State of California
AIR RESOURCES BOARD

STAFF REPORT: INITIAL STATEMENT OF RULEMAKING

PROPOSED AMENDMENTS TO LOW-EMISSION VEHICLE REGULATIONS

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TABLE OF CONTENTS

Page No.

I. INTRODUCTION 3

II. DESCRIPTION OF LOW-EMISSION VEHICLE PROGRAM 4
- A. LEV Emission Standards 4
- B. Phasing-In LEVs 5
- C. Accounting for Exhaust Reactivity 6

III. PROPOSED AMENDMENTS TO REACTIVITY ADJUSTMENT FACTORS 7
- A. Procedure for Calculating RAFs 7
- B. Vehicle Selection Criteria 8
- C. Airshed Modeling 8
- D. Status of the RAF Test Program 8
- E. Medium-Duty Baseline Specific Reactivity 12
- F. Proposal for Interim RAFs 14
- G. Effect of Change in NMOG Test Methods 16
- H. Environmental Impact of Reactivity Adjustment Factors 17

IV. MEDIUM-DUTY VEHICLE REVISED SIP PROPOSAL 18
- A. Description of Medium-Duty Vehicle Category 18
- B. Description of Revised SIP Proposal 19
- C. Emission Standards 20
- D. Inventory Analysis of Enhanced MDV Proposal 23
- E. Technological Feasibility 27
- F. Costs of Medium-Duty Vehicle Proposal 44
- G. Environmental Impact of Medium-Duty Vehicle Proposal 45

V. PROPOSED AMENDMENTS TO THE FUEL SPECIFICATIONS FOR M100 FUEL METHANOL 46

VI. SUMMARY OF PROPOSED MODIFICATIONS AND CLARIFICATIONS TO EXISTING REQUIREMENTS 48
- A. Section 1960.1. Exhaust Emission Standards and Test Procedures - 1981 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles 48
- B. Section 1956.8. Exhaust Emission Standards and Test Procedures - 1985 and Subsequent Model Heavy-Duty Engines and Vehicles. 49
- C. California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles. 49

D. California Exhaust Emission Standards and Test Procedures for 1987 and Subsequent Model Heavy-Duty Otto-Cycle Engines and Vehicles 49
E. California Non-Methane Organic Gas Test Procedures 49
F. California Assembly-Line Test Procedures for 1996 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles 50
G. California New Vehicle Compliance Test Procedure 50
H. California Motor Vehicle Emission Control and Smog Index Label Specifications 50

VII. ENVIRONMENTAL AND ECONOMIC IMPACT OF RULEMAKING 50

VIII. REFERENCES 53

Inventory Scenarios 56

PROPOSED MODIFICATIONS TO THE CERTIFICATION REQUIREMENTS AND TEST PROCEDURES OF THE LOW-EMISSION VEHICLE REGULATIONS

I. INTRODUCTION

When the original Low-Emission Vehicle (LEV) regulations were approved in 1990, the Air Resources Board (ARB or Board) instructed staff to periodically review the status of implementation of the regulations. During these reviews any new information which suggested that the program could be improved would be considered for incorporation into the regulations. Pursuant to the Board's direction, there have been several reviews of the program. In 1991, the Board approved the first reactivity adjustment factors (RAFs). In 1992, staff provided an update to the Board on the technological progress of low-emission vehicles. At that time the Board determined that the LEV program continued to be technologically feasible within the program timeframe. In 1993, the Board adopted additional RAFs and numerous amendments which further clarified existing provisions and added new requirements to facilitate implementation of the program. In 1994, the Board conducted a public meeting to discuss the status of technological development of low-emission and zero-emission vehicles. Again the Board concluded that no major changes to the program were necessary at that time and that the program requirements continued to be technologically feasible and cost-effective.

In this rulemaking, staff will be proposing the first regulatory action relating to the mobile source element of the State Implementation Plan (SIP). The proposed amendments pertain to increasing the requirements for low-emission medium-duty vehicles. Staff has worked extensively with members of industry to develop a plan that essentially achieves the emission reduction goals of the SIP while also providing suitable flexibility for industry in meeting these goals. Staff is also proposing a variety of modifications and new requirements including the adoption of new RAFs, amendments to the light-duty vehicle regulations, elimination of the M100 methanol fuel luminosity requirement, and clarifications of existing requirements. It should be noted that this hearing will not address electric or hybrid electric vehicles since a series of workshops is underway to further address these issues, and the staff plans to present its findings relative to these vehicles in a Board hearing in 1996.

The proposed amendments in this hearing would affect Title 13, California Code of Regulations (CCR), sections 1956.8, 1960.1, 1965, 2062, 2101, and 2292.1. In addition, the following test procedures are being modified: "California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles," the "California Exhaust Emission Standards and Test Procedures for 1987 and Subsequent Model Heavy-Duty Otto-Cycle Engines and Vehicles," the "California Non-Methane Organic Gas (NMOG) Test Procedures," the "California Assembly-Line Test Procedures for 1998 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles," the "California New Vehicle Compliance Test Procedure," and the "California Motor Vehicle Emission Control and Smog Index Label Specifications." Many of the regulatory amendments being proposed in this rulemaking are very detailed and technical in nature. For this reason, this staff report will only briefly summarize the nature of the proposed modifications. Sections III, IV, V and VI of the Staff Report are intended to be a non-controlling Plain English summary of the proposed amendments, as required by Government Code Section 11346.2(a). A complete description of the modifications is contained in Appendix A.

II. DESCRIPTION OF LOW-EMISSION VEHICLE PROGRAM

The LEV Program represents a primary element of California's long-term plan for reducing air pollution from future light- and medium-duty mobile sources. The program requires implementation of advanced mobile source control strategies to substantially improve California's air quality. The following is a summary of the LEV Program.

A. LEV Emission Standards

The LEV program contains four categories of increasingly stringent vehicle emission requirements: transitional low-emission vehicles (TLEV), low-emission vehicles (LEV), ultra-low emission vehicles (ULEV), and zero-emission vehicles (ZEV). These new categories apply to three classes of vehicles: passenger cars and light-duty trucks weighing less than 3751 pounds, light-duty trucks weighing between 3751 and 5750 pounds, and medium-duty vehicles 0-14,000 pounds. The largest class of vehicles is comprised of passenger cars and light-duty trucks (0-3750 lbs.) The 50,000 mile emission standards applicable to this class are shown in Table II-1. The emission standards applicable to other categories of vehicles will be discussed later in this report.

Table II-1
Light-Duty Low-Emission Vehicle Exhaust Emission Standards

Vehicle Class	NMOG[1]	CO	NOx
Tier 1[2]	0.25	3.4	0.4
TLEV	0.125	3.4	0.4
LEV	0.075	3.4	0.2
ULEV	0.040	1.7	0.2
ZEV	0	0	0

1 "NMOG" is non-methane organic gas and is comprised of non-methane hydrocarbons and all oxygenated hydrocarbons.

2 "Tier 1" refers to the non-methane hydrocarbon (NMHC) standard which applies to conventional gasoline vehicles.

B. Phasing-In LEVs

A unique feature of the LEV program is its market-based approach to implementation which affords considerable compliance flexibility to manufacturers. For light-duty vehicles, manufacturers are not required to phase-in specific percentages of vehicles certified to each of the low-emission vehicle categories. Instead, a fleet average requirement enables manufacturers to certify to any combination of low-emission vehicle categories as long as the overall fleet average is met. Compliance with the fleet average requirements is determined by calculating the sales weighted emission average of a manufacturer's vehicle fleet. Additional flexibility is provided through the use of a marketable credit trading system. Manufacturers that produce more low-emission vehicles than needed to meet the fleet average requirement will accumulate credits which can be banked, traded or sold to other manufacturers. The fleet average requirement for passenger cars and light-duty trucks (0-3750 lbs.) is as follows:

Table II-2 - Fleet Average Requirements
Passenger Cars and Light-Duty Trucks (0-3750 lbs.)

Model Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Fleet Average NMOG	0.250	0.231	0.225	0.202	0.157	0.113	0.073	0.070	0.068	0.062

The requirements for medium-duty vehicles are approached differently. Because of the lower production volumes and limited model availability of these vehicles, it was not practical to create a fleet average requirement. Instead, manufacturers of medium-duty vehicles are required to meet certain percentage phase-in requirements, but they can accumulate marketable emission credits for exceeding these phase-in percentages. This credit system also affords medium-duty vehicle manufacturers considerable compliance flexibility.

The only instance where certification of light-duty vehicles to a specific category is required is the introduction of ZEVs. Beginning in 1998 all large volume manufacturers with sales in California exceeding 35,000 vehicles per year (General Motors, Ford, Chrysler, Toyota, Nissan, Mazda and Honda), are required to introduce the following percentages of their passenger cars and very light-duty trucks as ZEVs:

Table II-3
ZEV Requirement

Model Year	1998	1999	2000	2001	2002	2003+
% Reqmt.	2	2	2	5	5	10

Intermediate volume manufacturers will have to meet the ZEV requirements starting with the 2003 model year.

Flexibility also exists for the introduction of ZEVs since manufacturers may forego producing the specified percentages of ZEVs in a given year by banking or acquiring credits generated from early production of ZEVs or from exceeding the production requirements, or by making up any deficits incurred in a given year by the end of the following year without penalty. A manufacturer that fails to make up the deficit within that time would pay a penalty that would not exceed $5,000 per ZEV.

C. Accounting for Exhaust Reactivity

One of the primary objectives of California's motor vehicle pollution control program has been to reduce ozone in the lower atmosphere, where it is the primary ingredient of urban smog. Ozone is formed in the atmosphere as a result of complex photochemical reactions of hydrocarbons with oxides of nitrogen ("NOx"). There are many different species of hydrocarbons emitted from mobile sources, each with a specific ability to react with NOx in the atmosphere to form ozone. The relative reactivity of the hydrocarbon species in the exhaust of vehicles powered by different kinds of fuels can also vary significantly.

To account for the varying reactivity of vehicle exhaust, the LEV program contains two new elements not previously used in mobile source emission control programs. The first is to identify all of the organic gases (hydrocarbons) measured in the exhaust. This was accomplished by establishing a non-methane organic gases (NMOG) standard which for the first time counted the full mass of all measurable non-oxygenated hydrocarbons containing twelve or fewer carbon atoms (excluding methane), and all oxygenated hydrocarbons (ketones, aldehydes, alcohols, and ethers). The second element is a mechanism under which the full mass of the NMOG emissions from vehicles operated on alternative or reformulated gasoline fuels will be adjusted by the applicable reactivity adjustment factor, or "RAF" according to the ozone reactivity of their exhaust.

The LEV regulations set forth procedures for establishing RAFs for different vehicle/fuel combinations. Although the regulations authorize the Executive Officer to establish RAFs under the procedures without a rulemaking, it is anticipated that all RAFs will be established by the Board in regular rulemakings. As discussed in the next section of this report, RAFs are based on a comparison of the ozone reactivity of an alternative fuel or reformulated gasoline low-emission vehicle to the ozone reactivity of a comparable conventional gasoline low-emission vehicle. The comparison of the reactivities of the two classes of vehicles is accomplished through the application of a "maximum incremental reactivity" (MIR) scale which identifies MIR values for the over 140 individual hydrocarbon species that can be found in vehicle exhaust. The MIR scale is designed to reflect the relative reactivities of the various species under one particular set of atmospheric conditions -- the conditions in which the maximum change in ozone results from any additional hydrocarbon. It is under these conditions that hydrocarbons (and consequently hydrocarbon controls) have the most impact on ozone formation. Lower values on the MIR scale represent a lower reactivity under these atmospheric conditions, and higher values represent higher reactivities. The scale was developed by Dr. W. P. Carter at the Statewide Air Pollution Research Center at the University of California, Riverside.

Once the RAF for a vehicle/fuel class is established, the exhaust emissions of vehicles in that class are multiplied by the RAF to determine compliance with the NMOG exhaust emission standard. For instance, if the NMOG emissions from a class of alternative fuel vehicles are one-half as reactive as the NMOG emissions from an equivalent conventional gasoline vehicle, the RAF would be 0.5. The vehicle would be allowed to emit twice the mass of NMOG as a conventional gasoline vehicle, because with the adjustment the NMOG emissions from the two vehicles would lead to the same amount of ozone formation.

III. PROPOSED AMENDMENTS TO REACTIVITY ADJUSTMENT FACTORS

A. Procedure for Calculating RAFs

In order to establish the reactivity adjustment needed for a low-emission vehicle operating on a clean fuel, the ozone reactivity of emissions from a conventional gasoline low-emission vehicle must be compared to the ozone reactivity of a comparable vehicle operating on a clean alternative or reformulated gasoline fuel. The RAF is calculated as shown below:

$$\text{RAF} = \frac{\text{ozone/gram of clean fuel low-emission vehicle NMOG emissions}}{\text{ozone/gram of conventional gasoline low-emission vehicle NMOG emissions}}$$

The terms in the numerator and denominator of the RAF equation are referred to as the "specific reactivity," or grams of ozone produced for each gram of NMOG emitted by a vehicle. In order to measure the specific reactivity of a vehicle operating on either conventional gasoline or a clean fuel, the NMOG exhaust of that vehicle is speciated (or separated) into its individual components. The mass emissions per mile (mg/mi) of each separate organic gas component is then multiplied by its associated maximum incremental reactivity value to determine the amount of ozone formed by that compound. Each of these individual values is added together and the resulting value is divided by the total exhaust NMOG mass to determine the specific reactivity of the exhaust of that vehicle. This process is used to determine the specific reactivity for both the numerator and denominator of the RAF equation. In order for a vehicle to demonstrate compliance with the NMOG emission standard, the NMOG mass emission level of a vehicle is multiplied by the RAF and the resulting value must be less than or equal to the applicable NMOG emission standard.

Manufacturers have two options when utilizing a RAF for a given fuel. They can establish their own specific reactivity for a particular engine family (to be used in the numerator of the RAF equation) or they can use the generic RAF developed by the ARB which applies to all vehicles and fuels in a given emission category (TLEV, LEV or ULEV). Both options utilize the same baseline specific reactivity (the denominator of the RAF equation) determined by the ARB.

B. Vehicle Selection Criteria

In the past, the ARB has selected vehicles for establishing generic RAFs which met the applicable emission standards for NMOG, CO and NOx in each emission category. To the extent possible, vehicles that utilized technologies expected to represent future production low-emission vehicles were selected for determining the specific reactivity values of the numerator of the RAF equation. This is important because the reactivity of NMOG emissions can also vary with vehicle technology as well as with the fuel used. When no actual pre-production or production vehicles existed, however, engineering judgment was used to select representative technology that could be installed on prototype test vehicles developed by ARB engineers. While the vehicles used to develop the generic RAFs are believed to be representative of future production designs, data will continue to be generated from actual production vehicles as they become available and updates or corrections to the database will be made as needed. Appendix C contains a description of the emission control equipment utilized by each of the clean fuel low-emission vehicles used in developing the ARB's database. It should be noted that vehicles utilized for establishing the baseline specific reactivity (denominator of the RAF equation) were assembled by ARB staff using prototype emission control technology available in the 1990 timeframe which would enable attainment of the low-emission vehicle standards using conventional gasoline. Unlike the numerator of the RAF equation, then, the baseline specific reactivity remains a fixed benchmark by which all future clean fuels and technologies are compared. Technologies applied to future low-emission vehicles which reduce ozone formation more than the technologies used on the baseline conventional gasoline vehicles would then be credited by yielding a lower RAF value.

C. Airshed Modeling

Professor Armistead Russell of Carnegie Mellon University has been retained to validate the RAFs through airshed modeling. The purpose of airshed modeling is to determine whether use of proposed reactivity-adjusted emissions would exacerbate ozone formation under certain atmospheric conditions. In the airshed modeling, the air quality impact from the reactivity-adjusted NMOG emissions of a clean fuel vehicle fleet are compared to the NMOG emissions of a conventional gasoline low-emission vehicle fleet. If the ratio of the ozone formed from each scenario is close to one, the reactivity-adjustment factor would be judged as reliable. This procedure has been employed by the ARB in the past for previously adopted RAFs. A complete description of the results of Dr. Russell's airshed modeling are attached in Appendix D. The results of Dr. Russell's modeling for each fuel are discussed in more detail later.

D. Status of the RAF Test Program

Since 1990, the ARB has been conducting testing to establish the specific reactivities for each emission and clean fuel category in order to determine the applicable generic RAFs. Table III-1 identifies the baseline specific reactivities and RAFs that have been adopted thus far (in bold).

Table III-1
Reactivity Adjustment Factors

	Light-Duty Vehicles			**Medium-Duty Vehicles**	
	TLEV	**LEV**	**ULEV**	**LEV**	**ULEV**
Fuel	**Baseline Specific Reactivity ($g\ O_3$ / g NMOG)**				
Conventional Gasoline	**3.42**	**3.13**	**3.13**	*3.13*	*3.13*
	RAFs				
Phase 2 RFG	**0.98**	**0.94**	0.94	0.94	0.94
M85	**0.41**	0.41	0.41	0.41	0.41
Natural Gas	*1.0*	*0.43*	*0.43*	0.43	0.43
LPG	*1.0*	*0.50*	*0.50*	0.50	0.50
E85					

Since the last biennial review in January, 1993, staff has conducted additional testing to establish the remaining RAFs for light-duty natural gas and liquefied petroleum gas vehicles and to establish a baseline specific reactivity for medium-duty vehicles. The test results from these programs are listed in the above table in *italics* and are summarized below. (The numbers that have been underlined will be discussed in Section F. below.)

1. **Light-Duty Natural Gas RAF**

Seven vehicles were provided to the ARB by the California Natural Gas Vehicle Coalition to be used in developing RAFs. All but one (a 1992 Crown Victoria) were capable of operating on both gasoline and natural gas. The 1992 Crown Victoria is a dedicated natural gas vehicle which employs a prototype system developed by Ford. Of the other seven vehicles, one used an ANGI fuel conversion retrofit kit and the remainder were retrofitted with IMPCO conversion systems.

Table III-2 contains a summary of the test results of the natural gas vehicles. A summary of the vehicle data and test results is contained in Appendix C-1 of this report. Based on the results of the seven ARB test vehicles, the staff is proposing an LEV/ULEV natural gas generic RAF of 0.43 (1.339/3.13). The airshed modeling conducted by Dr. Russell indicates there is no need for a correction to the RAF for LEVs and ULEVs operating on natural gas.

Table III-2

Vehicle	NMOG	CO	NOx	Ozone /gram NMOG
1992 Sierra Truck	0.067	1.433	0.243	1.124
1992 Corsica	0.022	0.350	0.090	1.423
1992 Ranger	0.027	0.537	0.174	1.249
1992 CrownVic	0.017	1.942	0.101	1.274
1991 Acclaim	0.033	1.762	0.149	1.143
1990 Caravan	0.018	0.860	0.223	1.441
1990 LeSabre	0.032	0.623	0.243	1.722
Average	**0.031**	**1.072**	**0.175**	**1.339**

With the exception of the 1992 Sierra pick-up truck, all of the vehicles met the ULEV NMOG levels, even without application of the proposed RAF. A combined LEV/ULEV RAF is being proposed because there does not appear to be any appreciable difference in the specific reactivities of natural gas vehicles with NMOG levels below 0.075 g/mi. It also appears that developing a generic TLEV RAF will not be necessary because it is expected that the emission control technologies utilized by natural gas vehicles to achieve the 0.4 or 0.2 NOx standard will also keep NMOG emissions below LEV levels. For this reason, staff is proposing a default TLEV RAF of 1.0 for vehicles operating on natural gas.

Statistical Confirmation of RAF. The regulations provide that manufacturers which choose to develop engine family specific RAFs must meet a certain statistical criterion. Specifically, the 95% confidence level for the test data must be less than or equal to 115% of the RAF. This criterion is applied to the variety of tests conducted for a particular engine family during the certification process to assure uniform performance of the vehicles. The ARB is not required, however, to meet this criterion in developing generic RAFs because different engine families/vehicles are used which diminish the confidence level of the statistical analysis. Nevertheless, the ARB subjects the test results for individual vehicles to this criterion in order to quantify the uniformity of the results. Appendix C-1 presents the results of application of the 95% upper confidence bound statistical criterion to the natural gas RAF data. While a few of the vehicles slightly exceed the 115% criterion as specified in the test procedures for engine-family specific RAFs, staff is still proposing that the data from these vehicles be used to establish an interim generic RAF. The variability was observed on vehicles that had been retrofitted to operate on both gasoline and natural gas, representing a less advanced technology than that expected to be utilized by fully optimized production natural gas vehicles. (Note that the Ford Crown Victoria, a fully optimized prototype vehicle, meets the 115% criterion.) Nonetheless, the specific reactivity was consistent across the test fleet. Further, these vehicles constitute the best available prototype vehicles for generating an interim generic RAF for natural gas. As more optimized vehicles become available, they will be added to the database and any needed revisions would be proposed.

2. Light-Duty Liquified Petroleum Gas RAF

The ARB tested seven liquefied petroleum gas (LPG) vehicles which were capable of operating on both gasoline and LPG. All of the vehicles were equipped with IMPCO conversion systems and were provided to the ARB by the Western Propane Gas Association (WPGA). A complete list of the equipment contained on the vehicles is contained in Appendix C-2.

The vehicles were tested using certification fuel which meets the specifications adopted by the Board in 1992. One specification of the fuel requires a 5% cap on the propene (propylene) content. The LPG industry has recently expressed concern about this limit because approximately one-half of the propane supply in California comes directly from refineries where the propene content is typically over 10%, especially in parts of northern California. The propane industry claims to have no control over the amount of propene contained in these refinery streams and has requested that the limit be increased to reflect typical refinery output. Staff is currently in the process of reviewing this issue but at the current time the 5% limit is being maintained in large part because of the high reactivity of propene and because production of Phase 2 gasoline in California refineries is likely to result in lower propene content in future refinery streams of LPG.

Table III-3 summarizes the test results of these vehicles. Appendix C-2 contains the summary of the speciated results and vehicle data for the LPG vehicles.

Table III-3

Vehicle	NMOG	CO	NOx	Ozone / gram NMOG
1991 Lumina	0.096	1.147	0.207	1.653
1992 Taurus	0.088	2.373	0.100	1.479
1992 Century	0.099	1.103	0.199	1.336
1993 Euro Lumina	0.098	1.779	0.178	1.475
1992 Century	0.102	2.560	0.117	1.356
1993 Taurus	0.078	0.524	0.096	1.323
1993 Regal	0.076	1.284	0.031	1.488
AVERAGE	**0.084**	**1.200**	**0.096**	**1.424**

The airshed modeling performed for the vehicles meeting the LEV standards indicates that an upward adjustment of ten percent is necessary for LPG vehicles. Therefore, a LEV RAF of 0.50 (1.424/3.13 + 10%) is being proposed for vehicles operating on LPG. It also appears that the specific reactivities of the ULEVs are essentially the same as the LEVs. For this reason staff is proposing the ULEV RAF be the same as the LEV LPG RAF. While the ULEVs were not subjected to airshed modeling, previous airshed modeling performed by Carnegie Mellon University researchers and others show that ozone formation is linear over small changes in emissions. Thus, the 10% RAF adjustment derived from emission data of LEVs operated on LPG would also apply to the combined ULEV/LEV results.

It also appears that developing a generic TLEV RAF will not be necessary again because it is expected that the emission control technologies utilized by LPG vehicles to achieve the 0.4 or 0.2 NOx standard will also keep NMOG emissions below LEV levels. For this reason, staff is proposing a default TLEV RAF of 1.0 for vehicles operating on LPG.

Statistical Confirmation of Data. Appendix C-2 contains the results of application of the 95% confidence level statistical criterion to the individual LPG data. All of the vehicles tested for the generic LPG RAF meet the statistical criterion applied to engine-family specific RAFs.

3. LEV M85 RAF

Only preliminary testing has taken place for establishing the M85 LEV RAF. To date, only one official vehicle has been tested, a Lumina. This vehicle is equipped with a close coupled catalyst in addition to the main underfloor catalyst that staff estimates is representative of the technology expected for meeting the LEV standards with M85. Table III-5 summarizes the results of the Lumina; Appendix C-3 contains a summary of the speciated results and vehicle data for the other M85 vehicles.

Table III-5

Vehicle	NMOG	CO	NOx	Ozone/g NMOG
1992 Lumina	0.095	1.159	0.157	1.646

E. Medium-Duty Baseline Specific Reactivity

To date, six vehicles have been tested on conventional gasoline to develop the baseline specific reactivity for medium-duty vehicles. Appendix C-4 contains a summary of the speciated results and vehicle emission control equipment. Table III-6 summarizes the emission results obtained to date by the ARB.

Table III-6

Vehicle	**Fuel**	**NMOG**	**CO**	**NOx**	**Ozone/g NMOG**
1993 F150 Truck	RF-A	0.119	0.840	0.663	2.422
1993 F150 Truck	RF-A	0.172	3.142	0.652	2.982
1994 F150 Truck	RF-A	0.059	0.739	0.313	3.257
1994 F150 Truck	RF-A	0.061	0.543	0.323	3.137
1994 F150 Truck	RF-A	0.063	0.765	0.346	3.102
AVERAGE		0.095	1.206	0.459	2.980

AAMA has also submitted data for development of the medium-duty vehicle baseline specific reactivity as well as for a Phase 2 RAF. Table III-7 lists the results obtained on conventional gasoline.

Table III-7
Conventional RF-A Gasoline
AAMA Data

Vehicle	**NMOG**	**CO**	**NOx**	**Ozone/g NMOG**
Chrysler 5.2L	0.202	2.57	0.23	3.92
GM 4.3L	0.123	2.42	0.35	3.57
GM 5.7L	0.155	1.73	0.57	4.07
GM5.7L	0.173	2.12	0.64	3.91
Ford 5.8L	0.098	2.56	0.36	3.53
Ford 5.8L	0.186	1.53	0.36	3.40

A review of these results indicates a large disparity in the specific reactivities of the vehicles provided by AAMA compared to the Ford trucks tested at the ARB. While the reason for this disparity is not readily apparent, as in past determinations, staff has elected to use only vehicles meeting the emission requirements of the category which also represent the capability of currently available emission control hardware in providing low specific reactivity values. The Ford trucks fit this criterion and exhibit a low average specific reactivity - 2.98 g ozone per g NMOG.[3] For the reasons discussed below, staff is proposing a baseline specific reactivity of

[3] It is noteworthy that neither the 1993 Ford truck, which meets the medium-duty LEV standards (0.160 g/mi), nor the 1994 Ford trucks, which meet the ULEV standards (0.100

3.13. Staff believes this is a reasonable determination since the 1994 Ford truck data lie in the range of data used previously for determining the baseline specific reactivity of light-duty vehicles.

F. Proposal for Interim RAFs

Since establishment of the RAF process, ARB staff, vehicle manufacturers and others have been testing a wide variety of vehicles on a variety of clean fuels in an attempt to establish generic RAFs. One impediment to this process is that while the clean fuels are readily available, vehicles with technologies representative of future production LEVs and ULEVs are few in number. This has hindered development of generic RAFs for a number of emission categories. Lack of generic RAFs, in turn, could hinder development of some low-emission vehicles since the emission level which a clean fuel vehicle must meet could be uncertain. Manufacturers have therefore requested that interim values be established for these remaining categories to allow sufficient lead time to incorporate low specific reactivity strategies into their future production vehicles. Staff is therefore proposing interim RAFs for these remaining categories that would be effective through the 2000 model year (shown in the Table III-1 in underline).

While a generous amount of information has been gathered to isolate the effects of a variety of fuels on exhaust reactivity, comparatively less test data currently exist to isolate the effects of engine technology and calibration choices. Since the reactivity of exhaust from motor vehicles depends both on the properties of the fuel used in the vehicle and the technologies and calibration techniques utilized in developing the emission control system, an interim RAF value will provide manufacturers with sufficient lead time to develop low specific reactivity emission control technology.

In previous staff reports for the LEV program, test data were presented for vehicles operating on conventional gasoline which demonstrated that specific exhaust reactivity of 3.13 grams ozone per gram of NMOG emissions was attainable using available production circa-1990 vehicles equipped with prototype electrically-heated catalyst systems. This capability determined the benchmark which future LEV and ULEV category vehicles would need to at least meet. For those fuels and technologies which could yield even lower specific reactivities, engine-family specific RAFs could be developed. The staff cautioned manufacturers, however, that if their calibration and technology choices for future low-emission production vehicles operating on Phase 2 gasoline in particular (since its generic RAF alone is close to 1.0) did not achieve a specific reactivity of the exhaust less than the baseline specific reactivity of 3.13 grams ozone per gram NMOG, the post-2000 generic RAF would be adjusted to a value greater than 1.0, (which would mean Phase 2 gasoline vehicle NMOG emissions would have to be less than the current NMOG standards in order to comply with the emission requirements for the LEV and ULEV categories). This should provide the needed incentive for manufacturers to investigate and implement primarily those technologies and calibration technologies which achieve both low NMOG emissions and low exhaust specific reactivity. This ensures that the ozone per mile of a clean fuel

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g/mi), uses an electrically-heated catalyst.

low-emission vehicle does not exceed that of the baseline prototype low-emission vehicles operating on conventional gasoline used previously to establish the technological feasibility of the low-emission standards.

Some preliminary work in evaluating technologies and calibration methods which can lower specific reactivity of exhaust has been done by Nissan as reported in the Society of Automotive Engineers paper 950807. These findings seem to indicate that for warm engine operation, those strategies which tend to reduce NMOG also tend to increase specific reactivity. These include low surface to volume (compact) combustion chamber designs, increased swirl characteristics, reduced exhaust gas recirculation, increased coolant temperature, and others. Areas where specific reactivity and NMOG were both reduced included use of palladium containing catalysts and close-coupling of these catalysts relative to the engine. Other results also suggest that increasing overall catalyst volume can reduce both NMOG and specific reactivity. Since production low-emission vehicles will utilize these catalyst features, the potential for achieving low specific reactivity seems favorable. Yet to be evaluated, at least based on the reported findings available to date, are evaluation of various cold start strategies for reducing both NMOG and specific reactivity. There is some indication, for example, that calibrating the cold start mixture ratios slightly rich of stoichiometric and using supplemental air injection to reduce NMOG results in lower exhaust specific reactivity than utilizing a warm-up strategy which operates slightly lean of stoichiometric coupled with high turbulence in the combustion chamber to promote complete combustion (without air injection). These effects warrant further investigation since the majority of exhaust reactivity is determined during cold engine starting and warm-up.

For the Phase 2 gasoline and methanol light-duty RAFs which are underlined in Table III-1, staff is proposing to carry over previously determined RAFs (i.e., the LEV RAF would be applied to ULEVs for Phase 2 gasoline and the TLEV RAF would be applied to LEVs and ULEVs for methanol) since the specific reactivity of vehicles is expected to decline as emissions decrease due to implementation of more advanced catalysts which light-off more quickly and/or are placed closer to the engine (which should yield lower specific reactivity of the exhaust). Carrying over a RAF from a higher emission category would then provide a conservative estimate of a RAF for the lower emission categories. This should protect against providing undeserved NMOG emission latitude by setting a RAF that is too low (thereby hurting air quality) while setting a reasonable RAF value upon which to target future low-emission vehicle designs.

For medium-duty trucks, the similarity in baseline specific reactivity with the light-duty vehicles coupled with the assessment that medium-duty trucks will likely utilize generally the same emission hardware and calibration approaches as light-duty vehicles, led staff to propose identical interim RAFs.

As production low-emission vehicles become available, ARB staff will evaluate the success of this approach and make adjustments to the generic RAFs as necessary. The ARB staff will also consider adjustments to the post-2000 generic RAFs if, after every reasonable effort, some engine effects yielding high specific reactivity remain which can not be explained and which do not enable some specific engines to achieve at least the baseline specific reactivity after applying all known reactivity reducing technologies and calibration strategies. This approach should achieve the proper balance in motivating vehicle manufacturers to thoroughly investigate and implement reactivity reducing approaches while providing some safety net should every reasonable effort to achieve at least the baseline specific reactivity fail. Manufacturers would need to document emission test results from their technology and calibration efforts in order to demonstrate an adequate good faith effort to reduce specific reactivity should they fail to meet the applicable baseline specific reactivity.

G. Effect of Change in NMOG Test Methods

In 1993, the ARB adopted significant changes to the laboratory methods used in the calculation and determination of the specific reactivity of vehicle exhaust emissions. All of the currently adopted light-duty baseline specific reactivity values (3.42 for TLEVs and 3.13 for LEVs and ULEVs) and RAFs (0.41 for M85 TLEVs, 0.98 for Phase 2 TLEVs and 0.94 for Phase 2 LEVs) were established using the prior methods. In order to determine whether the RAF values being proposed in the upcoming rulemaking would be different using the revised methods, staff conducted a study to determine equivalence of the methods.

To do this, staff selected four vehicles which had been tested using the old method and then re-tested these vehicles using the methods as revised in 1993. Table III-9 contains the results of the testing.

Table III-9
Comparison of NMOG Methods

Vehicle	**Method**	**NMOG**	**CO**	**NOx**	**Ozone/ gram**
1992 Crown Victoria	1990	0.098	1.645	0.313	3.484
	1993	0.113	2.136	0.364	3.338
1992 T-Bird(1)	1990	0.079	0.705	0.248	3.745
	1993	0.116	0.739	0.233	4.420
1992 Tempo	1990	0.065	1.02	0.151	3.151
	1993	0.069	1.29	0.130	3.249
1992 T-Bird(2)	1990	0.046	0.812	0.170	2.886
	1993	0.048	0.95	0.148	2.837

In three of the vehicles, there appears to be no significant difference in the specific reactivity of the exhaust. For the Ford Thunderbird (1), however, the emission levels shifted significantly between tests, which may have contributed to the difference in specific reactivities. In general, however, the data indicate that the two methods produce equivalent results.

H. Environmental Impact of Reactivity Adjustment Factors

The Low-Emission Vehicle (LEV) regulations were designed to be "fuel neutral," so that all alternative fuel vehicles could compete in the marketplace so long as they meet NMOG exhaust emission standards equivalent or lower in ozone forming potential as the NMOG standards set for vehicles fueled with conventional gasoline. The exhaust compositions of most alternative fuel vehicles are too different from conventional gasoline vehicles to assume that they have the same ozone-forming potential per unit of mass emissions. As discussed earlier, a RAF could allow a vehicle operating on an alternative fuel to emit a greater mass of NMOG; however, the net effect on ambient ozone should be no different for such a vehicle than for a conventional gasoline vehicles certified to the same low-emission vehicle standard.

Further, RAFs are calculated using the MIR scale, developed by Dr. William Carter. The principal advantage of this scale is that it defines reactivity in areas where NMOG control has its greatest benefits, the upwind areas where the highest emission densities are found. NMOG control is complementary to California's NOx control program, which has its greatest benefits in the downwind, peak ozone areas. There is little to be gained in designing a reactivity scale that is applicable only to areas where NMOG control has little or no benefit in reducing ambient ozone levels. More advantages of the MIR scale over other approaches include the ease of RAF calculations and existence of a framework that can easily incorporate chemical mechanism updates. While it is not possible to derive a single RAF that yields precisely equal air quality benefits in all places at all times, the RAF has proven to be a stable quantity for places where NMOG control is important, i.e., MIR conditions. This statement is supported by the consistency in the RAFs among all thirty-nine cities used in the derivation of the MIR scale, and the agreement between the MIR scale and the airshed modeling results, both for individual organic gases and the RAFs. This rulemaking does not involve the adoption or refinement of the MIR scale. The RAF mechanism and the initial MIR scale were established in the original Low-Emission Vehicle rulemaking.

Thus, it is not expected that the RAFs being proposed in this rulemaking will contribute to greater ozone formation than comparable conventional gasoline vehicles. This rulemaking proposal is designed to build upon and refine the regulatory structure established in the low-emission regulations. The proposed amendments are appropriately viewed as an integral part of the larger low-emission vehicle regulatory program, and are not expected to change the emission reductions that were originally projected to result from this program. [4]

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[4] For a complete discussion of the RAF rulemaking process and the environmental impacts of RAFs, please refer to the bibliography at this end of this staff report, which is incorporated by reference herein.

IV. MEDIUM-DUTY VEHICLE REVISED SIP PROPOSAL

When the U.S. Environmental Protection Agency (U.S. EPA) released its draft Federal Implementation Plan (FIP) in February, 1994, it was concluded that a more cost-effective plan was needed and an alternate, less costly State Implementation Plan (SIP) was prepared that would meet the federal air quality standards by 2010.

A vital part of the SIP strategy is the control of mobile sources. This is because on-road and off-road mobile sources together account for more than 70 percent of ozone precursor emissions in the state. The ARB's strategy for attainment of federal air quality standards is to implement a combination of improved control technology programs and market-based control measures. There are sixteen improved control technology measures set forth in the SIP aimed at reducing emissions from mobile sources. One of these measures concerns the medium-duty vehicle category. This category includes large pick-up trucks, vans, and delivery vehicles having gross vehicle weight ratings of between 6,001 to 14,000 pounds. While significant emission reductions from this category were required by the LEV regulations adopted in 1990, even further reductions are called for in the SIP. The goal of the SIP proposal was to achieve additional emission reductions of 4 tons per day (tpd) Reactive Organic Gases (ROG) and 32 tpd Oxides of Nitrogen (NOx) from vehicles in this category. The following proposal is designed to essentially achieve these goals.

A. Description of Medium-Duty Vehicle Category

A medium-duty vehicle (MDV) is defined as having a manufacturer's gross vehicle weight rating (GVWR) greater than 6,000 pounds and less than 14,000 pounds. Typically the medium-duty category consists of light and medium-size utility vans, pick-up trucks, small school buses and motor homes. MDVs account for an appreciable share of the motor vehicle emission inventory even though they comprise less than six percent of the vehicle population. MDVs are responsible for approximately nine percent of on-road hydrocarbon, thirteen percent of carbon monoxide and eleven percent of NOx emissions.

The medium-duty category is divided into two classes - chassis-certified vehicles and vehicles certified using the engine-dynamometer test procedure. Vehicles that are engine-dynamometer certified include incomplete gasoline vehicles[5] and those powered with diesel engines. Chassis-certified, or complete, vehicles are further divided into five weight categories (see Table IV-3). According to manufacturer's projections, approximately 70 percent of the MDV population fall into the chassis-certified category and weigh less than 8,500 GVW. These MDVs are mostly gasoline pick-up trucks and sport utility vehicles. The remaining 30 percent are engine-dynamometer certified vehicles and weigh between 8501 - 14,000 lbs. This category consists of large pick-up trucks, delivery vans, motor homes and small urban buses.

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[5] An incomplete vehicle usually consists of a chassis (and in some instances a cab) minus the cargo container. This allows a chassis/engine combination to be used in a variety of applications ranging from delivery vans, small school buses and motor homes.

B. Description of Revised SIP Proposal

In the SIP, staff proposed an accelerated phase-in of the cleanest vehicles in this category, ultra-low-emission vehicles (ULEVs). This proposal was based on an updated analysis of the feasibility of ULEVs. Based on consultations with the U.S. EPA, staff determined that by applying some of the expected advancements developed for light-duty vehicles, coupled with recent advances in diesel engine technology, cost-effective control technology would be available for MDVs to meet the ULEV requirements earlier than called for by the current requirements. Table IV-1 contains the SIP phase-in requirements.

Table IV-1
SIP Proposal

Model Year	Emission Category (% Phase-In)		
	Tier 1	LEV	ULEV
1998	80	10	10
1999	50	25	25
2000	0	50	50
2001	0	25	75
2002+	0	0	100

Due to significant manufacturing alterations that would be required in the earlier years of the implementation in the SIP, however, the automobile manufacturers asked staff to consider proposing an alternative phase-in for medium-duty vehicles that is designed to achieve equivalent emission reductions while minimizing the disruption to manufacturers' already established designs. Table IV-2 contains the revised SIP phase-in being proposed in this rulemaking. While the original SIP proposal calls for 100 % ULEVs in 2002, staff has estimated that the revised proposal would meet the NOx reductions and come close to meeting the ROG goal originally expected from this category. A complete analysis of the effect of this proposal on the expected emission reductions is set forth below in Section IV-D.

Table IV-2
Alternative SIP Proposal

Model Year	Chassis-Certified Phase-In (%)			Engine-Certified Phase-in (%)		
	Tier 1	LEV	ULEV	Tier 1	LEV	ULEV
1998	73	25	2	100	0	0
1999	48	50	2	100	0	0
2000	23	75	2	100	0	0
2001	0	80	20	100	0	0
2002	0	70	30	0	100	0
2003	0	60	40	0	100	0
2004 +	0	60	40	0	0	100

C. Emission Standards

In addition to the proposed modification to the phase-in requirements, staff is proposing changes to the actual emission standards. The following two tables (IV-3 and IV-4) contain the proposed emission standards (underlined) for chassis-certified vehicles and engine-dynamometer certified vehicles.

Chassis-certified Vehicles. For chassis-certified vehicles, staff is proposing to reduce both the 50,000 mile and 120,000 mile LEV NOx standard to ULEV levels beginning in 1998. This will help achieve the NOx emission reductions targeted in the SIP without requiring 100% ULEVs in 2002. In addition, staff is proposing a slight increase in the 120,000 mile ULEV NOx standard as requested by manufacturers because medium-duty vehicles experience more rigorous operating conditions (e.g., operating with a heavy cargo load) and therefore could experience greater emission deterioration than light-duty vehicles upon which the original values were derived. Staff is also proposing an increase in the ULEV CO and PM_{10} standards to LEV levels in order to allow manufacturers more flexibility in developing NOx emission control strategies. This increase is not expected to affect CO or PM_{10} attainment (see section IV-G for a discussion of the environmental impact of this proposal).

Pursuant to a request from the automobile manufacturers, staff is proposing an extension of the intermediate in-use standards which would give the manufacturers an extra margin for in-use compliance during the initial introductory period for LEVs and ULEVs that would ensure durable LEV and ULEV designs. While manufacturers will still need to demonstrate compliance with the actual emission standard at the time of certification, the slightly more lenient intermediate in-use standards will provide them with an extra cushion should they exceed the actual standards in-use by a small margin during the first few years of production. The current intermediate in-use LEV and ULEV standards sunset in 1999 and only include in-use liability to 50,000 miles. However, because the LEV NOx standard has been lowered to the ULEV level beginning in 1998, and because manufacturers will not be producing significant numbers of ULEVs until the 2001 model year, staff is proposing an extension of the intermediate in-use NMOG and NOx standards. Staff is also proposing the incorporation of 120,000 mile intermediate in-use standards because of the extended time with which manufacturers now have to comply. The numbers in parentheses for NMOG standards would apply to LEVs through the 1999 model year and to ULEVs through the 2002 model year. The intermediate in-use NOx standards would apply to LEVs and ULEVs through the 2000 model year.

TABLE IV-3
PROPOSED EXHAUST EMISSION STANDARDS FOR MEDIUM-DUTY CHASSIS-CERTIFIED VEHICLES
("g/mi")

Test Weight (lbs)	Durability Vehicle Basis (mi)	Vehicle Emission Category	NMOG	CO	NOx	PM
3751-5750	50,000	LEV	0.160 (.238)	4.4	0.4 (0.6)	n/a
		ULEV	0.100 (.128)	4.4	0.4 (0.6)	n/a
		SLEV	0.050	2.2	0.2	n/a
	120,000	LEV	0.230	6.4	0.6 (0.8)	0.10
		ULEV	0.143 (.160)	6.4	0.6 (0.8)	0.05
		SLEV	0.072	3.2	0.3	0.05
5751-8500	50,000	LEV	0.195 (.293)	5.0	0.6 (0.9)	n/a
		ULEV	0.117 (.156)	5.0	0.6 (0.9)	n/a
		SLEV	0.059	2.5	0.3	n/a
	120,000	LEV	0.280	7.3	0.9 (1.2)	0.12
		ULEV	0.167 (.195)	7.3	0.9 (1.2)	0.06
		SLEV	0.084	3.7	0.45	0.06
8501-10000	50,000	LEV	0.230 (.345)	5.5	0.7 (1.0)	n/a
		ULEV	0.138 (.184)	5.5	0.7 (1.0)	n/a
		SLEV	0.069	2.8	0.35	n/a
	120,000	LEV	0.330	8.1	1.0 (1.3)	0.12
		ULEV	0.197 (.230)	8.1	1.0 (1.3)	0.06
		SLEV	0.100	4.1	0.5	0.06
10,001-14000	50,000	LEV	0.300 (.450)	7.0	1.0 (1.5)	n/a
		ULEV	0.180 (.240)	7.0	1.0 (1.5)	n/a
		SLEV	0.09	3.5	0.5	n/a
	120,000	LEV	0.430	10.3	1.5 (2.0)	0.12
		ULEV	0.257 (.300)	10.3	1.5 (2.0)	0.06
		SLEV	0.130	5.2	0.7	0.06

In response to a request from the natural gas industry, a new category is being established, "Super Low Emission Vehicle" or "SLEV." This category is not required, but can be used to offset deficits created by the harder to control engine families because it receives extra NMOG credit equal to 1.7 times a LEV. This multiplier is based on the percent reduction from the LEV NMOG standard (e.g., a SLEV is 70% lower than a LEV; therefore the multiplier is 1.7). It is anticipated that primarily alternative fuel vehicles will be able to achieve these levels, which are 50% below the ULEV standards.

Engine-Dynamometer-Certified Vehicles. For engine-dynamometer certified vehicles, staff is proposing that the LEV ROG + NOx standard be decreased to 3.0 g/bhp-hr beginning in 2002 and that the ULEV CO, formaldehyde and particulate standards be increased to LEV levels. When the ULEV standards were originally proposed, the consensus was that only alternative fuel vehicles would be capable of certifying as a ULEV. While the latest technology analysis indicates that diesel vehicles will be capable of meeting this level, this assessment relies on the need to amend the particulate standard in order to provide manufacturers more surety in meeting the NOx standards. Finally, medium-duty vehicles certified to the engine-dynamometer standards will be allowed to certify to the Tier 1 standards through 2001 (one model year later than is allowed for the chassis-certified vehicles) to avoid emission requirements that are applicable for only one year.

Staff is also proposing new NOx standards for engine-dynamometer certified vehicles beginning in 2004 that would align with regulations that are currently being considered at the federal level. In July, 1995, the U.S. EPA, along with engine manufacturers and the ARB, issued a Statement of Principles outlining the proposed NOx standards. Specifically, the U.S. EPA is proposing both a combined NMHC + NOx standard of 2.4 g/bhp-hr and a combined NMHC + NOx standard of 2.5 g/bhp-hr with a NMHC cap of 0.5 g/bhp-hr. These standards are expected to result in emissions comparable to a 2.0 g/bhp-hr NOx standard. Because the final federal rule will not be available until next year, however, staff is proposing a 0.5 g/bhp-hr NMHC standard and a 2.0 g/bhp-hr NOx standard at this time. The ARB will consider adoption of the anticipated federal requirements for medium-duty vehicles within one year after adoption by the U.S. EPA. Table IV-4 sets forth the proposed standards.

TABLE IV-4
Medium-Duty Engine-Certified Emission Standards
(g/bhp-hr)

Model Year	Vehicle Emissions Category	Carbon Monoxide	Non-Methane Hydrocarbons and Oxides of Nitrogen	Formaldehyde	Particulates
1992 ~~and subsequent~~ - 2001	LEV	14.4	3.5	0.050	0.10
2002-2003	LEV	14.4	3.0	0.050	0.10
1992-2003	ULEV	~~7.2~~ 14.4	2.5	0.025	~~0.05~~ 0.10
1996 and subsequent	SLEV	7.2	2.0	0.025	0.05
2004 and subsequent	ULEV	14.4	NMHC 0.5 NOx 2.0	0.050	0.10

D. Inventory Analysis of Enhanced MDV Proposal

In order to determine the estimated emission reductions attributable to staff's proposal, it was necessary to analyze its effect on the emission inventory. However, the ARB's emission inventory is currently in the process of being revised with respect to the contribution of medium-duty vehicles. In order to develop the current proposal, staff needed to make several changes to the assumptions used in the emission inventory so that it would more accurately reflect the MDV fleet. To do this, staff prepared its own inventory model. This model, along with the corresponding assumptions, was developed in cooperation with experts representing industry in order to achieve consensus in the methodology. The following describes staff's inventory model, the corresponding assumptions made concerning the medium-duty vehicle fleet, and the estimated emission reductions attributable to staff's revised strategy for achieving the medium-duty vehicle (MDV) emission reductions required by the SIP in 2010.

1. SIP Proposal

The SIP proposal, adopted by the Board in November, 1994, called for the accelerated introduction of medium-duty ULEVs (100% in 2002) compared to the original LEV program requirements. Based on the inventory model available during the development of the SIP proposal ("SIP inventory model"), the goal of the SIP was to reduce the medium-duty vehicle emission inventory by 4 tons per day (tpd) for reactive organic gases (ROG) and 32 tpd for NOx in the South Coast Air Basin.[6] As mentioned above, these estimates were based on an inventory which characterizes the medium-duty fleet in very general terms. The emission inventory considered parameters such as number of registered vehicles on the road, number of vehicle miles traveled per day, and emission rates of the vehicles to estimate the emissions for a given area. Staff's more current inventory model ("revised SIP inventory model") includes several adjustments to the assumptions concerning the emission rates of medium-duty vehicles. The result is that the NOx reductions achieved from implementing the original SIP proposal are overestimated. Based on staff's more recent analysis, the actual NOx emission reductions achieved by the adopted SIP proposal are actually 23.5 tons per day. The adjustments are discussed below.

Reduction from Tier 1 Standards. The SIP inventory model assumed that the actual emission tonnage reductions are proportional to the percent reduction of the more stringent emission standard compared to 1995 (Tier 1) standards. For example, if the percent reduction of an emission standard is 50% (e.g., from Tier 1 to ULEV levels), the same percent emission tonnage reductions would be expected in the emission inventory.

The SIP inventory model assumed that the NOx reduction from Tier 1 to ULEV would be 50% for chassis-certified vehicles and also for engines certified to the engine-dynamometer

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[6] The SIP is designed to obtain benefits statewide, but the targeted final level of control is based primarily on the emission reductions needed for the South Coast Air Basin because of the severity of the problem in that air basin.

standards. For chassis-certified vehicles, however, the more accurate percent NOx reduction from Tier 1 to ULEV is 45%. For diesel engines, the more accurate percent reduction is 36% for NOx and 40% for ROG and for incomplete gasoline vehicles, it is 36% for NOx and 34% for ROG. The result is that the SIP inventory model overestimated the amount of ROG and NOx emission reductions.

Characterization of Engine-Dynamometer Certified Category. The SIP inventory model assumed that engine-dynamometer certified vehicles are certified to separate ROG and NOx standards and therefore assumed that if the chassis-certified NMOG standard were reduced by 50%, this same percentage would be applied to engine-dynamometer certified vehicles. However, engine-dynamometer certified vehicles must certify to a combined ROG + NOx standard. Based on 1995 certification data, staff has determined that the more accurate relative percent contribution to ROG + NOx for diesel engines is 5% ROG/ 95% NOx and for incomplete gasoline engines it is 15% ROG/ 85% NOx.

This adjustment reduces the NOx emission benefit in the revised SIP inventory model because the emission standards for ULEV engine-certified diesels and incomplete gasoline vehicles (8,500-14,000 lbs.) are not proportionally as stringent as those for chassis-certified vehicles when compared to 1995 (Tier 1) standards. For example, the NOx percent reduction for chassis-certified vehicles is 45%, while the NOx reduction for diesel vehicles is actually 36%. In addition, this benefit is further lessened because emissions from engine-certified vehicles comprise approximately 53% of the total NOx emissions from the medium-duty vehicle fleet. Hence, changing the inventory to reflect that vehicles certifying to the engine standards will not be required to reduce emissions to the same extent as vehicles certifying to chassis standards reduces the originally assumed benefits of the SIP proposal.

Incomplete Gasoline Vehicles. Incomplete gasoline vehicles in the 8,500-14,000 GVW category make up only a small portion of the fleet (5%), however, the SIP inventory model assumed that all incomplete gasoline vehicles would certify to the engine-dynamometer standards. According to a combination of certification data and manufacturer's projected sales estimates of the engine and chassis categories, staff has estimated that approximately 72% of gasoline vehicles in this weight class will continue to be certified to the optional engine standards and the remaining 28% will be chassis-certified.

Based on these three adjustments, the 2010 emission reductions attributable to the original SIP proposal are 3.8 tpd ROG and 23.5 tpd NOx. Table IV-5 contains the original and revised emission reduction estimates. The complete revised SIP scenario with the segregated tonnage reductions is attached as Scenario 1 at the end of this staff report. (More detailed information concerning the assumptions used in these calculations is contained in Appendix E.)

Table IV-5
2010 Original and Revised SIP Proposal
Estimated Emission Reductions

ROG	NOx
4	32
3.8	23.5

2. **Staff's Proposal**

In addition to the adjustments made to the original SIP inventory model, staff has also made the following adjustments to the inventory to reflect the proposed revisions to the medium-duty low-emission vehicle phase-in requirements and emission standards.

Engine-Certified Phase-In. The SIP proposal assumed that both chassis-certified vehicles and engine-dynamometer vehicles would meet the same phase-in requirements; however, staff now believes that it is not possible for engine manufacturers to meet the increasing phase-in requirements set forth in that proposal. The contribution of engine-dynamometer certified vehicles to the total medium-duty truck inventory, however, is significant (approximately 53% of the total NOx emissions) and needs to be accurately characterized. In most cases vehicle manufacturers have only one engine family in the engine category. This precludes them from producing increasing percentages of LEVs or ULEVs because, with only one engine family, a manufacturer will most likely produce 100% or 0% of a given category in a model year. In order to more accurately account for the contribution of engine-dynamometer vehicles to the inventory, staff has made the following calculation adjustments to the phase-in percentages:

Model Year	Chassis-Certified Phase-In (%)			Engine-Certified Phase-in (%)		
	Tier 1	LEV	ULEV	Tier 1	LEV[7]	ULEV
1998	73	25	2	100	0	0
1999	48	50	2	100	0	0
2000	23	75	2	100	0	0
2001	0	80	20	100	0	0
2002	0	70	30	0	100	0
2003	0	60	40	0	100	0
2004 +	0	60	40	0	0	100

It is important to note that while this table shows separate phase-in percentages for chassis-certified vehicles and engine-dynamometer certified vehicles, the existing regulation does not segregate these categories.[8]

Federal NOx Standard. The current medium-duty ULEV standard is 2.5 g/bhp-hr ROG + NOx for engine-dynamometer certified vehicles. Since the federal NOx standard being considered will apply to all engine-dynamometer certified categories, staff is proposing that the medium-duty ROG+NOx standard be aligned with the federal standards in 2004. Staff's current proposal includes a proposed separate 2.0 g/bhp-hr NOx standard and 0.5 g/bhp-hr NMHC standard (the heavy-duty standard is in terms of hydrocarbons instead of the more inclusive ROG) beginning in 2004 (signified as 100% ULEVs for the engine-dynamometer certified category), since federally-certified engines in this category are expected to meet these standards. While neither EMA nor the American Automobile Manufacturer's Association (AAMA) included this federal standard in their proposals because it has not yet been adopted by the U.S. EPA,[9] it would not be possible to

7 Beginning in 2002, the LEV standard will be reduced to 3.0 grams per brake horsepower-hour from 3.5 grams per brake horsepower-hour.

8 Under the current regulation (for example in 1998) a manufacturer need only produce LEVs equal to 25% of its entire fleet rather than 25% chassis-certified LEVs and 25% engine LEVs.

9 While EMA believes that the federal standard will probably be 2.0 grams per brake horsepower-hour in 2004, they oppose ARB adoption of this standard at this time. They prefer language that the ARB intends to adopt that standard concurrent with the federal government. They do not object to that number being used in the inventory for modeling purposes.

achieve the emission reduction goals of the SIP without making this a specific requirement.[10] Therefore, staff's proposal includes a 2.0 g/bhp-hr NOx standard and a 0.5 g/bhp-hr NMHC standard in 2004.

Contribution of ROG to ROG+NOx Standard. Finally, staff has reanalyzed the contribution of ROG emissions expected from a combined 2.5 g/bhp-hr ROG + NOx standard where 2.0 g/bhp-hr is the NOx standard. Current certification data indicate that diesels which meet a 2.0 g/bhp-hr NOx standard will have estimated ROG emissions of 0.11 g/bhp-hr while gasoline engines which meet a 2.0 g/bhp-hr NOx standard will have estimated ROG emissions of 0.35 g/bhp-hr. The effect of this adjustment is reflected in the revised emission reduction estimate.

The emission reductions attributable to the staff's current proposal are set forth in Table IV-6. The complete scenario is attached as Scenario 2 at the end of this staff report. This proposal, then, exceeds the revised NOx emission reductions calculated from the SIP. However, it also falls short of the estimated 32 tpd NOx reduction goal. (More detailed information concerning the assumptions used in these calculations is contained in Appendix E.)

Table IV-6
ARB/AAMA/EMA Proposal

	ROG	**NOx**
SIP	3.8	23.5
Staff Proposal	2.0	23.9

While the staff proposal achieves much of the expected ROG emission inventory reduction, technological uncertainty precluded the staff from proposing a more aggressive phase-in of advanced ROG specific technology at this time. The staff needs additional time to assess emerging technologies such as gas burner catalyst systems and hydrocarbon traps in terms of cost-effectiveness and reliability in achieving additional ROG reductions for the chassis-certified vehicles. Accordingly, staff plans to revisit this proposal in 1998 when additional development and evaluation of new ROG control technologies will be available and to propose any appropriate revisions.

E. Technological Feasibility

Although most of the engines in medium-duty vehicles are derived from gasoline passenger car applications, the increased weight and load capacity of these vehicles requires some alteration of the engine and emission control system design. These are necessary even though the

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[10] The counterproposal submitted by EMA (3.0 g/bhp-hr NOx in 2002 and 2.0 g/bhp-hr NOx in 2006) falls short of the SIP goal by approximately 2 tpd.

emission requirements for medium-duty vehicles have been adjusted upward relative to light-duty vehicles, largely because these vehicles can experience more severe operating conditions than passenger cars. Unlike light-duty vehicles, the medium-duty category also includes a significant number of diesel engines. Further, this category will likely include a higher proportion of alternative fuel vehicles since these vehicles more easily accommodate heavy, bulky fuel storage systems and are more likely to be used in fleet service.

Further complicating an analysis of the technological feasibility of emission requirements for medium-duty vehicles is the availability of an engine dynamometer certification process as an option to the chassis dynamometer certification process. The engine dynamometer option is limited, however, to incomplete gasoline vehicles (i.e., vehicles sold unfinished by the original manufacturer in order to allow for special applications such as motor home installations, large cargo boxes, etc., by secondary manufacturers.) and diesel engines.

The ARB staff has recently performed emission testing of some medium-duty vehicles in order to assess the capability of current technology. The following summary provides a discussion of numerous options to improve current emission performance, with special emphasis on the need for these control systems to remain durable throughout the vehicle life since these vehicles may operate on a more severe duty cycle than light-duty vehicles.

1. Chassis Certified - Gasoline Vehicle Technology

The ARB staff has been conducting a test program to assess the exhaust reactivity of current medium-duty vehicles for the purpose of determining RAFs. (See Part III of this staff report for a discussion of RAFs). Emission results from two 1994 Ford F150 trucks equipped with the 5.0 liter engine indicate capability of achieving ULEV emission levels at low to moderate mileage. The emission results of this vehicle model actually are well below the ULEV emission standards, especially for NMOG and CO. Emission results of similar 1993 Ford F150 models did not attain ULEV levels, but they did meet LEV levels. The probable reason for the better performance of the 1994 F150 compared to the 1993 version is incorporation of sequential multi-port fuel injection on the 1994 trucks since these trucks are otherwise apparently identical. The emission values of the Ford F150 trucks are shown below along with the applicable emission standards.

Table IV-7 - Emission Test Results of Ford F150 Trucks

Vehicle	Emission Controls	NMOG (g/mi)	CO (g/mi)	NOx (g/mi)
1993 Ford F150 - 5.0L 23,000 miles	TWC, ox. cat., secondary air inj., heated O2 sensor, EGR, multiport fuel inj.	0.088	0.798	0.630
1993 Ford F150 - 5.0L 27,400 miles	same as above	0.148	3.594	0.673
1994 Ford F150 - 5.0L 5,500 miles	TWC, ox. cat., secondary air inj., heated O2 sensor, EGR, sequential multiport fuel inj.	0.041	0.630	0.362
1994 Ford F150 -5.0L 10,500 miles	same as above	0.046	0.501	0.321
1994 Ford F150 - 5.0L 21,000 miles	same as above	0.055	0.591	0.366
LEV standard*		0.160	4.4	0.7
ULEV standard*		0.100	2.2	0.4

* Emission standards for medium-duty vehicles with test weight between 3751 and 5750 lbs.

Since all of the test vehicles had accumulated fairly low mileage in our initial tests, the staff recognizes the deteriorated emission levels will likely be higher than these results. Ford presented emission data from high mileage delivery vehicles equipped with an engine similar to the Ford F150's. Their data indicate that at higher mileages, deterioration can cause emissions to substantially exceed the ULEV standards before the applicable mileage requirements (i.e., 50,000 miles and 120,000 miles). While it is acknowledged that further development work could be needed on the Ford F150 to ensure low in-use emissions, staff estimates that the level of technology on this vehicle approximates the type of emission controls needed to achieve low-emission levels for the lighter vehicles of the medium-vehicle category, i.e., less than 8,500 pounds gross vehicle weight rating (GVW). By incorporating even further improved fuel controls such as those already used on several light-duty vehicles, e.g., dual oxygen sensor compensation systems, adaptive transient fuel control, air-assisted fuel injectors, and improving the durability and light-off characteristics of the catalyst system, in-use emission performance at high mileage should be enhanced.

For one of the ARB's 1994 F150 trucks, thermocouples were added to the catalyst to monitor peak catalyst temperatures during extreme driving conditions. In perhaps the most severe test, the truck was driven over the "grapevine" pass in Southern California with the truck pulling a 2000 lb. trailer and the truck bed filled with 1200 pounds of ballast (this is a 6 percent, 3 mile long grade). Despite the extreme conditions, catalyst temperatures remained below 800°C (with brief excursions to 900^0C), which suggests that newer palladium catalysts should easily withstand the most severe conditions without significant deterioration. In order to further evaluate the emissions durability of this vehicle, ARB staff also drove this truck over 2000 miles while loaded with 1400 pounds of payload in the bed and pulling a 3450 pound trailer. The truck was driven through various driving conditions and FTP tests were conducted as the miles accumulated to evaluate any emissions degradation which may occur. Although emission levels initially increased as the mileage accumulated, they eventually leveled off and have been decreasing to levels equivalent to those at the beginning of testing. The results of these tests seem to indicate that emission deterioration on this later model truck may not be as substantial as earlier projected. The results of the tests are shown in the Table below:

Emission Tests of 1994 Ford F150 XLT Pick-Up
(1400 lb. of payload and pulling a 3450 lb. trailer)

Date	Test	Mileage	NMHC (g/mi)	CO (g/mi)	NOx (g/mi)
5/18/95	10C30	26,884	0.074	0.583	0.441
5/19/95	10C31	26,907	0.108	0.916	0.400
5/23/95	10C32	26,927	0.090	1.135	0.404
5/24/95	10C33	26,962	0.098	0.980	0.406
6/23/95	10C34	28,982	0.079	1.098	0.480
6/28/95	10C35	29,090	0.069	0.638	0.466
6/29/95	10C36	29,102	0.081	0.742	0.403
6/30/95	10C37	29,113	0.085	0.700	0.382
7/7/95	10C38	29.160	0.068	1.006	0.369

a. Strategies to Reduce Emission Levels and Deterioration

Engine Improvements. One method manufacturers may use to improve emission performance is to reduce engine-out emission levels (i.e., prior to aftertreatment by the catalytic converter system). Engine-out emissions can be reduced through several techniques such as reducing crevice volumes around the pistons and improving fuel control and delivery.

Reduced Crevice Volumes. By reducing crevice volumes, unburned fuel trapped inside the area surrounding the piston above the top ring would be diminished, thereby decreasing hydrocarbon (HC) emissions. To reduce crevice volumes, vehicle manufacturers are redesigning engines to include pistons with reduced top "land" heights (the distance between the top of the piston and the first ring). Although reducing the top land height could reduce durability of the piston, especially for medium-duty vehicles with demanding duty cycles, it is projected that improved design and materials will allow moving the ring higher on the piston.

Improved Fuel Control. Improved fuel control can be achieved by incorporating some of the advanced technologies which are already being introduced on passenger cars such as dual oxygen sensor compensation systems, adaptive transient fuel controls, and air-assisted fuel injectors (1, 2). Since three-way catalytic converters operate most effectively at converting hydrocarbons, carbon monoxide, and oxides of nitrogen at a stoichiometric air/fuel ratio (where the amount of air is just sufficient to completely burn all of the fuel), precise fuel control is important in achieving maximum pollutant conversion efficiency (Figure 1).

a. **Dual Oxygen Sensor Compensation Systems**. Although the conventional (single oxygen sensor) fuel control systems which are installed on the majority of medium-duty gasoline vehicles (including the F15O trucks discussed previously) are capable of maintaining precise fuel control when new, they tend to deteriorate as they age. To maintain precise fuel control as a vehicle ages, dual oxygen sensor compensation systems can be used. These systems utilize the signal from a second oxygen sensor to compare with the primary oxygen sensor. The second oxygen sensor operates in a lower temperature environment and is less subject to poisons, so that it should operate reliably throughout the life of the vehicle. Should the primary oxygen sensor begin to exhibit slow response or drift in its calibration, the second oxygen sensor can be used to modify fuel control to correct for these effects. In this way, dual oxygen sensor compensation systems would allow medium-duty vehicles to maintain more accurate, precise fuel control as they age.

b. **Adaptive Fuel Controls**. Current vehicles incorporate an adaptive fuel control system which automatically adjusts for component wear, changing environmental conditions, varying fuel composition, etc. to more closely maintain a proper air-fuel ratio under some driving conditions. For most fuel control systems today, this adaptation process affects only steady-state operating conditions (i.e., constant or slowly changing throttle conditions). In the future, these systems are expected to be further improved to include adaptation during transient driving conditions (i.e., more rapid throttle changes). Medium-duty vehicles are projected to utilize this advanced fuel control in order to maintain low-emissions for more driving conditions.

c. **Air-assisted Fuel Injectors**. In order to encourage more complete burning and the attendant emission reductions of an improved air-fuel mixture, medium-duty vehicles can utilize air-assisted fuel injectors (1). By mixing air with the fuel as it is being injected into the combustion chamber, better fuel atomization, more efficient combustion and reduced emissions can be achieved. Because of its benefits, air-assisted injectors are increasingly being introduced on more passenger vehicle applications each year.

Improved Catalyst Systems. Another very important method vehicle manufacturers may utilize to help achieve and maintain low emissions is improving the catalyst system. The catalytic converter is the primary emission control component on vehicles today. It has the capability to convert more than 90% of the exhaust pollutants to harmless substances. However, the converter has little pollutant conversion capability until it reaches operating temperature. By locating a catalyst closer to the engine, the heat lost before the catalyst can be minimized, thereby allowing the catalyst to reach operating temperature more quickly. There are, however, concerns about the deterioration effects of higher catalyst temperatures which can result from moving the catalytic converter closer to the engine.

Although higher catalyst temperatures during vehicle warm-up are beneficial to pollutant conversion efficiency, catalyst temperatures that are otherwise too high can quickly degrade a catalyst. Catalysts are most susceptible to thermal degradation during sustained high speed or high load driving when exhaust temperatures are at their highest. Therefore, moving the catalytic converter closer to the engine, while reducing light-off times (i.e., the time it takes the catalyst to reach operating temperature) could also prematurely degrade the catalyst if exhaust temperatures are not controlled. However, due to several recent developments in catalytic converter design, manufacturers now have several options to prevent thermal deterioration while improving catalyst light-off.

Palladium high temperature catalysts. Three-way catalytic converters traditionally utilize primarily rhodium and platinum to control the emissions of all three major pollutants (HC, CO and NOx). Although this type of catalyst is very effective at converting exhaust pollutants, rhodium, which is primarily used to convert NOx, tends to thermally deteriorate at temperatures significantly lower than platinum. Recent advances in palladium-only and tri-metal (i.e., Pd-Pt-Rh) three-way catalyst technology, however, have improved both the light-off performance and high temperature durability of previous catalysts (4, 5, 6, 7).

Palladium-only and tri-metal catalysts have several advantages over platinum-rhodium three-way catalysts. First, palladium-only and tri-metal catalysts operate effectively at lower temperatures than rhodium catalysts (they have a conversion efficiency of 90% at temperatures 70°F lower than conventional catalysts according to one manufacturer). Second, palladium-only and tri-metal catalysts can tolerate temperatures up to 100°F higher than conventional three-way catalysts before thermal degradation would occur. Also, palladium is significantly less expensive than either rhodium or platinum, although specification of advanced high technology washcoats which improve catalyst performance and durability tend to restore overall catalyst costs to previous levels.

With the improvements in light-off capability, catalysts may not need to be placed as close to the engine as previously thought. However, if placement closer to the engine is still required for better emission performance, these improved catalysts would be more capable of surviving the higher temperature environment without deteriorating.

Electrically-heated Catalysts (EHCs). Instead of placing catalysts closer to the engine for improved pollutant conversion performance, manufacturers could utilize electrically-heated catalysts to provide the heat energy necessary to attain catalyst light-off. Using electrical energy to heat a metallic catalyst substrate has been proven in many studies to be an effective method to achieve lower emissions (8, 9). At this time, electrically-heated catalysts are considered to be a key technology which will allow the larger gasoline passenger cars to meet the ULEV requirements. Since the ULEV emission control technology required for the lighter medium-duty vehicles is projected to be similar to the larger passenger cars, EHCs may also be used on these vehicles. Use of EHCs on the larger medium-duty vehicles, however, may not be as effective since energy requirements to heat larger catalyst volumes may not be practical with available on-board electrical energy.

In the early years of EHC development, there was concern that the electrical energy and power requirements needed to provide the heat energy necessary to achieve ULEV emissions would require major upgrades to a vehicle's electrical system, including alternator upgrades, a separate dedicated battery to power the EHC and other electrical improvements. Recent advancements in EHC designs, however, have substantially reduced this concern. Largely by reducing the mass of the EHC, energy and power requirements have been reduced to levels low enough so that fewer electrical improvements would be needed on most passenger car applications while still achieving low-emission levels (8, 10). More recently, substantial upgrades have been made to the electrical connectors of the EHC itself (see Figure 2). The ARB has received indication from one vehicle manufacturer that for a potential light-duty truck application, EHCs are meeting their durability goals for the substrate structure, although further electrical connector evaluation is ongoing. While these systems could also be used in the lighter medium-duty vehicle classes, the larger vehicles may require additional electrical energy capacity and power (which may exceed a vehicle's conventional electrical system) to achieve low-emission levels. This additional electrical power and energy might be provided with some of the electrical upgrades described previously or possibly through the use of ultracapacitors (11).

With these improvements and continued development, EHCs are projected to be a viable technology at least for the lighter gasoline vehicles in the medium-duty vehicle class (less than 8,500 lbs.) within the timeframe of the proposed standards.

By-pass Catalysts. Some vehicle manufacturers are investigating the use of by-pass catalyst systems to reduce exposure to high exhaust temperatures. A bypass catalyst consists of a relatively small catalytic converter located close to the engine which operates only during cold-start conditions, and is bypassed at all other times. Because of its relatively small size and location, the bypass catalyst reaches operating temperature rapidly. Since it is bypassed during normal operating conditions, it would avoid the high temperature environment which can deteriorate the catalyst. Utilizing a bypass catalyst to avoid high exhaust temperatures is not a new concept. General Motors developed a bypass catalyst system during the early 1970s. GM's bypass system was intended to be used to meet the emission standards of that period, however, the standards eventually could be met without the system. Thus, it was never used in production.

The main technical concern with the bypass catalyst system is the reliability of the bypass valve. If the valve fails in the open position or if there is leakage past the valve, the bypass catalyst would be subjected to high temperatures which can decrease its life. In contrast, if the valve does not open properly, the quick light-off capability of the bypass catalyst would not be realized causing emissions to increase. Although monitoring the valve with an on-board diagnostic system would detect malfunctions, manufacturers are hesitant to use bypass systems unless reliability is proven.

Other concerns with the bypass system include the large amount of space required and the cost of the system. Since the bypass system requires an additional catalyst and associated piping be combined into a conventional catalyst system, adequate space under the vehicle or within the engine bay may be difficult to find. Also, some manufacturers have expressed concern regarding the complexity and cost of a durable by-pass valve. However, even with these concerns, at least one vehicle manufacturer continues to consider the bypass system a viable technology for their vehicle applications.

Fuel Burner or Exhaust Gas Ignition Systems. Instead of utilizing exhaust heat or electrical energy to warm the catalyst system, some manufacturers are developing systems which utilize the heat energy from fuel burning. Depending on the method of fuel delivery to the fuel burning device, these systems are called either fuel burner or exhaust gas ignition systems (12).

Fuel burners heat the catalyst using fuel delivered from the vehicle's fuel system. During cold-start situations, fuel and air are delivered directly to a burner which is located just before the light-off catalyst. An ignition device is then used to burn the fuel mixture to provide the heat energy needed to light-off the adjacent catalyst. Because fuel burners are capable of providing a large amount of heat energy quickly, the catalyst reaches operating temperature very quickly, thereby reducing cold-start emissions. Although the heat required for achieving ULEV emission performance can be attained by fuel burners, manufacturers have expressed concern regarding the complexity, durability, and cost of this system. With continuing development of the fuel burner system, the strengths of the system may outweigh the negatives.

As an alternative to the fuel burner system, manufacturers could instead incorporate exhaust gas ignition systems. Similar to the fuel burner, this system provides heat to light-off the catalyst quickly by burning fuel upstream of the catalyst. Unlike the fuel burner, however, the fuel is provided through a rich exhaust gas mixture from the engine. A rich air-fuel mixture is needed in the engine to provide sufficiently high concentrations of CO and hydrogen in the vicinity of the spark plug for igniting the mixture upstream of the catalyst to be heated. Since this method eliminates the need for a fuel injection system and burner assembly, complexity is reduced. However, like the fuel burner, a malfunction in the system could cause emissions to increase substantially. Also, there are concerns regarding the adverse effects of providing a very rich combustion mixture to the engine, e.g., dilution of the lubrication oil with unburned fuel.

Long-term Strategies. While the aftertreatment strategies discussed in the previous section have been under development for automotive use for several years, the following technologies are either fairly new or are considered to be longer-term solutions for reducing exhaust emissions on medium-duty vehicles (but still potentially applicable in the required timeframe for production). These strategies include the metal hydride cold start heater system and the lean NOx catalyst.

Metal Hydride Cold Start Heater Systems. Currently under development is a new technology which could provide enough engine starting heat energy to allow catalysts to reach operating temperatures within about 5 seconds without electrical power or the exothermic heat generated from burning fuel. Instead, heat would be generated through the exothermic reaction that occurs when hydrogen gas comes in contact with a metal alloy to form a metal hydride contained in a "heater" apparatus situated in front of the catalyst. This promising technology,which is being developed by Ergenics Inc., is called a metal hydride cold start heater. With the metal hydride heater system, Ergenics claims that temperatures of over 600^{o}C in several seconds can be achieved (36). While the amount of heat generated by this system is impressive, the heat generation process is also reversible. By applying heat to the "heater" metal hydride, e.g., from the engine exhaust, the hydrogen gas can be released through a one-way valve and returned to a "storage" apparatus (also a metal hydride). Once the hydrogen is placed back into the storage apparatus, it is then available for the next cold-start cycle (Figure 3).

Lean NOx Catalysts. For several years, vehicle manufacturers and their suppliers have been developing a catalytic converter which would be capable of reducing NOx emission under lean air-fuel ratio conditions. To achieve both low engine-out emissions and the highest possible fuel economy, engines would operate at the leanest practical air-fuel ratio. While both HC and CO conversion efficiencies at the three-way catalytic converter are high at lean air-fuel ratios, NOx conversion tends to be very poor due to the excess oxygen in the exhaust. Recent developments by Mazda and Toyota, however, seem to signal progress in this technology (13, 14).

According to an automotive industry paper from Mazda, a catalyst has been developed which is capable of achieving and maintaining high NOx conversion efficiency while under lean operating conditions. Their "lean NOx catalyst" system has been mass produced and is available in Japan on the Mazda 323 lean burn vehicle. Test results of this catalyst indicate NOx conversion of about 50% are achievable (on Japanese 10-15 mode emission tests) (13). Toyota has also developed a lean-NOx catalyst. Their catalyst oxidizes NOx under predominantly lean operating conditions and stores the resulting nitrate, which is later reduced by HC and CO during periods of stoichiometric air/fuel ratios. Test results of their catalyst indicated NOx conversion of over 80% NOx on a fresh catalyst with 60% conversion on a 100,000 km-equivalent catalyst (14).

Although lean burn gasoline engines are unlikely to be produced for medium-duty vehicle applications in the near future due to reductions in power and other concerns, the development of lean NOx catalyst technology would provide large benefits to diesel vehicles and alternative fueled-vehicles which are calibrated to operate lean. Lean NOx catalysts will be discussed further when diesel vehicle technology is presented.

2. **Engine Dynamometer Certified - Gasoline Engines**.

Weighting of Cold-Start Emissions. Unlike chassis dynamometer certified gasoline engines covered in the previous section, engines certified to the engine dynamometer test procedures do not have to achieve exceptionally low cold-start emissions. This is because the cold-start portion of the engine test procedure comprises only one-seventh of the total weighting in the overall emission calculation for the test. In contrast, the chassis test procedure weights the cold-start portion about one-quarter of the total emission weighting. Decreased emphasis is placed on cold-start emissions for vehicles certified to the engine test procedures because they are mainly used in commercial or more continuous applications which tend to have a lower ratio of cold-start driving. Since only incomplete and diesel vehicles are permitted the option of certifying according to engine test procedures, this assumption is reasonable. Due to the reduced emphasis on cold-start emissions with the engine test procedures, gasoline engines certified to this procedure will normally utilize some different emission control technologies to reduce emissions than those discussed in the previous section. Instead of focusing intently on cold-start technologies, these engines are projected to rely more on improved catalysts which have high conversion efficiencies when fully warmed-up and good resistance to thermal deterioration. Also, since controlling NOx emissions is especially difficult for heavier vehicles, these engines are likely to employ electronically-actuated exhaust gas recirculation (EGR) systems for attaining higher exhaust gas flow rates, particularly under high load operating conditions.

Improved Catalysts. Because incomplete vehicles tend to occupy the heavier weight classes of the medium-duty vehicle category (usually incomplete vehicles greater than 8,500 pounds) and are usually operated under a high load, these vehicles need catalytic converter systems which can handle high exhaust flow rates and temperatures for extended periods of time. Therefore, these vehicles will probably require increased precious metal loading and larger catalyst volumes to achieve greater emission reductions. As for the lighter weight classes of the medium-duty vehicle category (e.g. less than 8,500 pounds GVWR), palladium-only and tri-metal catalysts are projected for use in incomplete gasoline vehicles due to their resistance to high exhaust temperatures. Since cold-start emissions are less of an issue with these vehicles, the catalysts can be located further away from the engine to achieve improved protection from high temperatures.

Electronic Exhaust Gas Recirculation (EGR). One of the most effective emission controls for reducing NOx emissions is exhaust gas recirculation. Exhaust gas recirculation controls NOx emissions by reducing peak combustion temperatures in the engine. By recirculating spent exhaust gases into the intake manifold to reenter the engine, the dilution effect reduces peak combustion temperatures, and therefore, NOx emissions.

Most EGR systems in today's vehicles utilize a control valve which requires vacuum from the intake manifold to regulate the EGR flow rate. Under part-throttle situations where EGR is needed, engine vacuum is sufficient to open the valve. However, during throttle applications near or at full-throttle, engine vacuum is too low to operate the EGR valve. While EGR operation only under part-throttle driving conditions is often sufficient to control NOx for most vehicles, the heavier incomplete vehicles may require additional EGR during more frequent heavy throttle operation to reduce NOx emissions. Therefore, some vehicle manufacturers are projecting the need for electronically-actuated EGR systems on incomplete vehicles to provide sufficient EGR for NOx control under high load conditions.

3. Engine Dynamometer Certified - Diesel Engines

For diesel engines there is less concern about controlling HC and CO emissions since they are inherently well-controlled with regard to these emissions. Instead, achieving lower emissions for both NOx and particulate matter (PM) simultaneously presents the greatest challenge for diesels. This is because some of the more effective control strategies for reducing NOx emissions from the engine tend to increase PM emissions and vice-versa. Because of this NOx/PM "emission tradeoff", combinations of control technologies and strategies are often utilized to reduce both NOx and PM simultaneously. In order to achieve further reductions of these pollutants, combining of control strategies will continue to be necessary. Forecasting the combinations of technologies which will be used, however, is more difficult. This is because there is a wide variety of technologies available for reducing NOx and PM. Also, many of these technologies are still in the development stages or are evolving since engine manufacturers, independent laboratories, universities, and government laboratories continue to conduct research on a variety of engine-based and aftertreatment emission control technologies to achieve lower emission levels. Some of the technologies which have been identified by these studies for controlling NOx and PM will be presented in the following sections. In addition, some technology combinations will be discussed.

Strategies for Reducing NOx Emissions. Diesel engines operate by compression ignition which causes the air/fuel mixture to self-ignite under high temperature and pressure without the need for a spark plug or other ignition device. This combustion cycle also results in high flame temperatures. Since NOx formation is directly dependent on the flame temperature, NOx emissions increase as combustion temperatures increase. Therefore, NOx control technologies generally focus on reducing the combustion temperatures and the amount of time at which these high temperatures exist in the combustion chamber.

Turbochargers with Charge Air Cooling. On modern diesel engines, turbochargers are often added in order to increase the combustion efficiency of these engines. Turbochargers improve combustion efficiency by forcing more air into the cylinders than is possible with a naturally aspirated engine. The increased air in the cylinders allows additional fuel to be injected for improved power and efficiency. In addition to increasing power, turbocharging reduces fuel consumption and emissions of smoke and soot due to the increased pressure and excess air in the cylinder.

While the use of turbochargers can result in additional power and fuel economy, increased NOx emissions can also result. This is because turbochargers work by compressing the intake air, resulting in higher temperatures and NOx emissions. To solve this problem, charge air cooling is often used. By reducing the temperature of the intake charge, charge air cooling reduces NOx emissions and increases fuel economy (15, 16).

Charge air cooling can be accomplished with air-to-liquid or air-to-air heat exchangers. Traditionally, manufacturers used air-to-liquid heat exchangers, however, because of its more effective cooling, more manufacturers are increasingly utilizing air-to-air exchangers. Through incorporation of these more efficient heat exchangers to cool the intake charge, NOx emissions can be reduced.

Retarding Ignition. Similar to spark-ignition engines, retarding the time of ignition has a pronounced effect on reducing NOx emissions from diesel engines (15, 17, 18, 19). Because of its effect on NOx emissions and its low cost, ignition retard is one of the more common methods used for controlling NOx. On diesel engines, ignition is retarded by delaying fuel injection into the cylinder. Through this delay, flame temperatures in the combustion chamber are decreased resulting in reduced NOx formation. Unfortunately, retarding injection timing to reduce NOx emissions also tends to increase PM emissions and fuel consumption.

Fuel Injection Rate Shaping. In order to control PM emissions, engine builders have been increasing the fuel injection pressure of their engines. Although this technique can be effective at controlling PM, NOx emissions generally tend to increase with higher injection pressures (20). To offset the increase of NOx emissions with higher pressures, manufacturers can vary the fuel injection rate during injection. This technique is often called "rate shaping". In rate shaping, improvements in both NOx and particulate emissions are achieved by injecting only a small amount of fuel during the first phase of injection followed by an increased rate of injection during the later phases of injection. Varying the rate of fuel injection in this manner provides for smoother combustion, lower combustion temperature and reduced soot and NOx formation (16).

Exhaust Gas Recirculation. EGR is one of the most effective methods for reducing NOx emissions in diesel engines. By utilizing EGR, NOx emissions can be reduced under all engine load conditions (20). Researchers have observed 30% to 75% reductions in NOx emissions by utilizing EGR (20). One research organization, Ricardo Consulting Engineers, has projected that using EGR will allow diesel engines to achieve NOx emission levels of 2.0 g/bhp-hr. As explained earlier, EGR controls NOx emissions by reducing the peak combustion temperatures in the engine. Unfortunately, this reduction in temperature also can lead to an increase in PM emissions (20). Control of PM emissions attributed to EGR use, however, can be achieved through several techniques. One technique is to cool the recirculated exhaust gas. By cooling the recirculated exhaust, a larger amount of EGR can be used without increasing PM emissions (16, 21). Another technique which can offset the PM increase due to EGR is turbocharging the intake air. By increasing the amount of intake air into the cylinders, turbocharging allows additional EGR to be added without affecting PM emissions (22).

Although the potential NOx emission reductions achievable with EGR are impressive, there are concerns regarding possible reduced engine life resulting from EGR use. Since PM contained in the exhaust stream is abrasive, control strategies which remove PM from exhaust may play an important role in achieving good engine durability with EGR. One soot removal device which has been developed for use with EGR equipped engines reduces soot in the recirculated gas up to 84% (23). Other strategies which can be used to control PM will be discussed in a later section.

Lean NOx Catalysts. As mentioned earlier, effective lean NOx catalysts would be beneficial in controlling NOx for diesel vehicle applications. Unfortunately, development of lean NOx catalysts which can achieve high NOx conversion efficiencies both at high temperatures (above 400°C) and at low temperatures (below 400°C) has been difficult. At high temperatures, recent studies (24, 25) indicate that copper-zeolite catalysts are the most effective at achieving and maintaining high NOx conversion. NOx conversion of up to 60% has been reported with these catalysts (24). After 500 hours of aging, this copper zeolite catalyst was still able to achieve 25 to 40 percent NOx conversion efficiency at temperatures between 425 and 550°C (24). Although this drop in conversion efficiency is significant, it is a considerable improvement over zeolite catalyst designs as recent as 1993, which deactivated after 125 hours of aging (26). This improvement indicates that significant strides are being made by diesel catalyst manufacturers in the durability area of lean NOx catalysis.

For low temperature conversion of NOx, platinum-based catalysts can be used. These catalysts are quite active in the 200 to 300°C range for NOx reduction (up to 45%), and have fairly good durability (retaining 89% of its initial effectiveness after 650 hours of aging) (25). Since sulfates make up a portion of particulates, PM emissions can increase with these catalysts. In order to control both NOx and PM emissions without requiring lower sulfur diesel fuel, low temperature catalysts will need further improvements to reduce the production of excessive sulfates.

NOx Traps. An alternative for the reduction of NOx at low temperatures is the NOx trap. This device would be particularly useful for the control of NOx produced during idle or low speed/low load conditions where exhaust temperatures below 100°C exist (25). The NOx trap works by trapping and storing NOx at low temperatures, and releasing it at higher temperatures where it can be catalytically reduced. Since this device is still in the development stage, data is not yet available on its performance capability.

Strategies for Reducing PM Emissions. The exhaust particulate matter composition for a typical diesel engine consists of soot (or carbonaceous material), soluble organic fractions (from unburned fuel and oil), and water bound sulfates (Figure 4). These particulate matter are primarily formed through incomplete combustion of heavy hydrocarbons in the fuel and lubrication oil. In addition, sulfur contained in the fuel can contribute to particulate matter emissions. To reduce particulate emissions from diesels, several different approaches can be undertaken such as improvements to fuel injection, the engine, fuel composition, and aftertreatment.

Fuel Injection Improvements. One method which has been proven (27) to reduce particulate emissions is high fuel injection pressures (15, 17). Increased fuel injection pressure tends to decrease fuel droplet size and increase fuel vaporization rates, thereby increasing the burning rate of the mixture and reducing PM and smoke emissions (16). There is, however, a limit to how much injection pressures can be increased before NOx emissions increase. Therefore, in order to reduce PM emissions yet maintain NOx levels, use of increased fuel injection pressures may need to be combined with NOx reducing strategies such as ignition retard. In addition to increasing injection pressure, other fuel injection improvements which have been identified as affecting PM emissions include varying the fuel injection rate, eliminating fuel dribble at the end of injection, optimizing injection spray angle to control fuel adhering to the cylinder walls, and others, (21).

Combustion Chamber Improvements. Since soot is the largest component of PM emissions, reducing soot emissions by encouraging complete combustion can significantly reduce PM emissions. Methods which can be used to control PM emissions include advancing ignition timing, increasing the compression ratio, varying air-fuel mixing according to engine speed/load, and increasing the amount of air inducted into the combustion chamber (e.g. turbocharging) (2, 15, 17, 28). Many of these modifications, however, can increase NOx emissions if not carefully implemented. Also, since particulate matter emissions have been shown to correlate well with lubrication oil consumption, strategies which reduce oil consumption such as improved valve stem seals, turbocharger seals, piston rings, and other oil control techniques will play an important role in reducing PM emissions.

Particulate Traps. In addition to reducing particulate emissions from the engine, vehicle and engine manufacturers can also apply emission control strategies which treat the particulates exiting the engine. These aftertreatment systems include particulate traps and oxidation catalysts.

Although particulate traps have been demonstrated to be up to 90 percent effective at controlling these emissions, early designs of traps have proven to be unreliable, complex, and fairly costly. Particulate trap systems utilize a substrate positioned in the engine exhaust stream to trap particulates. Once trapped, the accumulated particulates are then removed through burning. This process, which is often called "regeneration," is the most challenging aspect in the development of effective and reliable particulate trap systems. This is because the temperature at which particulates normally oxidize (400-600^{o}C) is higher than the exhaust temperatures under many operating conditions (21, 29). Also, oxidation of the trapped particulates can create very high temperatures which can damage the substrate. Therefore initiating and controlling the regeneration process to ensure reliable regeneration without damage to the trap is the central development concern of these devices. As a result of this concern, industry and research institutions are conducting development and research on more reliable regeneration methods. Some of the regeneration methods being investigated include reverse pulse air, catalytic systems, and utilizing fuel additives (29, 30, 31). If this research results in a simple, relatively inexpensive, effective, and durable trap system, particulate traps may be among the technologies used for meeting lower PM emissions.

Oxidation Catalytic Converters. Another aftertreatment device which could be applied to diesel vehicles to reduce particulate emissions is the oxidation catalytic converter (or oxidation catalyst). This device utilizes a substrate similar to that of catalysts for Otto-cycle engines. Unlike a particulate trap, an oxidation catalyst does not trap any of the solid particulate matter. Instead, these devices rely on catalysts added to the substrate to reduce the temperature of oxidation or burning of the soluble organic fraction (SOF) portion of particulate matter. Besides reducing SOFs, the oxidation catalyst also oxidizes gaseous HC and CO emissions. Engine tests have shown that oxidation catalysts typically remove 50 to 80 percent of SOF emissions (16). Unfortunately, these catalysts have little effect on reducing soot emissions. Furthermore depending on the exhaust temperatures, activity of the catalyst, and sulfur content of the fuel, oxidation catalysts may also encourage formation of the sulfate portion of particulate emissions. Because of the tendency of these catalysts to form sulfate particulates while reducing SOF particulates, the particulate control efficiency for oxidation catalysts tends to be lower than for particulate traps (around 30 to 50%). However, by careful placement of the catalyst to control exhaust temperatures and controlling catalytic activity by modifying catalyst formulations, sulfate emission levels should be containable without increasing the SOF emission levels.

NOx/PM Emission Control Combinations. As mentioned earlier, several manufacturers and institutions have been working on achieving further diesel emission reductions by using combinations of the technologies described above. In these studies various technology combinations were evaluated. The results of these studies are presented in Table IV-8. Note that only one of the technology combinations presented includes the use of aftertreatment devices. It is projected that inclusion of aftertreatment with any of the technology combinations in Table IV-8 would result in further emission reductions.

Table IV-8: FTP Emission Results of Various Emission Control Combinations

Technology Combination	NOx g/bhp-hr	PM g/bhp-hr
Fuel injection improvements (27)	3.5	0.10
Cooled EGR, oxidation catalyst (17)	2.8	0.10
EGR, charge air cooling (22)*	1.8	not available
Cooled EGR, charge air cooling (32)*	1.9	0.22
Cooled EGR, charge air cooling (17)**	2.3	0.12
Cooled EGR, charge air cooling, swirl (33)*	1.9	0.13
Multiple injection, EGR, charge air cooling (20)	2.2	0.07
EGR, fuel injection and air delivery improvements (16)	2.0	0.15
EGR, fuel injection and air delivery improvements, particulate trap (16)	2.0	0.05

* European R-49 13-mode test
** Steady-state test

4. Alternative Fuel Technology

Since the emission characteristics of motor vehicles depends on both the vehicle technology and the fuels used, industry has been investigating fuels other than gasoline and diesel to achieve lower emission levels. Some of the cleaner-burning fuels being considered include liquid petroleum gas, natural gas, methanol, and dimethyl ether (34). In the medium-duty vehicle category, Chrysler is already producing compressed natural gas(CNG) vehicles. Their 5.2 liter CNG engine is certified to California's LEV standards and is available on several vehicle models.

In the heavy-duty weight class, several manufacturers are producing CNG and liquid natural gas (LNG) heavy-duty engines for applications that traditionally utilized diesel engines.

Detroit Diesel Corporation manufacturers the DDC Series 50G heavy-duty engine. This engine is fueled with CNG and is currently being tested in about 200 HDV applications including urban buses. Cummins and Hercules are also producing natural gas engines. Cummins has produced CNG versions of their L-10 diesel engine for urban use and has recently developed an L-11 engine which can run on LNG. Hercules makes two natural gas engines, a 3.7 liter and a 5.6 liter engine. These engines are also being utilized in urban buses.

These gaseous fueled engines generally can achieve (ROG+NOx) emission levels below 3.0 g/bhp-hr and PM levels below 0.05 g/bhp-hr with one engine attaining (ROG+NOx) and PM levels below 2.0 g/bhp-hr and 0.05 g/bhp-hr, respectively. Furthermore, a 7.3 liter Navistar direct injection engine which was fueled with a dimethyl ether was shown in one study to be capable of achieving emission levels below the ULEV standards for heavy-duty engines (34). The emission test results of this engine were 2.4 g/bhp-hr for NOx+ROG, and 0.033 g/bhp-hr for PM.

F. Costs of Medium-Duty Vehicle Proposal

The ARB staff has performed a comprehensive cost analysis of the LEV and ULEV requirements of the MDV proposal. This analysis consisted of two main steps. First, a projection of the emission control technologies required by low-emission vehicles was made. Second, the costs associated with developing, producing, and assembling LEVs and ULEVs with the projected technologies were evaluated. By considering industry technical papers, conducting emission tests on medium-duty vehicles, evaluating the status of light-duty vehicle technology, and consulting with manufacturers, the ARB staff was able to project the technologies which will likely be utilized on LEVs and ULEVs. Concerning the cost methodology utilized to determine the various costs associated with developing, producing , and assembling these vehicles, staff referenced a method similar to that for light-duty low-emission vehicles prepared in April 1994. Descriptions of the cost methodology and the analysis are also discussed in detail in Appendix F. From the analysis, the following conclusions were drawn:

<u>Gasoline Vehicles</u>

* The incremental retail costs of gasoline low-emission MDVs would be minimal. Compared to Tier I vehicles, the additional retail cost of a LEV is estimated to average $169, and a ULEV $260. It should be noted that as in the case of light-duty low-emission vehicle cost estimates, the projected cost for each emission category (i.e., TLEV, LEV, ULEV, etc.) is an average cost assuming the new vehicle fleet is <u>entirely</u> TLEV, LEV, or ULEV. Since only 40 percent of the medium-duty fleet will be required to be ULEVs under the current proposal, however, manufacturers will certify the easiest to comply engine families as ULEVs, and certify the more difficult and/or costly ones as LEVs. Thus, the average cost of a ULEV with the current proposal would be much less than the cost presented for this analysis (e.g., although the staff's ULEV cost estimate included some EHC systems for the most difficult to certify engine families, these would probably never be needed under the current proposal with only a 40%

ULEV requirement so that actual ULEV costs will be lower than $260 in this program).

* The cost-effectiveness of gasoline low-emission vehicles relative to Tier I vehicles would be favorable, averaging less than $0.50 per pound of pollutants reduced. This value was calculated by utilizing two different approaches. The first method divides the total cost of the proposal by the sum of the total hydrocarbons, NOx, and CO (the latter discounted by a factor of seven). The second approach applies one-half the cost to the reduction of criteria pollutants (HC plus NOx) and the other half to reduction of toxic air contaminants. Motor vehicle control measures typically range up to $5 per pound of emissions reduced while stationary source controls range up to $10 per pound of emissions reduced. As a comparison, the cost-effectiveness of light-duty low-emission vehicles averaged less than $1 per pound of emissions reduced.

Diesel Vehicles

* The incremental retail costs of diesel low-emission MDVs would be moderate. Compared to Tier I vehicles, the additional cost of a LEV would average about $348, and a ULEV $425.

* The cost-effectiveness of diesel low-emission vehicles relative to Tier I vehicles is consistent with other mobile source measures, averaging less than $1.50 per pound of pollutants reduced. This value was found by applying the same two methods utilized to calculate the gasoline low-emission vehicle cost-effectiveness above.

G. Environmental Impact of Medium-Duty Vehicle Proposal

The medium-duty vehicle requirements being proposing in this rulemaking are not expected to have any significant adverse impacts on the environment, with the exception of a slight increase in CO and PM_{10} emissions. Staff's proposal achieves significant emission reductions for NMOG and NOx by increasing the number of ULEVs required from 15% (adopted by the Board in 1990) to 40% and by increasing the stringency of the NOx standards. The proposal also includes, however, a slight relaxation of the ULEV CO and PM_{10} standards in order to give manufacturers greater chance of success in developing low NOx strategies to meet the stringent NOx levels being proposed in this rulemaking. NOx control is a critical part of California's plan to meet the federal and state ozone standards because California has six areas of non-attainment for the federal ambient air quality standard for ozone. For this reason, staff expects that a slight increase in the CO and PM_{10} standards will likely have only a minimal impact on the environment whereas reducing NOx will provide substantially greater benefits. The contribution of MDVs to the total CO inventory is relatively minor. For example, under the current proposal, the MDV CO inventory would be increased to 322 tpd from 298 tpd for the South Coast Air Basin. Given that the total CO inventory is 6600 tpd for the South Coast Air Basin, it is doubtful that this slight increase would significantly affect the CO attainment status of the basin. The South Coast Air Quality Management District will be reviewing the CO attainment plan in 1996, however, and will make any adjustments to the plan needed for CO attainment. For other areas of California outside the South Coast Air Basin, this slight CO increase should not affect CO attainment. Thus, the greater success in achieving the NOx goals gained by moderating the CO standard for ULEVs more than outweighs the slight disbenefit of increase in CO emissions.

In terms of the PM_{10} effects, there is no alternative to allowing the slightly higher ULEV PM_{10} standard in order to ensure achieving the desired NOx levels, based on the staff's most recent technology assessment. However, even though the proposed regulations would allow more PM_{10} to be emitted directly from medium-duty vehicles, the low NOx emissions will also mitigate this increase by reducing the formation of secondary PM_{10} in the atmosphere. (One of the constituents of secondary PM_{10} is ammonium nitrate which is formed from NOx in the atmosphere.) In addition, the ARB is currently working with the U.S. EPA to develop nationwide standards for low-NOx diesel vehicles. Reduction of PM_{10} emissions will also be considered through this national program and the ARB has committed to considering adoption of these standards should the national program include stricter standards.

To summarize, the proposed medium-duty vehicle amendments will result in significant emission reductions of NMOG and NOx, and this consideration overrides any adverse environmental impacts that may occur as a result of slight increases in CO and PM_{10} emissions. As explained above, there are no feasible mitigation measures or alternatives that would reduce CO and/or PM_{10} emissions while at the same time providing the substantial overall health benefits realized by the significant NMOG and NOx emission reductions.

V. PROPOSED AMENDMENTS TO THE FUEL SPECIFICATIONS FOR M100 FUEL METHANOL

When the fuel specifications were originally adopted for M100 fuel methanol in 1992, a requirement was included that it produce a luminous flame throughout the entire burn duration. The reason for this luminosity requirement was that M100 burns without a readily visible flame under maximum daylight conditions. The deadline for compliance with this requirement was delayed to January 1, 1995, because an acceptable luminosity additive had not been identified at the time of adoption of the fuel specifications. Subsequent to the initial hearing, several research projects were conducted to investigate potential luminosity additives. As the January, 1995, deadline approached, however, it became clear that a suitable additive could not be identified which satisfied the criteria set by the Board; namely, a reasonable cost additive that would enhance luminosity without increasing emissions. Because of the rapidly approaching January, 1995, deadline, staff approached the Board in December, 1994, with an interim proposal to allow M100 vehicles to be equipped with a fire suppression system instead of requiring only the addition of a luminosity enhancing agent to the fuel. This proposal would allow the several hundred M100 vehicles currently in operation in California to continue in service until an acceptable alternative could be identified since these vehicles were already equipped with fire suppression systems.

At the hearing the Board heard compelling testimony on the relative safety of M100 compared to gasoline and diesel. Based on this evidence, the Board instructed staff to conduct a comparative risk assessment of M100 as a motor vehicle fuel. The Board resolved that if, after evaluating existing risk assessments, staff concluded that the relative fire safety of M100 as shown by the existing data justifies deletion of the luminosity requirement, staff should return to the Board with a regulatory proposal to repeal the requirement. Pursuant to the Board's directive, staff has conducted that risk assessment. The following is a summary of staff's investigation and recommendation.

Staff examined several studies related to M100 and safety. The most comprehensive assessment of the safety of M100 as a motor vehicle fuel was performed by the U.S. EPA in 1990. The results of their investigation were reported in a Society of Automotive Engineers (SAE) paper entitled, "Summary of the Fire Safety Impacts of Methanol as a Transportation Fuel." The evidence presented by the U.S. EPA demonstrates that the overall risk associated with M100 is significantly less than gasoline and essentially the same as with diesel fuels.

The conclusion reached by the U.S. EPA is largely based on historical data which strongly indicate that fuel flammability characteristics can significantly impact the rate at which vehicle fires occur. There are a number of fuel properties of methanol which cause it to be both less likely to ignite than gasoline, as well as less likely to cause injury if it does ignite. These properties include volatility, lower flammability limit, vapor density, diffusivity in air and heat of combustion/vaporization. A summary of U.S. EPA's examination of these properties is covered below.

Volatility. Fuel volatility determines the rate at which vapor is produced from exposed fuel and strongly affects the rate at which ignition occurs. The volatility of M100 is 4.6 psi RVP compared to 8-16 psi for gasoline. According to the U.S. EPA's investigation, the difference in volatility could result in as much as a 70% reduction in vehicle fires.

Lower Flammability Limit (LFL). LFL is the minimum concentration of fuel vapor in air which is required for ignition. The higher the LFL the more unlikely that ignition will occur. The LFL for M100 is 6.0 volume percent while the LFL for gasoline and diesel fuel is 1.4 and 0.6 volume percent, respectively. Thus, the U.S. EPA concludes that the concentration of M100 in air would have to be approximately four times greater than that of gasoline in order for ignition to occur.

Vapor Density. Gasoline has a vapor density two to five times greater than air, while diesel fuel is five to ten times greater. In contrast M100 is 1.1 times that of air. Thus, M100 has a greater tendency to disperse in air and avoid potential ignition sources.

Diffusivity of Fuel Vapor. Diffusivity is the rate at which a flammable concentration of vapor will disperse to harmless levels in the atmosphere. M100 has approximately twice the propensity for diffusion compared to gasoline or diesel fuel.

Heat of Combustion/Vaporization. The heat produced while M100 is combusted or vaporized is much lower than that of gasoline. Thus, the rate of fire propagation and the extent of injuries should be much lower for an M100 fire compared to gasoline.

Based on their investigation and assessment of the comparative risk of M100, the U.S. EPA concludes that there is an acceptable risk associated with the use of M100 as a motor vehicle fuel. The U.S. EPA further concludes that a significant (perhaps as high as 95%) reduction in fatalities, injuries and property damage associated with fuel-related vehicle fires is possible with M100 relative to gasoline.

Conclusion and Recommendation. When the luminosity requirement was first proposed, staff's concern was that unsuspecting accident victims and firefighters would not be able to detect the invisible flame of an M100 fire and could potentially be seriously injured. The ensuing negative publicity could potentially end the use of M100 fuel as a motor vehicle fuel in California. In light of the study conducted by the U.S. EPA, however, it is apparent that the risk for fire is low and the potential for the above-mentioned scenario very small. In addition, there is other evidence which further mitigates the risks associated with the use of M100. First, the majority of the M100 vehicles currently in operation are transit buses and are already equipped with fire suppression equipment. Second, staff has been informed that there is pending legislation which will require all school buses to be equipped with fire suppression equipment regardless of the fuel being used. Finally, the remaining M100 vehicles are medium-duty fleet vehicles which are fueled at a central location by trained personnel. In those instances, the risk would be very low that an untrained person would come in contact with an M100 fuel spill or fire.

Therefore, based on the reasonable evidence that supports this conclusion, staff is recommending that the Board remove the M100 luminosity requirement .

VI. SUMMARY OF PROPOSED MODIFICATIONS AND CLARIFICATIONS TO EXISTING REQUIREMENTS

The following section summarizes in general terms the modifications staff is proposing in this rulemaking. Due to the detailed and technical nature of many of these modifications, a detailed explanation is contained in Appendix A. Appendix C contains the proposed modified regulatory text of sections affected in Title 13, California Code of Regulations.

A. Section 1960.1. Exhaust Emission Standards and Test Procedures - 1981 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles

In addition to the proposed changes to the medium-duty vehicle requirements noted in section IV of this staff report, staff has revised the format of the regulation for ease of reference. Staff is also proposing to extend the intermediate in-use compliance standards for light-duty LEVs and LEVs. Since manufacturers will probably not introduce light-duty LEVs until 1998 and ULEVs in 2001, staff is proposing an extension through 1999 for LEVs and through 2002 for ULEVs. This extension will provide manufacturers with additional time for proving the technology required to meet the light-duty standards. The proposed regulatory text is contained in Appendix C-section 1960.1 and description of the proposal in contained in Appendix A.

B. Section 1956.8. Exhaust Emission Standards and Test Procedures - 1985 and Subsequent Model Heavy-Duty Engines and Vehicles.

Incomplete medium-duty vehicles and engines used in medium-duty vehicles have the option of certifying to the chassis standards contained in Title 13, section 1960.1 or to the heavy-duty standards contained in section 1956.8. Staff is proposing modifications to the medium-duty vehicle requirements as part of the SIP strategy for ozone attainment. A complete description of the modifications is contained in the staff report. The actual text of the modification is contained in Appendix C-section 1956.8.

C. California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles.

Changes identical to those made in Title 13, CCR section 1960.1 have been made to section 3 of these test procedures, including the proposed medium-duty vehicle requirements. Pursuant to requests from manufacturers and based on testing conducted by the ARB, staff is proposing that the multiplier used for ULEVs to determine compliance with the 50ºF requirement be changed from 1.0 to 2.0. The majority of the remaining modifications are for clarification and to conform the text of these test procedures with the text contained in other test procedures.

D. California Exhaust Emission Standards and Test Procedures for 1987 and Subsequent Model Heavy-Duty Otto-Cycle Engines and Vehicles.

Changes identical to those made in Title 13, CCR section 1956.8 concerning the proposed medium-duty vehicle requirements have been made to these test procedures. In addition, the test procedures have been updated to reflect expected new federal regulations for heavy-duty otto-cycle engines.

E. California Non-Methane Organic Gas Test Procedures

These test procedures set forth the methods for the calculation and measurement of non-methane organic gases. These methods are dynamic because new and improved measurement techniques and methods are continually being developed. The majority of the changes proposed in this rulemaking result from the development of improved measurement techniques. Some of the more important modifications provide additional flexibility for other laboratories to account for differing techniques, determine the frequency of multipoint and limit of detection calculations and permit the addition of new techniques because of upgrades to existing equipment and methods of measurement.

F. California Assembly-Line Test Procedures for 1996 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles

The Assembly-Line Test Procedures have a dual purpose - 1) to ensure that the functional portions of the emission control system are tested prior to release of the vehicle from the assembly-line and 2) to ensure that a representative sample of the vehicles produced is tested to assure compliance with the emission standards to which they are certified. Since the Assembly-Line Test Procedures have not been substantially revised since 1983, staff is proposing that a new document be created which applies to 1996 and subsequent model passenger cars, light-duty truck and medium-duty vehicles. The new document is not substantially different than the previous version; however, it has been updated to reflect current practices and new testing requirements (such as those for on-board diagnostics). In addition, text has been added to clarify existing procedures such as the correct method for choosing representative vehicles, adding another option for loading the evaporative canister and standardizing the reporting format to reduce costs for both manufacturers and the ARB.

G. California New Vehicle Compliance Test Procedure

The New Vehicle Compliance Test Procedures allow the ARB to test vehicles before they are delivered to the ultimate purchaser. Since this test procedure has not been updated since May 1979, modifications are being proposed in order to bring the testing procedure more in line with current practices (such as the new evaporative emission requirements) and new regulations such as second generation on-board diagnostics.

H. California Motor Vehicle Emission Control and Smog Index Label Specifications

The purpose of the California Motor Vehicle Emission Control and Smog Index Label Specifications is to ensure that emission control equipment can be properly identified and maintained in order for vehicles and engines to meet the applicable emission standards in-use. This is especially important for the Smog Check process so that the technician can properly identify the vehicle and its emission controls. The proposed revisions to these specifications involve adding a ninth character to the bar code which identifies the emission standard to which the vehicle was certified, replacing a previously existing exemption for motorcycles that was inadvertently omitted, updating terminology and SAE practices, and adding a requirement for a window label specifying a vehicle's smog index number pursuant to Senate Bill 2050.

VII. ENVIRONMENTAL AND ECONOMIC IMPACT OF RULEMAKING

Environmental Impact. Many of the proposed modifications to these regulations are detailed, technical amendments intended to clarify the certification and testing requirements for low-emission vehicles and to facilitate their introduction in California. The scope of these amendments is broad -- from clarification of the laboratory testing methods for exhaust measurement to updating the assembly-line test procedures to reflect the introduction of on-board diagnostics equipment on vehicles. These amendments are intended to provide relief to manufacturers because they simplify many aspects of the vehicle certification process and are not expected to have a significant negative impact on the environment as they do not affect exhaust emissions. The effect of these regulations on small volume vehicle manufacturers is not expected to have a significant impact because many of the alternatives relieve their regulatory burden as well. More significant modifications being proposed include amendments for reactivity adjustment factors and the requirements for medium-duty vehicles. The environmental impact of these proposals is discussed in their respective sections in the staff report.

Economic Impact. In developing this regulatory proposal, the ARB staff evaluated the potential economic impacts on private persons and businesses. The proposed revisions are intended to clarify and facilitate the implementation of the Low-Emission Vehicle/Clean Fuels Regulations, and to accelerate the introduction of ULEVs in the medium-duty fleet by the year 2003. The modifications of the certification process are not expected to affect costs to businesses. While a small number of California businesses may be adversely affected by the medium-duty vehicle proposal, in general, the medium-duty vehicle proposal is not expected to affect California businesses significantly because the expected cost increases (as detailed in Section IV.F of this report) would be well under one percent of the cost of the vehicle (less than $500 for vehicles which have retail prices between $25,000 and $50,000). Consumers expect that new vehicle prices will routinely increase three to four percent each year, and staff does not expect that these proposed regulatory amendments will have a noticeable impact on California businesses which purchase these kinds of vehicles.

The increase in costs to the three auto manufacturers is estimated to be about $1.5 million annually. This cost increase would have no noticeable impact on the profitability of U.S. auto manufacturers. In 1994, auto manufacturers collectively reported approximately $414 billion in net profit. The cost increase associated with the proposed revisions would have reduced this profit level by about 0.01 percent -- a minor change in the profitability of auto manufacturers.

Since the proposed revisions impose no noticeable impact on the profitability of U.S. vehicle manufacturers, no significant change in consumer price, employment, business competitiveness, or the status of businesses in California is expected. By simplifying the certification process, vehicle manufacturers will receive some resource reductions from the modifications to the proposed regulations. The Executive Officer has therefore determined that adoption of the proposed regulatory action will not have a significant adverse economic impact on the ability of California businesses to compete with businesses in other states, or on directly affected private persons. In accordance with Government Code section 11346.3, the Executive Officer has also determined that this regulatory action will not affect the creation or elimination of jobs within California, the creation of new businesses and the elimination of existing businesses within California, or the expansion of businesses currently doing business within the State of California. It is possible, however, that some individual businesses may be adversely affected by this regulatory action, even though overall there should be no significant adverse economic impact on businesses as a whole. For example, it is possible that some individual business which either purchases or sells medium-duty vehicles might be adversely impacted due to some unusual circumstances pertaining to that particular business. Therefore, the Executive Officer finds that the adoption of this regulatory action may have a significant adverse impact on some businesses. The Board's Executive Officer has also determined, pursuant to Government Code sections 11346.5(a)(3)(B), that the regulation will affect small business.

The amendments being proposed in this rulemaking are the result of extensive discussions and meetings with the affected parties (e.g., automobile manufacturers and oil refiners). Staff has considered all of the alternatives proposed by industry and, unless the proposed change would lessen the effectiveness of the original requirement, was able to incorporate industry's proposed amendment into the regulation. Staff is satisfied that consensus has been achieved with all of the affected parties for this rulemaking and that no other alternatives considered by the agency would be more effective in carrying out the purpose for which the regulation is proposed or would be as effective or less burdensome to affected private persons than the proposed regulation. However, interested parties are invited to submit other proposals for consideration. These submissions may include the following considerations:

(i) The establishment of differing compliance or reporting requirements or timetables which take into account the resources available to businesses;
(ii) Consolidation or simplification of compliance and reporting requirements for businesses;
(iii) The use of performance standards rather than prescriptive standards; or
(iv) Exemption or partial exemption from the regulatory requirements for businesses.

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Inventory Scenarios

Scenario 1: 100% ULEV Scenario presented in the SIP with Revised Baseline tpd Emissions

Model-Year	Chassis-Certified Phase-in			Diesel Engine-Certified Phase-in		
	Tier 1	LEV	ULEV	Tier 1	LEV	ULEV
1998	80%	10%	10%	80%	10%	10%
1999	50%	25%	25%	50%	25%	25%
2000	0	50%	50%	0	50%	50%
2001	0	25%	75%	0	25%	75%
2002 & Sub.	0	0	100%	0	0	100%

	NOx Baseline w/ Enhanced I/M		ROG Baseline w/ Enhanced I/M		TPD Reduced from Revised Baseline	
	SIP	Revised	SIP	Revised	NOx	ROG
M2/M3 (≤ 8500 lbs GVW)	33.58 tpd	same	8.57 tpd	same	10.87 tpd	2.00 tpd
Gasoline M4/M5 (8500 to 14000 lbs GVW)	29.09 tpd	20.10 tpd engine	3.55 tpd	3.96 tpd engine	4.45 tpd	0.70 tpd
		8.15 tpd chassis		0.99 tpd chassis	2.64 tpd	0.23 tpd
Diesel M4/M5 (8500 to 14000 lbs GVW)	29.4 tpd	27.51 tpd	2.6 tpd	4.01 tpd	5.53 tpd	0.89 tpd
TOTAL TPD RED.					23.49 tpd	3.82 tpd

Scenario 2: Current Staff Proposal

Model-Year	Chassis-Certified Phase-in LEV NOx=ULEV NOx in 1998			Engine-Certified Phase-in LEV=3.0 g/bhp-hr NMHC+NOx in 2002-3 D -ULEV NOx=2.0, NMHC=0.11 G -ULEV NOx=2.0, NMHC=0.35		
	Tier 1	LEV	ULEV	Tier 1	LEV	ULEV
1998	73%	25%	2%	100%	0	0
1999	48%	50%	2%	100%	0	0
2000	23%	75%	2%	100%	0	0
2001	0	80%	20%	100%	0	0
2002	0	70%	30%	0	100%	0
2003	0	60%	40%	0	100%	0
2004 & Sub.	0	60%	40%	0	0	100%

	NOx Baseline w/ Enhanced I/M		ROG Baseline w/ Enhanced I/M		TPD Reduced from Revised Baseline	
	SIP	Revised	SIP	Revised	NOx	ROG
M2/M3 (≤ 8500 lbs GVW)	33.58 tpd	same	8.57 tpd	same	11.45 tpd	0.53 tpd
Gasoline M4/M5 (8500 to 14000 lbs GVW)	29.09 tpd	20.10 tpd engine	3.55 tpd	3.96 tpd engine	3.67 tpd	0.66 tpd
		8.15 tpd chassis		0.99 tpd chassis	2.78 tpd	0.06 tpd
Diesel M4/M5 (8500 to 14000 lbs GVW)	29.4 tpd engine	27.51 tpd engine	2.6 tpd engine	4.01 tpd engine	6.04 tpd	0.79 tpd
TOTAL TPD RED.					23.94 tpd	2.04 tpd