels vary and the range of LEV emission control improvements is diverse.

Table 4. Honda Civic 1.5 Liter TLEV and 1.6 Liter LEV US06 Emissions at 4,000 Miles

	NMHC (g/mi)	NOx (g/mi)	NMHC+NOx (g/mi)
TLEV	0.082	0.065	0.147
LEV	0.042	0.022	0.064

III. IN-USE DRIVING SURVEYS

In order to assess the amount of driving not covered by the current FTP certification test, both the U.S. EPA and the ARB conducted in-use driving surveys during the summer of 1992. The ARB driving survey was conducted in the Greater Los Angeles Metropolitan Area by Sierra Research of Sacramento, California. A technique developed by Sierra known as the “chase-car” method was used. In this technique, a laser range-finder device is mounted behind the grille of a vehicle equipped with special on-board instrumentation capable of high-frequency sampling of the distance between the “chase-car” and the “target vehicle.” This information, when differentiated over time and compared to the speed of the chase-car, allows an accurate measurement of the speed of the target vehicle. To ensure that the generation of data are representative of real-world driving patterns, Sierra took special precautions to avoid detection by the driver. Such precautions included mounting equipment in the chase car in a manner that was invisible to an observer, and not following drivers through traffic changes such as lane changes, turns at intersections, and other maneuvers. One hundred of the most commonly performed trips in the Los Angeles basin, based on California Department of Transportation data, were driven in order to generate these data. A 1993 ARB Research Division publication, “Characterization of Driving Patterns and Emissions from Light-Duty Vehicles in California” describes in detail the Los Angeles driving survey.

The U.S. EPA driving surveys were conducted in the following cities: Spokane, Washington; Baltimore, Maryland; and Atlanta, Georgia. Most of these data were obtained through the instrumentation of approximately 60 customer vehicles with on-board dataloggers. The dataloggers permitted direct measurement of vehicle speed as well as other parameters such as throttle position, engine speed, tailpipe air-fuel ratio, and manifold pressure. These data are believed to have some shortcomings resulting from the selection of drivers for the survey, because it is believed that extremely aggressive drivers would be less likely to participate in such a survey. However, in its entirety, the data are still considered a valid representation of driving behavior in these cities.

The U.S. EPA and ARB driving surveys are believed to be the most comprehensive public survey of driving patterns ever undertaken. Several million dollars were spent on these driving surveys, which recorded many hundreds of hours worth of driving data. It is of interest that the original FTP test was based on far less on-road driving data than those generated in this survey. Charts 1 and 2 are U.S. EPA-generated plots of speed and power distributions, respectively, for each of the four cities in the driving survey[2]. Power is defined as 2 times velocity times acceleration. It is the best single function for describing instantaneous engine load, based on externally measured parameters such as velocity. Power is proportional to the instantaneous horsepower output of the engine, in horsepower.

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[2] U.S. EPA FTP Review Project Preliminary Technical Report. May 1993.

Chart 1 indicates that a substantial proportion of driving is above the FTP maximum speed of 57 miles per hour (mph). In the Los Angeles area, over five percent of driving based on the speed distribution is above 57 mph. These are considered to be the high-speed events not covered by the FTP wherein emission increases may occur. Chart 2 shows the distribution of power from the driving surveys in the four cities. Although the maximum power on the FTP is 192 mph*mph/second, less than five percent of the FTP power distribution is above 100 mph*mph/second and approximately one percent above 150 mph*mph/second. Thus, even within its speed-acceleration realm of control, the FTP is not considered to be representative of current driving. As shown, vehicles spend a substantial fraction of time at power levels greater than those experienced during the FTP. These are considered to be high-load events wherein emission increases may occur. As a result of the conclusions drawn from these driving surveys, additional work was undertaken to develop driving cycles to assess the emission impact of the significant proportions of this high-speed, high-load driving outside FTP regimes.

IV. DRIVING CYCLES

In-use data indicated a need to assess the emission impact of off-cycle driving. New test cycles were needed to characterize the driving regimes not represented by the FTP. The U.S. EPA generated a test cycle known as REP05 (shown in Chart 3.) This test cycle was intended to be fully representative of off-cycle as well as on-FTP driving. For the purposes of this discussion, "representative" means that the off-cycle driving is represented on the test cycle in the same proportions as is present in current in-use driving. This cycle has been generally used by the U.S. EPA staff for assessment of the emission impact of off-cycle driving.

The U.S. EPA also generated a non-representative test cycle known as HL07, which consisted of a series of severe, near-wide-open-throttle accelerations, with constant speed cruises. This cycle was generated essentially as a control cycle, with the intention of ensuring that vehicles did not enter commanded enrichment during high-load conditions. Commanded enrichment, in which vehicle air-fuel ratio is altered from the usual 14.4/1 ratio to about 12.5/1, is used to provide additional power during high-load events. It also cools the exhaust, thus minimizing high-temperature catalyst conditions. However, as a non-representative cycle, a number of shortcomings were identified with this cycle. For example, neither the full range of vehicle speed and load conditions nor minor speed deviations are represented. Consequently, it was not used for the present regulations.

For the purposes of controlling off-cycle emissions, the ARB staff developed from the Los Angeles chase-car data a test cycle known as the ARB01B test cycle. A speed-time trace of this cycle is shown in the attached Chart 4. Although staff considers this cycle a "semi-representative" test cycle, it is designed to ensure emission control at the very extremes of vehicle operation such as speeds of 80 mph and accelerations of 8 mph/second, while still containing a significant proportion of more moderate off-cycle driving, such as 60 - 70 mph cruise operation and less severe accelerations. The primary criterion used by ARB staff in generating this cycle was that no speed-acceleration condition would be represented at less than half the frequency it would experience on a representative test cycle. This was chosen as the minimum requirement necessary to ensure that, if used as a future regulatory control cycle, automobile manufacturers would control off-cycle emissions over the full range of vehicle operation.

The control cycle ultimately agreed-upon by the ARB, U.S. EPA and Industry for high-speed, high-load emission control was generated by splicing together portions of the ARB01B and REP05 cycles. This US06 control cycle is shown in Chart 5. The US06 test cycle, at 10 minutes in length, is a relatively short test cycle. Both the ARB01B and REPO5 test cycles are over 20 minutes in length. In general, longer test cycles allow for a more representative and complete coverage of the driving regime for regulatory control, but also result in higher testing costs due to the additional testing time required to drive such cycles. In response to manufacturers' concerns, the U.S. EPA and ARB staff agreed to pursue a relatively short test cycle, but chose to over-represent the frequency of severe driving events (wherein the largest emission increases are observed). In the US06 driving cycle, severe driving events of high accelerations and high speeds are represented at two to three times the actual, in-use frequency.

V. TEST PROGRAMS TO DETERMINE OFF-CYCLE EMISSION IMPACT

Based on the test cycles described above, the ARB, U.S. EPA, and automobile manufacturers conducted several emission test programs to determine the effect of off-cycle driving on emissions from motor vehicles. With the exception of the ARB/Industry test programs described below, detailed descriptions of these test programs have already been published in a U.S. EPA document[3] and in the SAE paper 94-CO16, "The Execution of a Cooperative Industry-Government Exhaust Emission Test Program." The interested reader is advised to refer to these documents for descriptions of these programs.

VI. ARB/INDUSTRY TEST PROGRAMS

From June 1995 through February 1997, the Air Resources Board conducted emission research testing programs to set future vehicle emission standards. These standards would be used to control off-cycle emissions: high-speed, high-load emissions and emissions that occur with the air-conditioner running. Full descriptions of these emission test programs are available in the Test Plans for these programs, available upon request. The purpose of this document is to summarize the design, implementation, and results of these programs. Two main programs are summarized: the US06 high-speed, high-load emission test program, conducted from June 1995 through February 1997, and the air-conditioner emission test program, conducted from April 1996 through February 1997.

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[3] U.S. EPA. Final Technical Report on Aggressive Driving Behavior for the Revised Federal Test Procedure Notice of Proposed Rulemaking. January 31, 1995.

A. US06 Emission Test Program

This program was conducted as a cooperative effort with the motor vehicle industry, with all major manufacturers participating in the test program. Details of the test plan were discussed with the automobile industry from December 1994 through March 1995, and agreed-upon at a March 31, 1995 meeting between the ARB and the automobile industry in El Monte, California. In this program, nineteen vehicles were tested on the US06 test cycle using single-roll dynamometers. Nine of the nineteen were current production vehicles tested at the ARB's El Monte laboratory, while the other ten were prototype LEVs tested at participating manufacturers' laboratories.

The ARB and the motor vehicle industry agreed that all testing for this program would be conducted with 50,000-mile equivalent aged catalysts and oxygen sensors. Using the data generated from the program, the future US06 emission standard would include a 50,000-mile in-use standard tentatively based on the test results of the vehicle with the 4th-lowest (or 20th percentile) NMHC plus NOx emission level. It was also agreed that this standard would include a "headroom" factor, designed to allow vehicle manufacturers sufficient compliance margin with the emission standard. This factor would be either 1.3 or 2, depending on the performance of the test vehicle relative to actual LEV emission levels. FTP results from the test vehicles are included in Appendix 1, Table A. It was assumed at the outset of the program that the LEV prototypes would be representative of actual future LEVs. However, upon completion of the program it was determined that about half of the prototype vehicles would require additional work in order to comply with the LEV standards. Thus, the headroom factor applied to these vehicles was adjusted accordingly.

Fifteen of the nineteen vehicles were "rich-bias" tested, in which a slight air-fuel ratio shift from the usual vehicle stoichiometric air-fuel ratio was induced. This was done to assess whether lower NOx emissions could be produced in this manner. For each vehicle tested, several different air-fuel ratios were chosen, in order to determine the optimal setting that produced the lowest NMHC plus NOx emissions. A detailed description of the "rich-bias" calibration is contained in Section VII. The US06 emission results from the nineteen vehicles tested are included in Tables 5 and 6, including baseline and optimal bias results. Tests performed without the bias optimization are indicated. The Honda ULEV was a prototype vehicle tested by the ARB. Although not officially part of the ARB/Industry test program, it was included to represent the emissions from a ULEV.

The current production vehicles tested by the ARB were selected to have relatively low emissions compared to the current fleet, and thus to have emission characteristics similar to those of vehicles to be certified to the LEV standards. Criteria used for selection included certification NMHC and NOx emissions on the FTP cycle and NOx emissions over the Highway Fuel Economy Test. The highway test criterion was included to ensure that vehicles were attaining

Table 5. ARB/Industry US06 Test Program: 50,000-Mile Baseline[A] Emissions (g/mi)

Test Vehicle	NMHC	CO	NOx	NMHC+NOx
Passenger Cars and Light-Duty Trucks under 3751 lbs. loaded vehicle weight				
Honda ULEV[B]	0.004	0.378	0.021	0.025
ARB-Mazda 626[C]	0.023	1.802	0.042	0.065
GM-1	0.016	1.004	0.05	0.066
ARB-Accord	0.017	1.456	0.050	0.067
ARB-Grand AM[C]	0.037	4.905	0.049	0.086
Ford-1	0.027	0.55	0.32	0.347
Ford-2	0.006	2.1	0.120	0.126
GM-3[D]	0.014	1.210	0.117	0.131
ARB-Neon	0.011	0.743	0.274	0.285
Honda-1[D]	0.035	3.082	0.154	0.189
Nissan-1	0.038	0.533	0.198	0.236
ARB-Bonneville	0.015	0.202	1.030	1.045
ARB-Civic	0.087	2.204	0.134	0.221
ARB-Lexus SC300	0.020	0.318	0.482	0.502
ARB-Grand Marquis	0.005	1.922	0.367	0.372
Chrysler-1[D]	0.02	2.6	0.43	0.45
Toyota-1[D]	0.006	0.68	0.48	0.486
Average[E]	**0.024**	**1.514**	**0.235**	**0.259**
Light-Duty Truck over 3750 lbs. loaded vehicle weight				
ARB-Ranger	0.018	0.327	0.637	0.655
Medium-Duty Vehicles[F] up to 8501 lbs. test weight				
GM-2 (MDV2, 90,000 mi)	(Not Available)	-	-	-
Chrysler (MDV2, 100,000 mi)	0.030	1.96	1.600	1.630

[A] “Baseline” denotes stoichiometric configuration, unless otherwise indicated, without “rich-bias.”

[B] Not officially part of test program but included as representing a ULEV.

[C] Tested under production calibration only.

[D] Tested with stoichiometric calibration only; optimized “rich-bias” emissions were not obtained.

[E] Average excludes vehicles without bias optimization (footnote D), due to the effect of this optimization on reducing vehicle NMHC plus NOx emissions.

[F] Both medium-duty vehicles were inadvertently tested at weights higher than those specified by the U.S. EPA regulations for US06 control, therefore these emission levels are expected to be higher than those from using correct test weights. In addition, these vehicles would be expected to show somewhat lower results when tested with 50,000-mile aged components.

Table 6. ARB/Industry US06 Test Program: 50,000-Mile Optimized Emissions (g/mi)

Control Strategies: Stoichiometric Calibration, Bias Optimization

Test Vehicle	**NMHC**	**CO**	**NOx**	**NMHC+NOx**
Passenger Cars and Light-Duty Trucks under 3751 lbs. loaded vehicle weight				
Honda ULEV[A]	0.004	0.378	0.021	0.025
ARB-Mazda 626[B]	0.023	1.802	0.042	0.066
GM-1	0.016	1.004	0.050	0.066
ARB-Accord	0.010	0.675	0.065	0.075
ARB-Grand AM[B]	0.037	4.905	0.049	0.086
Ford-1	0.013	0.6	0.101	0.114
Ford-2	0.004	2.1	0.12	0.124
GM-3[C]	0.014	1.210	0.117	0.131
ARB-Neon	0.014	2.059	0.172	0.186
Honda-1[C]	0.035	3.082	0.154	0.189
Nissan-1	0.06	0.83	0.140	0.20
ARB-Bonneville	0.019	1.539	0.182	0.201
ARB-Civic	0.087	2.204	0.134	0.222
ARB-Lexus SC300	0.074	1.446	0.164	0.238
ARB-Grand Marquis	0.011	2.750	0.245	0.256
Chrysler-1[C]	0.02	2.6	0.43	0.45
Toyota-1[C]	0.006	0.68	0.48	0.49
Average[D]	**0.029**	**1.899**	**0.117**	**0.146**
Light-Duty Truck over 3750 lbs. loaded vehicle weight				
ARB-Ranger	0.040	1.677	0.290	0.330
Medium-Duty Vehicles[E] up to 8501 lbs. test weight				
GM-2 (MDV2, 90,000 miles)	0.028	3.7	0.583	0.611
Chrysler (MDV2, 100,000 miles)	0.060	5.56	0.82	0.88

[A] Not officially part of test program but included as representing a ULEV.

[B] Tested under production calibration only.

[C] Tested with stoichiometric calibration but without bias optimization.

[D] Average excludes vehicles without bias optimization (footnote C), due to the effect of this optimization on reducing vehicle NMHC plus NOx emissions.

[E] Both medium-duty vehicles were inadvertently tested at weights higher than those specified by the U.S. EPA regulations for US06 control, therefore these emission levels are expected to be higher than those from using correct test weights. In addition, these vehicles would be expected to show somewhat lower results when tested with 50,000-mile aged components.

extremely low warmed-up NOx levels at high speeds, as an indication of emission performance on the US06 test cycle. In general, vehicles selected had FTP NOx emissions of approximately 0.1 g/mi, and Highway Fuel Economy Test NOx emissions of 0.02 g/mi or less. Test vehicle descriptions are provided in Appendix 1, Table B.

One point of interest from Table 6 is that the “bias”-tested light-duty vehicles showed more relatively consistent emission rates (between 0.06 and 0.30 g/mi NMHC plus NOx, with most vehicles near or below 0.2 g/mi.) On the other hand, the baseline emissions on these vehicles ranged between 0.06 and 1.04 g/mi NMHC plus NOx. For this reason, the bias strategy is believed to be an effective means of reducing light-duty vehicle 50,000-mile US06 emissions to 0.2 g/mi or below, but is not necessarily sufficient with current production and LEV prototype technology and catalyst sizing to reduce emissions below this value on every vehicle.

It was observed during the testing conducted at the ARB’s laboratories that many vehicles appeared to exhibit unrealistically large emission increases resulting from the use of the 50,000-mile aged components. Several vehicles showed double, or more, the baseline FTP NOx emission levels when tested with the aged components. These are very large increases when compared with certification durability documentation indicating, on average, a 10 - 20 percent NOx increase from 4,000 to 50,000 miles. Although current certification durability procedures may somewhat under-represent the actual effect of in-use vehicle aging, it can not explain the severe emission deterioration caused by the simulated aged components. Based on staff communications with manufacturer representatives, many of the aged components were aged to a relatively severe degree, as only one car in ten in the real-world would experience. In addition, although aging techniques are highly proprietary, it is believed that many of the aging techniques conducted used “lean-spike” aging, in which catalysts are subjected to a lean, high-temperature condition during aging. Although this is a standard technique for quickly aging a catalyst, whether this accurately duplicates the effects of in-use aging over the high-load US06 modes where high NOx levels are observed is unknown.

As a result of concerns with the aged components, staff initiated low-mileage US06 testing, both at the baseline setting and at the optimal bias setting previously determined with the 50,000-mile aged components. Previous evidence suggested that the optimal bias point would be the same for both low-mileage and 50,000-mile conditions; therefore, a re-optimization was not performed at the low-mileage conditions. This testing continued throughout the remainder of the ARB test program, and was continued thereafter on seven additional test vehicles, obtained through rental agencies. (See Appendix 1, Table C for the vehicle description.) These additional vehicles were tested at the low-mileage state in which they were obtained without aged hardware, ranging from 3,500 to 20,800 miles, with an average of 10,000 miles. The purpose of the low-mileage testing was to provide data to support a possible low-mileage US06 standard, a primary element of the staff’s proposal, as well as to affirm the viability of a stringent 50,000-mile standard.

Results of the passenger car low-mileage baseline and optimized testing are presented in Tables 7 and 8, respectively. The baseline NMHC plus NOx emissions averaged 0.289 g/mi. With the "rich-bias," NMHC plus NOx emissions were reduced to under 0.20 g/mi, with an average of 0.092 g/mi. Eight vehicles performed at levels under 0.1 g/mi NMHC plus NOx, with the average result of these being 0.06 g/mi NMHC plus NOx. As discussed in the Staff Report, these data were used in discussions with the automotive industry for the purpose of determining the proposed NMHC plus NOx standards on the US06 test.

After the completion of the passenger car portion of the ARB US06 Test Program, seven light duty trucks and medium-duty vehicles were also tested at low mileage. As in the passenger car testing, the "rich-bias" emission control technique was used to reduce NMHC plus NOx emissions over the US06 test. These emission results are also shown in Tables 7 and 8.

B. Air-Conditioner Emission Test Program

The ARB Air-Conditioner Emission Test Program was conducted using vehicles similar to those used in the US06 program, with most vehicles updated to 1996 models. The vehicles were tested on single-roll dynamometers over the SC03 test cycle to determine air-conditioner emission impact. Aged components were not used for this program; all testing was conducted with vehicles in the low-mileage state, as received from the rental agencies. As with the US06 test program, vehicles were tested under a variety of bias configurations, with the intent of finding the optimal setting for minimum NMHC plus NOx emissions over the SC03 test cycle. The SC03 test cycle, shown in Chart 6, is a 10-minute cycle designed by the U.S. EPA and promulgated on October 22, 1996 for the control of air-conditioner related exhaust emissions. The cycle is representative of driving behavior immediately following a hot-start, as well as driving behavior in those regimes covered by the current FTP.

The air-conditioner test program was conducted on eight passenger cars and eight light-duty trucks and medium-duty vehicles from April 1996 through February 1997. For this program, two different test procedures were used. One of these procedures was an environmental cell procedure. It is designed to represent the effects of ambient conditions on the test vehicle, including temperature, humidity, wind-speed, and solar loading. The ARB's environmental cell testing was conducted in a running loss test facility, with full temperature control capability. A road-speed modulated fan designed to discharge air to the vehicle grille at the speed of the dynamometer roll was used to simulate actual on-road wind flow. In addition, portable humidifiers were added to the test cell. Two space heaters were installed in the test vehicle's passenger cabin to provide a supply of heat that the sun and asphalt would ordinarily radiate to the vehicle. All of this effort was undertaken because the work performed by an air-conditioning system, and hence the additional engine load and emissions caused by this system, is strongly dependent on the environmental circumstances under which the system is used.

Table 7. ARB US06 Test Program: Baseline Low-Mileage US06 Testing (g/mi)

Test Vehicle	NMHC	CO	NOx	NMHC+NOx
Passenger Cars				
Dodge Intrepid	0.009	0.073	0.092	0.101
Honda Civic (LEV)	0.042	14.778	0.022	0.064
Honda Civic (TLEV)*	0.083	1.964	0.065	0.148
Honda Accord*	0.009	1.018	0.033	0.042
Mazda 626	0.022	3.251	0.036	0.058
Mazda 929	0.040	3.120	0.859	0.899
Mercury Grand Marquis*	0.005	0.489	0.113	0.118
Nissan Maxima	0.057	3.744	0.490	0.547
Nissan Sentra	0.029	6.586	0.536	0.565
Plymouth Neon*	0.006	0.392	0.195	0.201
Pontiac Grand Am	0.042	4.650	0.025	0.067
Pontiac Bonneville	0.004	0.063	0.653	0.657
Average	**0.029**	**3.344**	**0.260**	**0.289**
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight				
Chevrolet Astrovan	0.029	1.257	0.389	0.418
Medium-Duty Vehicles from 3571-5750 pounds test weight				
Chevrolet 1500 P/U	0.011	0.177	0.553	0.564
Ford F150 P/U	0.04	12.54	0.048	0.088
Average	**0.026**	**6.36**	**0.30**	**0.326**
Medium-Duty Vehicles from 5751-8500 pounds test weight				
Chevrolet Suburban	0.085	6.65	0.388	0.473
Dodge Ram Van	0.036	4.98	0.604	0.64
Ford E-250 Van	0.027	5.46	0.947	0.974
Ford E-350 Van	0.081	13.63	0.064	0.145
Average	**0.057**	**7.68**	**0.50**	**0.558**

* Tested with stoichiometric calibration

Table 8. ARB US06 Test Program: Low-Mileage Optimized “Rich-Bias” Emissions (g/mi)

Test Vehicle	NMHC	CO	NOx	NMHC+NOx
Passenger Cars				
Dodge Intrepid	0.008	0.044	0.050	0.058
Honda Civic (LEV)	0.042	14.778	0.022	0.064
Honda Civic (TLEV)*	0.083	1.964	0.065	0.148
Honda Accord	0.009	1.018	0.033	0.042
Mazda 626	0.022	3.251	0.036	0.058
Mazda 929	0.033	3.126	0.118	0.151
Mercury Grand Marquis*	0.015	1.467	0.039	0.054
Nissan Maxima	0.053	1.995	0.090	0.143
Nissan Sentra	0.024	5.065	0.163	0.187
Plymouth Neon*	0.007	1.167	0.070	0.077
Pontiac Grand Am	0.042	4.650	0.025	0.067
Pontiac Bonneville**	0.017	0.754	0.035	0.052
Average	**0.030**	**3.273**	**0.062**	**0.092**
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight				
Chevrolet Astrovan	0.091	3.72	0.065	0.156
Medium-Duty Vehicles from 3571-5750 pounds test weight				
Chevrolet 1500 P/U	0.014	0.387	0.208	0.222
Ford F150 P/U	0.04	12.54	0.048	0.088
Average	**0.027**	**6.46**	**0.128**	**0.155**
Medium-Duty Vehicles from 5751-8500 pounds test weight				
Chevrolet Suburban	0.105	7.23	0.200	0.305
Dodge Ram Van	0.058	7.66	0.349	0.407
Ford E-250 Van	0.009	2.73	0.201	0.21
Ford E-350 Van	0.081	13.63	0.064	0.145
Average	**0.063**	**7.81**	**0.204**	**0.267**

* Tested with stoichiometric calibration
** Tested on twin-roll dynamometer

For all air-conditioner-on testing in this facility, the temperature was maintained at 95°F (+/- 3°F), the humidity was maintained at 40 percent relative humidity or 100 grains per pound of dry air, and the road-speed fan was used. Due to time constraints, direct simulation of the solar load through the use of special, high-intensity metal halide lamps was not considered for this program. However, vehicle space-heaters were used to simulate the effects of the solar heat in the passenger cabin. The heaters ensured that the cabin temperature at the start of the SC03 test was approximately 120°F, the approximate vehicle temperature expected after a 10-minute soak at the above ambient conditions during a sunny day. In addition, the heaters were used during the test at lowered settings corresponding to 500 - 1000 British thermal units per hour heat output. This was done to ensure that by the end of the 10-minute test, the vehicle cabin temperature had stabilized at 75°F (+/- 3°F). Equilibrium cabin temperatures under given environmental conditions vary from one vehicle to the next. Based on data presented by the American Automobile Manufacturers Association, at the above conditions, equilibrium cabin temperatures between 68° and 85° F are expected. For this program, staff decided to simply use 75°F as a standard equilibrium temperature. This results in underloading of some vehicles and in overloading others, with some likely corresponding engine load and emission effect.

The other SC03 test procedure was conducted in a standard test cell, at typical ambient FTP conditions (68°- 86°F), using an air-conditioner simulation developed by Toyota. The Toyota procedure uses a highly simplified method to simulate the air-conditioner system load under high-temperature conditions. In this testing, the vehicle air-conditioner is on and turned to the "MAX" or recirculation mode, the fan setting is at the maximum, and the system temperature is set to "HOT." While the driver's side window is open, all other windows remain closed during the test. By setting the system temperature to "HOT," the vehicle cabin is flooded with hot air. This air is then recirculated to the air-conditioning system, which cools the air. After the air is cooled, it is reheated by the vehicle's heating system (as a result of the "HOT" temperature setting) before entering the cabin compartment. By using the Toyota simulation, the air-conditioner compressor runs virtually all of the time. In lieu of the "HOT" temperature setting during the recirculation mode, the compressor would likely be off during most of the test because the air in the cabin would stay relatively cool in the absence of a heat load. With the exception of the first few minutes, typical cabin temperatures during this test are 100°F and above, so that the air-conditioning system is generally very well-loaded.

Fuel economy impacts generally correlate well with those observed in environmental chamber testing, where all environmental effects are directly simulated. However, emissions do not consistently correlate nearly as accurately on a vehicle to vehicle basis. Nevertheless, the U.S. EPA has allowed this procedure for a short period of use for future vehicle certification since it can be conducted in a standard test cell, and it allows adequate time for manufacturers to build environmental cells. One reason for the reduced emission correlation may be the absence of the full heat load during start conditions. This test begins with the vehicle cabin at a temperature less than the stabilized 100+ F temperature. It generally takes a few minutes for the vehicle cabin to warm up sufficiently in order to properly load the vehicle air-conditioner system. Another reason for the reduced correlation may be the absence of cycling in the air-conditioner compressor during the Toyota simulation. Under real-world conditions, the compressor typically cycles on and off, putting a transient load on the engine.

At a practical level, one difficulty with this procedure is that the high cabin temperatures pose a safety and comfort issue for the vehicle driver. For this reason it is recommended that during the Toyota procedure testing, the driver wear a “cool” suit, ice vest, or other means to mitigate the high-temperature heat load in the vehicle cabin.

For the ARB testing, eight vehicles were tested using the Toyota procedure with five of these tested using the environmental cell procedure described above. The environmental cell testing typically yielded somewhat higher emission results, approximately 30 percent for this testing, than those observed using the Toyota procedure. A correlation with a full environmental cell that meets the environmental cell requirements promulgated by the U.S. EPA for air-conditioner testing was not conducted on these vehicles for the Toyota simulation or the ARB environmental cell simulation. However, a previous study conducted by the automotive manufacturers compared the emission results of the Toyota simulation and the full environmental cell. It showed that, on average, the Toyota simulation produced approximately 80 percent of the NOx emissions from the full environmental cell. Due to the lack of available data on the correlation of the ARB environmental cell method, these data were not used in the SC03 standard-setting procedure. Thus, the proposed ARB standards were based on the data from the Toyota simulation.

Test vehicle descriptions are provided in Appendix 2. Toyota simulation data, in both baseline and optimal bias configurations, are summarized in Tables 9 through 10, respectively. As with the US06 testing, considerable reductions were found from the use of the biasing technique on many of the passenger cars, with the average g/mi reduction being over 60 percent. The passenger cars optimized by the ARB averaged 0.13 g/mi NMHC plus NOx over the Toyota procedure with the air-conditioner turned on, compared to an average of 0.360 g/mi without the optimization. Smaller reductions, if any, were observed over most of the light-duty trucks and medium-duty vehicles. It is believed that these vehicles are presently calibrated slightly rich of stoichiometry and are therefore already somewhat optimized for air-conditioner emission control. In addition, these vehicles showed smaller percentage emission increases from the use of the air-conditioner, therefore smaller reductions would be expected.

VII. “RICH-BIAS” CALIBRATION TECHNIQUE

The “rich-bias” air-fuel ratio modifications described in the ARB/Industry Test Programs were performed in a variety of ways. Manufacturers generally altered vehicle air-fuel ratio set-points through modification of the vehicle computer software calibrations, while the ARB used a device known as an “oxygen sensor fault simulator” for this purpose. This device alters the air-fuel ratio dependent voltage signal produced by the oxygen sensor, before this signal is sent

Table 9. ARB Air-Conditioner Test Program: Baseline SC03 Air-Conditioner-On Emissions (g/mi)

Test Vehicle	NMHC	CO	NOx	NMHC+NOx
Passenger Cars				
Dodge Intrepid	0.052	1.180	0.222	0.274
Ford Taurus FFV	0.015	1.380	0.066	0.081
Honda Accord	0.008	0.240	0.162	0.170
Honda Civic (LEV)	0.021	1.440	0.082	0.103
Mazda (Prototype)	0.004	0.170	0.533	0.537
Plymouth Neon	0.007	1.980	0.303	0.310
Pontiac Bonneville	0.002	0.230	0.614	0.616
Pontiac Grand AM	0.014	1.350	0.776	0.790
Average	**0.015**	**0.996**	**0.345**	**0.360**
Light-Duty Trucks from 3751-5750 pounds loaded vehicle weight				
Chevrolet Astrovan	0.030	0.851	0.270	0.300
Chevrolet Blazer	0.048	0.447	0.129	0.177
Ford Aerostar*	0.006	0.066	0.427	0.433
Ford Explorer	0.009	0.490	0.190	0.199
Average	**0.023**	**0.464**	**0.254**	**0.277**
Medium-Duty Vehicles from 3571-5750 pounds test weight				
Ford F-150 P/U	0.024	0.460	0.067	0.091
Medium-Duty Vehicles from 5751-8500 pounds test weight				
Chevrolet Suburban	0.087	1.500	0.460	0.547
Ford E-250 Van	0.007	0.196	0.660	0.667
Ford E-350 Van	0.039	3.040	0.008	0.047
Average	**0.044**	**1.579**	**0.376**	**0.420**

* The air-conditioner system was somewhat underloaded using the AC2 simulation method, as the “Defrost” setting was necessary to return hot air to the air-conditioning system.

Table 10. ARB Air-Conditioner Test Program: Optimized SC03 Air-Conditioner-On Emissions (g/mi)

Test Vehicle	NMHC	CO	NOx	NMHC+NOx
Passenger Cars				
Dodge Intrepid	0.063	1.600	0.096	0.159
Ford Taurus FFV	0.015	1.380	0.066	0.081
Honda Accord	0.007	0.290	0.117	0.124
Honda Civic (LEV)	0.021	1.440	0.082	0.103
Mazda (Prototype)	0.002	0.095	0.061	0.063
Plymouth Neon	0.010	2.390	0.183	0.193
Pontiac Bonneville	0.032	1.540	0.137	0.169
Pontiac Grand AM	0.040	1.760	0.116	0.156
Average	**0.024**	**1.312**	**0.107**	**0.131**
Light-Duty Trucks from 3751-5750 pounds loaded vehicle weight*				
Chevrolet Astrovan	0.170	3.710	0.050	0.220
Chevrolet Blazer	0.045	0.491	0.106	0.151
Ford Aerostar**	0.013	0.271	0.133	0.146
Ford Explorer	0.030	1.510	0.117	0.147
Average	**0.065**	**1.496**	**0.10**	**0.166**
Medium-Duty Vehicles from 3571-5750 pounds test weight*				
Ford F-150 P/U	0.024	0.460	0.067	0.091
Medium-Duty Vehicles from 5751-8500 pounds test weight*				
Chevrolet Suburban	0.087	1.500	0.460	0.547
Ford E-250 Van	0.016	0.650	0.329	0.345
Ford E-350 Van	0.039	3.040	0.008	0.047
Average	**0.047**	**1.730**	**0.27**	**0.313**

* The LDT and MDV portion of the test program was conducted in an expedited manner, and duplicate tests at the optimal setting were not performed.

** The air-conditioner system was somewhat underloaded using the AC2 simulation method, as the "Defrost" setting was necessary to return hot air to the air-conditioning system.

to the vehicle computer. The vehicle fueling is continually modified based on this signal, which ranges between 0 and 1 volt (Chart 7). For the ARB's work, the voltage signals were generally multiplied by a constant factor between 0 and 1. During some testing, an additive factor between +120 and -120 millivolts was also used. Changing the effective voltage response of the vehicle oxygen sensor system (comprising the sensor and the fault simulator) has the effect of communicating a different apparent air-fuel ratio to the computer, based on the received voltage signal, as indicated in Chart 8. The computer responds to this change in voltage signal by changing the actual air-fuel ratio to compensate for the apparent change in tail-pipe air-fuel ratio produced by the sensor voltage manipulation. This results in a higher-than-usual true oxygen sensor signal (shown in Chart 9), corresponding to a richer air-fuel mixture. It is this compensating effect believed to be reflected in changed block-learning adaptive learning system fuel settings that allowed the ARB staff to re-calibrate the test vehicle air-fuel ratio settings. It is similar to the effect of simply changing the mean oxygen sensor voltage (or "switching threshold") via vehicle re-calibration, as indicated in Chart 10. The ARB's technique of modifying tailpipe air-fuel ratio is not intended as a future vehicle design scenario. It is simply an engineering method that allowed the ARB staff to simulate the effects of the actual software calibration which vehicle manufacturers would perform in order to alter the air-fuel ratio settings.

The ARB testing was conducted, in general, by using voltage multiplier settings between 0.7 and 1.0 in 0.05 increments and determining the multiplier setting resulting in optimal NMHC plus NOx emissions over the US06 test cycle. The voltage multiplier increment of 0.05 is believed to correspond to a change in air-fuel ratio of approximately -0.03. Current engines generally operate with Phase II gasoline at the stoichiometric air-fuel ratio of approximately 14.4 to 1. For those vehicles in which a benefit from this air-fuel ratio change was observed, optimal benefits were typically observed at voltage multipliers between 0.75 and 0.90, corresponding to air-fuel ratio changes of from -0.06 to -0.15.

An example of the effects of the "rich-bias" technique on a 1995 Pontiac Bonneville is presented in the Charts 11 and 12. Charts 11 and 12 show the total tailpipe NMHC plus NOx and CO emissions, respectively, at various bias-settings. For this vehicle, the optimal bias-setting was at a multiplier of 0.75. At the optimal setting, the "rich-bias" reduced the US06 NMHC plus NOx emissions over 90 percent relative to emissions from the baseline configuration. At this optimal "rich-bias" setting, US06 CO emissions increased approximately 0.7 g/mi. It should be noted that the vehicle air-fuel ratio distribution curve is somewhat degraded by use of the voltage multiplier technique, indicating a loss in air-fuel ratio control. An extreme example of this phenomenon on the Pontiac Bonneville is indicated in the lambda distributions for the original baseline setting and the 0.65 multiplier setting (Chart 13). A sharp distribution of lambda values typically signifies good air-fuel control and is characteristic of lower exhaust emissions. The "rich-bias" resulted in a flattened lambda distribution, suggesting a loss of air-fuel control. Thus, it is believed that "rich-bias" modifications made through actual software modifications, such as a vehicle manufacturer would use, may allow lower optimal test results than attained in the test program.

The observed reductions in NOx emissions are likely due to reduced engine-out NOx emissions and an increase in catalyst NOx conversion efficiency. It is generally accepted that engine-out NOx emissions are highly temperature-dependent and affected by variables such as ignition timing, load, speed, and air-fuel ratio. By slightly decreasing the air-fuel ratio with the "rich-bias" technique, engine-out NOx emissions will be reduced. At a rich air-fuel ratio, the catalyst NOx conversion efficiency increases in a typical catalyst. Given the improved engine-out and exhaust gas aftertreatment of NOx emissions, "rich-bias" technique resulted in substantial reductions in US06 NMHC plus NOx emissions.

A supplemental explanation for the reduction of US06 NMHC plus NOx emissions relates to the ratio of exhaust gas composition CO to NOx in the catalytic reduction mechanism. This may explain the effectiveness of a US06-cycle-specific air-fuel ratio strategy. A possible theoretical description for this is that engine-out nitric oxide (NO) emissions at stoichiometry increase much more dramatically with load than CO emissions. (For the purposes of this discussion NO and NOx are being treated synonymously.) Given the basic NO conversion reaction $2NO + 2CO \rightarrow N_2 + 2CO_2$, increased exhaust CO concentrations as a result of "rich-bias" would drive the equation further to the right, resulting in higher NO conversion rates. It is possible that at high-load stoichiometry, there is insufficient CO reductant, given the shortened exhaust residence times in the catalyst, to fully convert the additional NO generated during high-load operation. This may also explain why certain vehicles showed no reduction from biasing: if the catalyst is sufficiently large to reduce the impact of the shortened residence time, no benefit would be expected from the use of bias technique.

A. US06 Test

1. ARB Low-Mileage Test Program

The ARB tested twelve passenger cars, a light-duty truck from 3,751-5750 pounds loaded vehicle weight, and six medium-duty vehicles at low-mileage using this emission control strategy.[4] Table 11 compares the baseline NMHC plus NOx emissions and the "rich-bias" optimized emissions. Although the baseline passenger car NMHC plus NOx emissions averages 0.289 g/mi and were as high as 0.9 g/mi, the "rich-bias" calibration strategy reduced NMHC plus NOx emission levels to under 0.20 g/mi with an average of 0.092 g/mi. The percent NMHC plus NOx reduction on passenger cars were on average 68 percent. Similar emission reductions were observed on light-duty trucks and medium-duty vehicles with an average NMHC plus NOx reduction of 52 percent. The "rich-bias" technique did not reduce the US06 NMHC plus NOx emissions from vehicles with low baseline NMHC plus NOx emission performance on

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[4] Kwan, Parker, and Nolan. "Effectiveness of Engine Calibration Techniques to Reduce Off-Cycle Emissions." SAE Paper 971602.

Table 11. ARB US06 Test Program: Low-Mileage NMHC Plus NOx Reductions Using the "Rich-Bias" Calibration Technique

	NMHC plus NOx (g/mi)		
Test Vehicle	**Baseline**	**Optimized**	**Percent**
Passenger Cars			
Dodge Intrepid	0.101	0.058	43
Honda Accord	0.042	0.042	0
Honda Civic (LEV)	0.064	0.064	0
Honda Civic (TLEV)*	0.148	0.148	0
Mazda 626	0.058	0.058	0
Mazda 929	0.899	0.151	83
Mercury Grand Marquis*	0.118	0.054	54
Nissan Maxima	0.547	0.143	74
Nissan Sentra	0.565	0.187	67
Plymouth Neon*	0.201	0.077	62
Pontiac Bonneville**	0.657	0.052	92
Pontiac Grand Am	0.067	0.067	0
Average	**0.289**	**0.092**	**68**
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight			
Chevrolet Astrovan	0.418	0.156	63
Medium-Duty Vehicles from 3571-5750 pounds test weight			
Chevrolet 1500 P/U	0.564	0.222	61
Ford F150 P/U	0.088	0.088	0
Average	**0.326**	**0.155**	**52**
Medium-Duty Vehicles from 5751-8500 pounds test weight			
Chevrolet Suburban	0.473	0.305	36
Dodge Ram Van	0.64	0.407	36
Ford E-250 Van	0.974	0.21	78
Ford E-350 Van	0.145	0.145	0
Average	**0.558**	**0.267**	**52**

* Tested with stoichiometric calibration
** Tested on a twin-roll dynamometer

the US06 such as the two Honda Civics and the Mazda 626. The original calibration on these vehicles may have already included a slightly fuel-rich calibration at high-speed and high-loads.

2. “Rich-Bias” Overlap

Due to overlap between low to moderate speed and load points on both the US06 and the FTP cycle, the “rich-bias” calibration method used by the ARB to reduce US06 NMHC plus NOx emissions would also affect FTP emissions. NMHC and CO emissions typically increased with the “rich-bias” calibration. Since the proposed US06 NMHC plus NOx is a combined standard, the NMHC emission increase is offset by the NOx decrease. However, in the FTP where separate non-methane organic gases and NOx emission standards are applicable, the NMHC emission increase could be problematic.

To address this potential effect on FTP emissions, only specific portions of the US06 calibration that fall outside the FTP speed and load points, i.e., high-speed and high-load points, can be selectively “rich-biased” to achieve US06 NOx reductions similar to the calibration method used by the manufacturers. Due to the complexity of modifying specific speed and load calibrations, partial “rich-bias” calibration testing was not conducted by the ARB staff. However, staff employed a computer model using modal (second by second) emission data to estimate the actual US06 emission reductions that may be achieved without adversely affecting FTP emissions. Modal data from a Pontiac Bonneville tested at 50,000-equivalent miles were available for this analysis. Because modal FTP emission data were limited, the warmed-up LA4 modal emission data were used as a surrogate. By selectively “biasing” only the US06 regimes that fall outside the FTP, the computer model showed that 98 percent of the full “bias” NMHC plus NOx emission reduction was maintained. From a US06 baseline of 0.941 g/mi NMHC plus NOx, the full “rich-bias” calibration reduced NMHC plus NOx emission to 0.201 g/mi, and the modeled partial “rich-bias” calibration reduced emissions to 0.216 g/mi. At this partial “rich-bias” set point, the hot LA4 NMHC emissions remained unchanged, CO emissions increased by less than 0.1 g/mi, and NOx emissions decreased by 0.076 g/mi. Thus, by calibrating only those US06 speed and load points outside the FTP, the vast majority of US06 NMHC plus NOx emission reductions was maintained without significantly affecting FTP emissions.

3. Manufacturer Test Program

Data on manufacturer test vehicles show similar trends to the ARB test program. Manufacturers provided complete information on five LEV-prototypes using the “rich-bias” calibration. The “rich-bias” calibration modifications were done by directly changing the software calibration so that only speed and load regimes outside the FTP were “rich-biased.” Consequently, the FTP emissions were minimally affected. Due to the confidential nature of the LEV-prototype information, a description of the vehicle characteristics will not be provided, and the designation of the vehicles will be based solely on the manufacturer’s name and a numeric value.

Table 12 shows the manufacturer US06 emission data of passenger cars and a light-duty truck at 50,000-equivalent miles (the mileage obtained by aging the critical exhaust emission control components to 50,000 miles and placing them on a stabilized vehicle with approximately 4,000 miles), and a medium-duty vehicle at 100,000-equivalent miles. The average NMHC plus NOx emission reduction on the passenger cars using the "rich-bias" calibration was 45 percent. Similar to the ARB test program, NMHC plus NOx emissions were reduced to 0.20 g/mi and below. These emission levels are equivalent to those at 50,000 miles, and lower 4,000 mile emissions are expected.

Table 12. Manufacturer Prototype LEVs: US06 NMHC Plus NOx Reductions Using "Rich-Bias" Testing

	US06 NMHC+NOx (g/mi)		
Test Vehicle	**Baseline**	**"Rich-Bias"**	**% Reduction**
Passenger Cars			
Nissan-1	0.24	0.20	17
Ford-2	0.35	0.12	66
GM-1	0.111	0.066	41
Average	**0.23**	**0.13**	**45**
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight			
Ford-1	0.124	0.124	0
Medium-Duty Vehicle from 3751-5750 pounds test weight (100,000 miles)			
Chrysler	1.630	0.88	46

In both the ARB and manufacturer test programs, the majority of the vehicles showed a 30 to 80 percent reduction in US06 NMHC plus NOx emissions, with an average of approximately 55 percent. However, as observed in the ARB's test program, this strategy did not reduce the emissions on vehicles which exhibited low baseline US06 NMHC plus NOx emissions.

B. Air-Conditioner Test

As discussed earlier in Section VI.B., “Air-Conditioner Emission Test Program,” the ARB test program was conducted to assess air-conditioner emission levels and potential emission reductions that may be achieved by the “rich-bias” calibration. Since the data from the Toyota air-conditioner simulation tests were used for the SC03 standard-setting, only this set of data will be used in this analysis of the “rich-bias” effects on air-conditioner emissions.

Table 13 shows the NMHC plus NOx emission differences between the baseline and the “rich-bias” calibration. The baseline air-conditioner-on NMHC plus NOx emissions were 0.36 g/mi. The average “rich-bias” NMHC plus NOx reduction for passenger cars was 64 percent, similar to that achieved in the ARB US06 test program. Relatively smaller reductions were observed with light-duty trucks and medium-duty vehicles. The average NMHC plus NOx emission reduction of the four light-duty trucks was 40 percent. Only one vehicle was tested in the medium-duty vehicle category from 3751 to 5750 pounds test weight. No emission reductions would be needed on this vehicle to comply with the proposed SC03 emission standards due to its low baseline NMHC plus NOx emissions. Of the three medium-duty vehicles from 5751 to 8500 pounds test weight, only one vehicle showed an emission reduction with the “rich-bias.” As with the US06 test program, vehicles with low baseline SC03 emissions did not show an emission reduction with the “rich-bias” calibration technique. This is likely due to the inclusion of a slight “rich-bias” strategy at high speed and load points in the production calibration. In addition, the light-duty trucks and the medium-duty vehicles did not respond to the “rich-bias” calibration as effectively as the passenger cars. Again, this may be due to a better optimized production calibration of the trucks which already include a “rich-bias” at the higher speed and load points.

VIII. ENVIRONMENTAL AND ECONOMIC IMPACTS OF THE PROPOSED REGULATIONS

A. Summary of Calculations

As outlined in the Staff Report, the air quality impacts of the proposed regulations have been calculated using the ARB’s EMFAC-7G motor vehicle emission model. In general, data from the ARB’s test programs were used, along with certain U.S. EPA data regarding air-conditioner effects on emissions and summer-time air-conditioner usage. Only running emissions were used for calculation purposes, as the proposed regulations are not expected to have a large impact on cold or hot-start emissions. In addition, for LEVs, emissions during hot-start conditions are relatively similar to those under running conditions. The calculations performed are considered preliminary due to the relatively small number of vehicles tested and are not an official ARB modification of the EMFAC-7G emission model. Modifications to take

Table 13. ARB Test Vehicles: SC03 NMHC Plus NOx Reductions Using the "Rich-Bias" Calibration Technique (g/mi)

	NMHC+NOx		
Test Vehicle	**Baseline**	**Optimized**	**Percent Reduction**
Passenger Cars			
Dodge Intrepid	0.274	0.159	42
Ford Taurus FFV	0.081	0.081	0
Honda Accord	0.170	0.124	27
Honda Civic (LEV)	0.103	0.103	0
Mazda (Prototype)	0.537	0.063	88
Plymouth Neon	0.310	0.193	38
Pontiac Bonneville	0.616	0.169	73
Pontiac Grand AM	0.790	0.156	80
Average	**0.360**	**0.131**	**64**
Light-Duty Trucks from 3751-5750 pounds load vehicle weight *			
Chevrolet Astrovan	0.300	0.220	27
Chevrolet Blazer	0.177	0.151	15
Ford Aerostar**	0.433	0.146	66
Ford Explorer	0.199	0.147	26
Average	**0.277**	**0.166**	**40**
Medium-Duty Vehicles from 3571-5750 pounds test weight *			
Ford F-150 P/U	0.091	0.091	0
Medium-Duty Vehicles from 5751-8500 pounds test weight *			
Chevrolet Suburban	0.547	0.547	0
Ford E-250 Van	0.667	0.345	48
Ford E-350 Van	0.047	0.047	0
Average	**0.420**	**0.313**	**25**

* The light-duty truck and medium-duty vehicle portion of the test program was conducted in an expedited manner, and duplicate tests at the optimal setting were not performed.

** The air-conditioner system was somewhat underloaded using the AC2 simulation method, as the "Defrost" setting was necessary to return hot air to the air-conditioning system into account the effect of under-represented operating regimes such as air-conditioner operation are currently under consideration, but have not undergone the full regimen of testing necessary to modify the EMFAC-7G model.

In general, the emission benefit calculations proceed according to the following methodology: First, for the vehicles subject to the US06 and air-conditioner requirements, the baseline running exhaust emission inventory was computed according to the EMFAC-7G emission model. Next, this baseline inventory estimate was adjusted upwards to include the effects of US06 and air-conditioner operation. The effects of US06 and air-conditioner control were then applied to this inventory estimate to generate emission benefit estimates.

As noted above, the calculations were only performed for the *fraction* of vehicles that would be subject to the US06 and air-conditioner requirements, so that the baseline inventories do not represent complete fleet inventories for the given model years.

B. Baseline Emission Inventory Adjustment

The unadjusted baseline emission calculations of reactive organic gases (ROG), CO, and NOx are shown in Table 14. The apparent increases in emissions with time are not to be interpreted as actual "real-world" increased emissions. They result from the increased numbers of vehicles that will be certified to the proposed standards (whose phase-in begins in the 2001 model year). Actual emissions from the total vehicle fleet will generally be decreasing during this period as a result of the proposed regulations.

Table 14. South Coast Air Basin Running Exhaust Emissions - Unmodified Baseline (Tons per Day)

Calendar Year	ROG	CO	NOx
2010	4.6	425.3	65.4
2015	6.8	637.9	87.8
2020	8.2	776.9	102.4

The next task in the emission calculations was to perform an estimation of the emissions not yet included in the EMFAC-7G model. The US06 emissions in this model are based upon the Unified Cycle, which is a representative test cycle capturing approximately 95 percent of the vehicle miles traveled in the Los Angeles Basin. This includes a significant fraction of the non-FTP-type driving. Although the Unified Cycle does not capture some of the most extreme driving events occurring in in-use driving (as are contained in the US06 test cycle), it is believed to contain a reasonable representation of non-FTP driving. For this reason, no adjustment to the

EMFAC-7G running inventory was made to include the effects of extreme US06-type operation not included in the Unified Cycle.

The EMFAC-7G running exhaust emission inventory was then provisionally adjusted to account for emission increases resulting from use of the air-conditioner. Based upon the original U.S. EPA/Industry air-conditioner emission test program conducted at the Delphi environmental chamber facility in Rochester, New York, the following percentage emission increases relative to air-conditioner-off emissions were observed under hot, stabilized driving conditions (i.e., Bag 2 and Bag 3 of the FTP):

NMHC (ROG):	27%
CO	69%
NOx	113%

These factors, with modifications described below, were incorporated into the unmodified baseline emissions in Table 14. Although different emission increases were observed during the ARB's air-conditioning testing, these percentage increases were used in the inventory calculations because the ARB testing was conducted using only the "Toyota" air-conditioner simulation. The Toyota simulation does not represent the full effects of air-conditioner usage on vehicle emissions. In addition, in the ARB test program only one test per vehicle was run at the baseline air-conditioner off and on conditions.

The ARB test program data suggested that heavier trucks and medium-duty vehicles show considerably smaller percentages of air-conditioner-related emission increases than passenger cars. Thus, the percentage increases outlined above were used to adjust only the running exhaust emission inventory of passenger cars and light-duty trucks under 3751 pounds loaded vehicle weight. Based on data from the ARB test program, staff estimated that light-duty trucks over 3750 pounds loaded vehicle weight and medium-duty vehicles would show approximately 50 percent of the percentage emission increases exhibited by passenger cars. For these vehicle classes, the unmodified baseline emissions shown in Table 14 were adjusted by the following percentage increases:

NMHC (ROG):	14%
CO	35%
NOx	57%

A summertime air-conditioner usage factor of 0.52, as used by the U.S. EPA, was incorporated into the above air-conditioner calculations. This factor was determined from the amount of compressor on-time observed in the U.S. EPA study of summertime air-conditioner usage in Phoenix, Arizona.

The South Coast Air Basin running exhaust emission inventory estimates, as adjusted for uncontrolled baseline air-conditioner usage, are contained in Table 15 for the calendar years

2010, 2015, and 2020. Only vehicles that would be subject to the proposed emission standards are included in these calculations. This comprises approximately 60 percent of the fleet in 2010 and rises to over 90 percent by 2020. Statewide estimates would be approximately 2.5 times the South Coast Air Basin estimates. As with Table 14, the apparent increases in emissions with time are not actual "real-world" increased emissions but are as a result of increased numbers of vehicles certified to the proposed standards. Neither the baseline nor the modified baseline inventory includes the effect of US06 or air-conditioner controls, which are discussed in the next section.

Table 15. South Coast Air Basin Running Exhaust Emissions - Modified Baseline (Tons per Day)

Calendar Year	ROG	CO	NOx
2010	5.1	543.9	93.8
2015	7.5	815.2	125.9
2020	9.1	992.3	146.5

C. US06 and Air-Conditioner Emission Control Calculations

Emission effects with US06 and air-conditioner emission control based on the proposed standards were calculated in the following manner. Using the U.S. EPA summertime air-conditioner usage factor of 0.52, the modified inventory above was split into an air-conditioner off (0.48) and on (0.52) portion. For the air-conditioner-off portion, reductions due to US06 emission controls were calculated by using ARB Unified Cycle Bag 2 testing performed over 5 vehicles in baseline, production configuration, and also in a stoichiometric, bias-optimized configuration. Compared to the baseline configuration, the latter configuration resulted in decreases in NOx emissions of 26 percent, CO decreases of 3 percent, and NMHC increases of 31 percent. In this case, emission reductions due to the optimized configuration were assumed to equal those that would occur as a result of US06 emission controls associated with the proposed regulation. Thus, the air-conditioner-off portion of the modified baseline running exhaust emission inventory was adjusted using these factors to account for US06 emission controls.

Estimation of the air-conditioner-on emission benefit was performed in a somewhat different manner. ARB bias optimization test data over the SC03 test cycle (similar to the Unified Cycle, except for the exclusion of speeds over 54 mph) showed an approximate reduction of 70 percent for air-conditioner-on NOx emissions. This was equivalent to reducing air-conditioner-on NMHC plus NOx test results approximately 45 percent *below* baseline, air-conditioner-off levels. This is a highly unusual result, and the ARB staff does not believe it is likely that air-conditioner-on NOx emissions will be reduced by this percentage on LEVs. As a conservative estimate, the ARB staff has assumed that with the proposed standards LEV air-conditioner-on NOx emissions will equal air-conditioner-off levels. The staff therefore assumed a 53 percent reduction in air-conditioner-on NOx emissions for passenger cars, and a 36 percent reduction for light-duty trucks and medium-duty vehicles.

To calculate the effects of the proposed air-conditioner standards on NMHC and CO emissions, staff compared the NMHC and CO air-conditioner-on SC03 results in the baseline configuration to those in the optimized-bias configuration. Increases in both constituents were generally seen from the biasing technique. When the modal data from the baseline air-conditioner-on tests were examined, the staff found that several vehicles exhibited large CO spikes over acceleration modes, with maximum CO levels reaching 0.5 - 1 gram per second. These increases were not observed over the air-conditioner-off tests, and staff has assumed that these spikes are the result of commanded enrichment strategies that are unlikely to be used on LEVs certified to the US06 standards, which will not allow much use of commanded enrichment strategies. Staff therefore subtracted off the effects of these spikes, for both CO and NMHC, for the optimized-bias results. When this is done, the effects of air-conditioner control are to increase NMHC emissions by 50 percent and reduce CO emissions by 7 percent. Emissions estimates for the controlled scenario including the effects of US06 and air-conditioner control are given in Table 16. As with the previous tables, the apparent increases in emissions with time are not to be interpreted as actual “real-world” increased emissions but are as a result of increased numbers of vehicles certified to the proposed standards.

Table 16. South Coast Air Basin US06 and Air-Conditioner-Controlled Running Exhaust Emissions (Tons per Day)

Calendar Year	ROG	CO	NOx
2010	7.2	512.1	57.1
2015	10.6	767.5	76.7
2020	12.9	934.2	89.4

By subtracting controlled emissions from the baseline running exhaust emissions in Table 15, the emission differences are the air quality emission benefits shown in Table 17. Statewide emission benefits are shown in Table 18. Benefits are reported as positive numbers, and disbenefits are reported as negative numbers. Although the calculational methodology used result in a CO emission benefit of 58 tons per day in the South Coast Air Basin in 2020, note that the CO emission benefit is cited as a range from 0 to 58 tons per day. As a result of uncertainty in predicting future commanded enrichment design scenarios and the reduction of commanded enrichment CO spikes as discussed previously, the calculated A/C-on CO emission reductions may not be fully realized. This could result in less than 58 tons per day CO emission benefit. In addition, there are uncertainties in the assumptions regarding CO emission effects as a result of the “rich-bias” strategy. The modeled effects of off-cycle control include the use of “rich-bias” over FTP conditions, which tends to lower the CO emission benefit. However, since such biasing is highly unlikely to occur (as discussed earlier in Section VII.A.2., “Rich-Bias” Overlap), actual CO emission benefits are probably underestimated. Given the favorable cost-effectiveness of the proposed regulations (based on the ROG plus NOx emission benefit discussed below) and the aforementioned uncertainties, staff chose not to include the estimated CO emission benefits in the cost-effectiveness analysis.

Table 17. South Coast Air Basin Emissions Benefits of US06 and Air-Conditioner Controls (Tons per Day)

Calendar Year	ROG	CO	NOx
2010	-2.1	0 to 32	36.7
2015	-3.1	0 to 48	49.2
2020	-3.8	0 to 58	57.1

Table 18. Statewide Emissions Benefits of US06 and Air-Conditioner Emissions Controls (Tons per Day)

Calendar Year	ROG	CO	NOx
2010	-5.3	0 to 80	91.8
2015	-7.8	0 to 120	123.0
2020	-9.5	0 to 145	142.8

D. Cost-Effectiveness of the Proposed Regulations

Based upon the calculations above, the total statewide NMHC plus NOx air quality benefit of the proposed regulations is 133 tons per day. As outlined in the Staff Report, two scenarios were used to calculate test facility costs, depending on the air-conditioner simulation used to conduct the SC03 test. The first is for the use of an air-conditioner simulation, and the second is for the use of an environmental cell. The cost-effectiveness of the regulation is calculated at $1,530 per ton or $0.77 per pound with the air-conditioning simulation and $2,110 per ton or $1.05 per pound with the environmental cell test.

The cost per emissions reduced calculation above is most likely significantly overestimated due to the National LEV program. Assuming its implementation, with the fixed costs of this California regulation then greatly reduced, the cost-effectiveness of this regulation then becomes $887 per ton or $0.44 per pound for the simulation scenario and $1,200 per ton or $0.60 per pound for the environmental cell scenario. This compares favorably to $5 per pound, which is a typical cost-effectiveness value for an air pollution control measure.

Appendix 1

ARB/Industry US06 Test Program: FTP Data and Vehicle Description

Table A. ARB/Industry US06 Test Program: 50,000-Mile Vehicle FTP Emissions

Test Vehicle*	NMHC	CO	NOx
ARB Test Vehicles			
Honda Civic	0.091	1.619	0.147
Honda Accord	0.060	0.917	0.141
Mazda 626	0.169	3.080	0.112
Mercury Grand Marquis	0.195	2.415	0.161
Plymouth Neon	0.070	1.317	0.144
Pontiac Bonneville	0.065	1.199	0.164
Pontiac Grand Am	0.069	0.992	0.295
Ford Ranger P/U (LDT2)	0.150	1.502	0.209
Lexus SC300	0.147	1.570	0.178
Industry Test Vehicles			
GM-1	0.051	0.783	0.082
GM-2	0.059	0.650	0.123
GM-3 (MDV2, 90K)	0.114	2.100	0.199
Ford-1	0.056	0.33	0.14
Ford-2 (LDT2)	0.072	1.744	0.065
Chrysler-1	0.05	0.5	0.16
Chrysler-2 (MDV2, 100K)	0.12	1.18	0.41
Honda-1	0.043	0.905	0.101
Nissan-1	0.059	0.721	0.078
Toyota-1	0.065	0.96	0.16
Passenger Car Average	**0.088**	**1.198**	**0.146**
Passenger Car LEV Standard	**0.075**	**3.4**	**0.20**

* All vehicles are passenger cars unless otherwise indicated.

Table B. ARB/Industry 50K US06 Test Program: ARB Test Vehicle Description

Test Vehicle	Model Year	Engine Displacement (L)	Inertia Test Weight (lbs)	Mileage (Miles)
Passenger Cars				
Honda Civic	1994	1.5	2,625	3,500
Honda Accord	1995	2.2	3,250	19,600
Mazda 626	1995	2.5	3,250	10,600
Mercury Grand Marquis	1995	4.6	4,000	5,800
Plymouth Neon	1995	2.0	2,750	20,800
Pontiac Bonneville	1995	3.8	3,750	6,800
Pontiac Grand Am	1995	2.3	3,250	19,400
Ford Ranger P/U	1995	3.0	4,250	1,100
Lexus SC300	1995	3.0	4,000	17,200

Table C. ARB Low-Mileage US06 Test Program: Test Vehicle Description

Test Vehicle	Model Year	Engine Displacement (L)	Inertia Test Weight (lbs)	Mileage (Miles)
Passenger Cars				
Dodge Intrepid	1996	3.5	3,750	4,500
Honda Civic (LEV)	1996	1.6	2,750	4,200
Honda Civic (TLEV)*	1994	1.5	2,625	3,500
Honda Accord	1995	2.2	3,250	7,600
Mazda 626	1995	2.5	3,250	10,600
Mazda 929	1995	3.0	3,750	18,800
Mercury Grand	1995	4.6	4,000	5,800
Nissan Maxima	1996	3.0	3,500	4,100
Nissan Sentra	1996	1.6	2,750	8,800
Plymouth Neon*	1995	2.0	2,750	20,800
Pontiac Bonneville	1995	3.8	3,750	6,800
Pontiac Grand Am	1995	2.3	3,250	19,400
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight				
Chevrolet Astrovan	1996	4.3	4,750	22,400
Medium-Duty Vehicles from 3571-5750 pounds test weight				
Chevrolet 1500 P/U	1997	5.0	4,750	5,100
Ford F150 P/U	1996	5.0	5,250	15,900
Medium-Duty Vehicles from 5751-8500 pounds test weight				
Chevrolet Suburban	1996	5.7	6,500	23,200
Dodge Ram Van	1996	5.9	6,000	28,000
Ford E-250 Van	1996	5.8	6,500	7,800
Ford E-350 Van	1996	7.5	8,000	16,300

Appendix 2

ARB Air-Conditioner Test Program: Vehicle Description

ARB Air-Conditioner Test Program: Test Vehicle Description

Test Vehicle	Model Year	Engine Displacement (L)	Inertia Test Weight (lbs)	Mileage (Miles)
Passenger Cars				
Dodge Intrepid	1996	3.5	3,750	4,900
Ford Taurus FFV	1996	4.0	3,750	6,400
Honda Accord	1996	2.2	3,250	3,300
Honda Civic (LEV)	1996	1.6	2,750	4,300
Mazda (Prototype)*	-	-	-	-
Plymouth Neon	1996	2.0	2,875	7,300
Pontiac Bonneville	1996	3.8	3,750	16,300
Pontiac Grand AM	1996	2.4	3,250	10,200
Light-Duty Truck from 3751-5750 pounds loaded vehicle weight				
Chevrolet Astrovan	1996	4.3	4,750	20,900
Chevrolet Blazer	1997	4.3	4,500	4,500
Ford Aerostar	1997	3.0	4,000	3,800
Ford Explorer	1996	4.0	4,750	10,900
Medium-Duty Vehicles from 3571-5750 pounds test weight				
Ford F-150 P/U	1996	5.0	5,250	17,300
Medium-Duty Vehicles from 5751-8500 pounds test weight				
Chevrolet Suburban	1996	5.7	6,500	23,700
Ford E-250 Van	1996	5.8	6,500	8,200
Ford E-350 Van	1996	7.5	8,000	16,400

* Confidential information

Appendix 3

ARB US06 and SC03 Test Programs: Test Data

Appendix 4

References
(Technical Support Document and Staff Report)

References
(Technical Support Document and Staff Report)

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Appendix 5

Proposed Amendments to the “California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles”

Appendix 6

Proposed Amendments to the “California New Vehicle Compliance Test Procedure”