State of California
AIR RESOURCES BOARD
Stationary Source Division

PROPOSED ADOPTION OF REGULATIONS LIMITING THE SULFUR CONTENT AND THE AROMATIC HYDROCARBON CONTENT OF MOTOR VEHICLE DIESEL FUEL

Prepared by:

Fuels Section
Criteria Pollutants Branch

October 1988

DA 1100

State of California
AIR RESOURCES BOARD
Stationary Source Division

PROPOSED ADOPTION OF REGULATIONS LIMITING THE SULFUR CONTENT AND THE AROMATIC HYDROCARBON CONTENT OF MOTOR VEHICLE DIESEL FUEL

Prepared by:

Fuels Section
Criteria Pollutants Branch

October 1988

ACKNOWLEDGEMENTS

This report was prepared with the help of the staff from other divisions at the Air Resources Board. We would particulately like to thank:

Principal Author

John Courtis
Stationary Source Division

Contributing ARB Staff from

Research Division
Compliance Division
Mobile Source Division
Technical Support Division
Office of Legal Affairs

Reviewed and Approved by

Peter D. Venturini, Chief, Stationary Source Division
Ronald A. Friesen, Assistant Chief, Stationary Source Division
Dean C. Simeroth, Chief, Criteria Pollutants Branch
Bill Lovelace, Manager, Fuels Section

TABLE OF CONTENTS

Page

ATTACHMENTS

INTRODUCTION AND SUMMARY

A. OVERVIEW

This report presents an analysis of costs and benefits for various scenarios of reducing the sulfur and aromatic hydrocarbon content of motor vehicle diesel fuel. In addition, this report presents proposed regulations to limit the sulfur content and the aromatic hydrocarbon content of motor vehicle diesel fuel in the state of California. The proposed regulations would reduce emissions of sulfur dioxide (SO_2), particulate matter (PM), and oxides of nitrogen (NO_x) from diesel-fueled motor vehicles. The proposed regulations would also reduce, to a lesser extent, other air contaminants emitted from diesel-fueled motor vehicles.

The proposed regulations are part of the Air Resources Board's long range plan to reduce emissions from motor vehicles. This motor vehicle plan includes: measures to reduce excess emissions from in-use vehicles; stricter emission standards for new vehicles; improvements in motor vehicle fuel quality; and programs to encourage the use of alternative cleaner fuels.

Benefits of Control. The sulfur contained in motor vehicle diesel fuel produces emissions of SO_2 and contributes to emissions of PM. The aromatic hydrocarbon content of motor vehicle diesel fuel affects emissions of NO_x and PM, including some toxic pollutants.

A reduction of emissions of SO_2, PM, and NO_x would improve air quality, help to attain ambient air quality standards where they are exceeded, and reduce the health risks of people exposed to affected pollutants. Specific statewide benefits attributable to adoption of the proposed regulations are estimated as follows for 1995:

- o SO_2--reduced by 80 tons per day. This is an 82 percent reduction of SO_2 emitted by vehicles that burn diesel fuel not now regulated for sulfur content.
- o PM--reduced by 14 tons per day, a 25 percent reduction of particles emitted by diesel-fueled vehicles. A number of toxic pollutants are emitted with these particles.
- o NO_x--reduced by 53 tons per day, a 7 percent reduction of NO_x emitted by diesel-fueled vehicles.

We estimate that for the South Coast Air Basin, the potential increase in the number of lung cancers from exposure to carcinogenic compounds in diesel exhaust particulate matter is 300 to 650 for lifetime (70 years) exposure for the period 1995 to 2065. We estimate that the proposed regulations would result in approximately 30 to 110 fewer potential cancers in the South Coast Air Basin. This is a 10 to 17 percent reduction.

Reducing particulate matter emissions from diesel-fueled motor vehicles would also provide economic benefits related to reduced soiling and improved visibility. We estimate that, in the South Coast Air Basin alone, the reduction of particulate matter emissions that would result from our proposal would have an economic benefit of more than $40 million per year from reduced soiling and improved visibility. Statewide, those benefits would exceed $60 million per year.

Need for emission reductions. Diesel vehicle exhaust is believed to contain over 1000 different compounds of which over 100 have been identified. The emissions of these compounds contribute to a wide variety of air quality problems. Sulfur dioxide emissions contribute to ambient concentrations of sulfur dioxide, particulate sulfate, and fine particulate matter (PM_{10}). Sulfur dioxide emissions also contribute to acid deposition. Oxides of nitrogen contribute to ambient concentrations of nitrogen dioxide and PM_{10}. Emissions of NO_x also participate in the formation of ozone and contribute to acid deposition. Emissions of particulate matter contribute to ambient concentrations of PM_{10}.

All of these emissions contribute to visibility degradation. In addition to adding to the atmospheric burden of pollutants for which ambient air quality standards have been established, exhaust emissions from diesel-fueled vehicles contain mutagenic and carcinogenic compounds, are malodorous, cause soiling, and are broadly perceived by the public as a serious air pollution nuisance.

Magnitude of diesel vehicle emissions. There are approximately 200,000 heavy-duty diesel vehicles in California, consuming over 1.5 billion gallons of diesel fuel per year. Thus, diesel-fueled vehicles are major sources of emissions of SO_2 and NO_x, and significant sources of particulate matter when compared to sources of readily controlled particulate matter. We estimate that the statewide 1990 exhaust emissions from diesel-fueled motor vehicles statewide will be about 100 tons per day of SO_2, 700 tons per day of NO_x, and 100 tons per day of particulate matter.

Basis for emission reduction estimates. A major study now in progress has provided the basis for our estimates of emission reductions. The Coordinating Research Council (CRC) is conducting a test program to evaluate the effects of fuel quality on emissions from heavy-duty diesel-fueled motor vehicles. The CRC is an organization funded by the American Petroleum Institute and the Society of Automotive Engineers. The CRC has released to us the data from the first two sets of engine tests (three engines are being tested). We used the CRC data to estimate the emission reduction potential of limiting the sulfur content and the aromatic hydrocarbon content of motor vehicle diesel fuel. The results of our analyses are consistent with the results of other less rigorous studies on the effects of fuel sulfur and aromatic hydrocarbon content on particulate matter and NO_x emissions.

Fuel modification technology. Diesel fuel sulfur content can be reduced at refineries by using the hydrodesulfurization process, one of a number of generic oil refining processes referred to as hydroprocessing. In this process, hydrogen and the oil to be treated are heated and passed over a catalyst to produce a chemical reaction that releases the sulfur as hydrogen sulfide gas. Aromatic hydrocarbons can be reduced using similar hydroprocessing equipment though temperature and pressure have to be increased and more expensive catalysts are required.

What the proposed regulations would do. The proposed regulations would: (1) limit sulfur content statewide at 0.05 percent for all refiners, and (2) limit aromatic hydrocarbon content statewide at 10 percent for large refiners and 20 percent for small refiners. The sulfur content of motor vehicle diesel fuel in the South Coast Air Basin and Ventura County is already controlled to 0.05 percent. For areas outside the South Coast Air Basin, we estimate the average sulfur content of motor vehicle diesel fuel to be 0.28 percent. The estimated statewide aromatic hydrocarbon content of diesel fuel, including the South Coast Air Basin, is 31 percent. Thus, the proposed regulations would reduce the sulfur content of motor vehicle diesel fuel (outside the South Coast Air Basin and Ventura County) by more than 80 percent and the aromatic hydrocarbon content by about 65 percent.

Cost-effectiveness of control. Both the cost and the effects of control are complicated to estimate, subject to controversy, and could vary substantially with future decisions of the refining and diesel vehicle manufacturing industries. The ARB staff has used what it considers to be a reasonable scenario to make estimates.

In evaluating the cost-effectiveness of reducing the sulfur content and aromatic content of motor vehicle diesel fuel as an emission control strategy, we considered the cost-effectiveness values for PM and NO_x emissions reductions as if 50 percent of the overall cost of the fuel content changes are assigned to each pollutant species. We also considered the cost-effectiveness for total pollutants reduced, that is, the cost of control divided by the reductions in emissions of SO_2, PM, and NO_x. Reducing the sulfur content of diesel fuel to 0.05 percent, and the aromatic hydrocarbon content to 10 and 20 percent for large and small refiners respectively, would result in the following cost-effectiveness values:

	Cost-Effectiveness ($/Pound)*		
	PM	NO_x	All** Pollutants
Large Refiners (0.05% Sulfur, 10% Aromatics)	3.1	3.5	3.3
Small Refiners (0.05% Sulfur, 20% Aromatics)	3.6	8.0	5.0

* Based on a cost to large refiners of 11 cents per gallon and a cost to small refiners of 12 cents per gallon.

** "All Pollutants" includes directly emitted PM, NO_x, and secondary sulfate PM.

Regulation of diesel vehicle emissions. The Air Resources Board (ARB or Board) has adopted emission standards for new on-road diesel-fueled vehicles. These standards address the same gaseous exhaust emissions as for gasoline-powered vehicles, but also include limits for particulate matter. Regulations adopted by the Board are expected to reduce overall emissions of particulate matter from diesel-fueled vehicles and to reduce the rate of increase in NO_x emissions in the coming decades. The Board has also adopted requirements for the sulfur content of motor vehicle diesel fuel sold for use in the South Coast Air Basin and Ventura County. The diesel fuel quality regulations being proposed herein are an integral part of the Board's overall strategy to further reduce emissions from diesel-fueled motor vehicles.

Supporting documentation. This report is accompanied by a Technical Support Document, prepared by the ARB staff, that contains detailed discussions of the information presented here. The Technical Support Document is incorporated by reference as part of this report.

Report authorship. This report and the accompanying technical support document were prepared by the ARB staff. Much of the information in these documents is based on the previously mentioned CRC fuel quality/emissions tests, and a report on the cost of refinery processing to meet various diesel fuel specifications that was prepared by Arthur D. Little, Inc., under contract to the ARB.

Public participation. In developing the proposed regulations, we held five consultation meetings to discuss the basis of the proposals, projected emission inventories for diesel-fueled motor vehicles, cost estimates, emission reduction estimates, and regulatory formats. We also met with representatives of refinery trade organizations to discuss special concerns of those groups. We solicited information regarding costs and fuel quality effects on emissions from consultation meeting participants and entertained a presentation, made earlier this year to the Environmental Protection Agency, by representatives of the American Petroleum Institute and the Engine Manufacturers Association on diesel fuel composition effects on emissions. As of the date of publication of this report, we are continuing to solicit information from the public and to investigate the appropriateness of other limits for aromatic hydrocarbon content.

Environmental impacts of the proposed regulations. The implementation of the proposed regulations would result in reductions in emissions from diesel-fueled motor vehicles. There could also be minimal increased emissions from refineries engaged in additional processing to meet the proposed diesel fuel specifications. District new source review rules require facilities which expand their operations to use best available control technology and to offset any major increases in emissions. These should ensure that such increases would be small. There are possible adverse hazardous waste impacts from the disposal of spent refinery catalysts, but such potential adverse impacts, if any, would be readily mitigated by recycling the catalysts for metals reclamation. We have not determined any other adverse environmental impacts of the regulation.

B. RECOMMENDATION

We recommend that the Board adopt the proposed new sections of Title 13, California Code of Regulations. Those sections are: Section 2255 - Sulfur Content of Motor Vehicle Diesel Fuel and Section 2256 - Aromatic Hydrocarbon Content of Motor Vehicle Diesel Fuel. The texts of the proposed regulations are presented in Attachments B and C. We also recommend that the Board Amend Section 2252 -- Sulfur Content to make that section consistent with proposed Section 2255.

I.

NEED FOR EMISSION REDUCTIONS

A. POLLUTANTS EMITTED

Diesel-fueled motor vehicles are a source of a variety of air pollutants. Among the pollutant species that diesel-fueled motor vehicles emit are:

- o Particulate matter
  - Carbonaceous Soot
  - Adsorbed Organic Compounds
  - Sulfates
  - Nitrates
- o Sulfur Dioxide
- o Oxides of Nitrogen
- o Gaseous Hydrocarbons
- o Carbon Monoxide
- o Toxics or Potential Toxics
  - Benzene
  - Polynuclear Aromatic Hydrocarbons (PAH)
  - PAH Derivatives
  - Aldehydes

B. AIR QUALITY IMPACTS

Various investigators have found that diesel fuel quality affects emissions from diesel-fueled motor vehicles. A number of evaluations show the relationship between sulfur and aromatic hydrocarbon content of diesel fuel and increased emissions of a variety of air pollutants.

Emissions of sulfur dioxide are a function of the sulfur content of fuel. We estimate that the statewide average diesel fuel sulfur content, outside of the South Coast Air Basin and Ventura County, is about 0.28 percent or 2800 ppm. The sulfur content of motor vehicle diesel fuel in the South Coast Air Basin and Ventura County is currently limited to 0.05 percent or 500 ppm. Sulfur dioxide emissions directly affect ambient concentrations of sulfur dioxide and sulfate and contribute to ambient levels of fine particulate matter.

Oxides of nitrogen are products of combustion and are emitted from mobile and stationary sources. The Board has established requirements limiting emissions of oxides of nitrogen from motor vehicles, and the air pollution control districts have regulations to control oxides of nitrogen from stationary sources. Tests have shown that the aromatic content of diesel fuel affects emissions of oxides of nitrogen from diesel vehicles.

Oxides of nitrogen emissions directly affect ambient concentrations of nitrogen dioxide, participate in atmospheric reactions which form ozone, and contribute to ambient fine particulate matter concentrations. In addition, emissions of oxides of nitrogen and sulfur dioxide contribute to both visibility degradation and the formation of wet and dry acid deposition.

Diesel-fueled vehicles are also sources of directly emitted particulate matter in the form of soot and sulfate aerosols. The sulfur and aromatic content of diesel fuel affect emissions of these pollutants. Most of the particulate matter that results from combustion in diesel engines, including secondary particulate matter formed in the atmosphere, is in the fine particulate matter (PM_{10}) size range. The PM_{10} air quality problem may be the most intractable air quality problem in California. The federal standards for PM_{10} are exceeded in four of the state's air basins while the state standard for PM_{10} is violated in virtually the entire state.

The reduction of emissions from diesel-fueled motor vehicles is one of the key measures that can be implemented to help attain the federal PM_{10} standard and to move toward achieving the state PM_{10} standard.

Diesel vehicles also emit a number of pollutants that have been identified as toxic air contaminants (TAC) or are considered potential toxic compounds. Such compounds include specific toxicants such as benzene, and classes of compounds such as aldehydes, polynuclear aromatic hydrocarbons (PAH) including benzo(a)pyrene, and PAH derivatives.

C. HEALTH EFFECTS

Exposure to PM_{10} and sulfates interferes with the respiratory system, and acute daily exposures have been associated with increased mortality, respiratory illness, increases in asthma attacks, and increases in hospital and emergency room visits.

Diesel exhaust has also been linked to cancer in occupational exposures. Although there is no formal Department of Health Services risk assessment for diesel vehicle exhaust, we have estimated the number of potential cancer incidences from exposure to ambient diesel exhaust particulate matter concentrations in the SCAB using data from other published sources. We estimate that, for a 70 year lifetime exposure at current and projected ambient levels, potential excess cancers from diesel vehicle exhaust particulate matter are 300 to 650 for the population of the SCAB. The exposure to diesel-fueled motor vehicle exhaust emissions in the SCAB corresponds to a potential individual lifetime risk of 29 to 63 per million population.

The table below shows a comparison of estimated cancer risk for ambient diesel vehicle particulate matter in the SCAB and for some other substances that have been formally identified by the Board as toxic air contaminants.

Estimated Cancer Risk per Million Population
from Ambient Concentrations
of Various Substances in the SCAB

Substance	Estimated Risk (Cancer Risk per Million Population)
Diesel Vehicle Particulate Matter	29 to 63
Benzene	92 to 710
Ethylene Dibromide	1 to 4
Ethylene Dichloride	1
Hexavalent Chromium	6 to 73

The table shows that the risk from diesel particulate matter in the SCAB is comparable to the risk from hexavalent chromium, and much greater than the risk from ambient concentrations of ethylene dibromide and ethylene chloride.

Diesel exhaust is thought to contain well over 1000 compounds, of which over 100 have been identified. The cancer causing potential of diesel exhaust may result from a number of these compounds. Many of the identified compounds are known carcinogens and/or mutagens. These toxic compounds are found both in the particle phase (such as many of the polycyclic aromatic hydrocarbons) and in the vapor phase (such as benzene and formaldehyde). Benzene has been linked to leukemia in workers exposed to the solvent vapors, and formaldehyde has been shown to cause lung tumors in rats when inhaled. A class of compounds present in diesel exhaust is the nitro-polycyclic aromatic hydrocarbons, or nitro-PAHs for short. Nitro-PAHs are found in both the particle and vapor phase and many are potent mutagens in bacterial short-term genotoxicity tests. Many of the nitro-PAHs are also animal carcinogens.

While only one component of diesel exhaust (benzene) has been formally identified by the ARB as a toxic air contaminant, PAHs, formaldehyde, and acetaldehyde, all of which are present in diesel exhaust, are either under review or scheduled for review as suspected TACs.

In addition to contributing to the air quality problems discussed above, the emission of soot or smoke from diesel-fueled vehicles elicits a strong negative reaction from the public. The sooty emissions are visible evidence of air pollution and have an adverse economic impact by contributing to soiling. The public's concern with emissions from diesel vehicles results in numerous complaint letters as well as support for measures to reduce diesel smoke. Over 20 mayors and other officials of Southern California municipalites have written letters requesting that the Board adopt stringent specifications for motor vehicle diesel fuel. Those letters are appended to the Technical Support Document.

D. EXISTING REQUIREMENTS

The Air Resources Board is designated by state law as the agency responsible for controlling emissions from motor vehicles. As part of that responsibility, the Board is empowered to specify the composition of motor vehicle fuels when the fuel specifications affect vehicle emissions. The responsibility of the Board and existing requirements for diesel-fueled motor vehicles and fuels are discussed in this section.

1. Vehicle Standards

The Board has adopted emissions standards for on-road diesel-fueled vehicles. In August 1982, the Board adopted particulate matter emissions standards for 1985 and later model year diesel passenger cars, light-duty diesel trucks, and medium-duty diesel-fueled vehicles. These groups of vehicles are also subject to hydrocarbon, carbon monoxide, and NO_x emission standards as are gasoline-powered vehicles.

In April 1986, the Board adopted emissions standards for new on-road heavy-duty diesel engines. The heavy-duty diesel engine standards are very similar to the federal emissions standards promulgated by the EPA in 1985, and include increasingly stringent limits for emissions of NO_x and PM. The PM standard for heavy-duty diesel engines is 0.60 grams per brake-horsepower-hour, effective now, 0.25 grams per brake-horsepower-hour in 1991, and 0.10 grams per brake-horsepower-hour in 1994. Urban buses must meet the 0.10 gram per brake-horsepower-hour limit in 1991.

2. Diesel Fuel Regulations

In July 1981, the Board adopted regulations limiting the sulfur content of motor vehicle diesel fuel as amendments to Section 2252, Title 13, California Administrative Code (now the California Code of Regulations). Section 2252, as amended, requires diesel fuel for use in motor vehicles in the

SCAB and Ventura County to contain no more than 500 ppm sulfur (0.05 percent sulfur by weight). Individual small refiners (refiners with crude oil capacities less than 50,000 barrels per day) were exempt from the initial requirement but were made subject to the same limits at subsequent hearings in 1985. As of January 1, 1989, all motor vehicle diesel fuel sold in the South Coast Air Basin and Ventura County is subject to the 0.05 percent sulfur limit. The aromatic content of diesel fuel is not limited by current regulations nor is sulfur content outside the South Coast Air Basin and Ventura County.

3. Legislative Requirements

In recent years the Legislature has indicated a strong interest in reducing diesel emissions by regulating diesel fuel composition. Until 1987 the ARB had exclusive authority to regulate diesel fuel. In 1987, the Legislature added Section 40447.6 to the Health and Safety Code providing that as of January 1, 1989, the South Coast Air Quality Management District (SCAQMD) could adopt, subject to the approval of the ARB, regulations to specify the composition of diesel fuel manufactured for sale in the SCAQMD.

Senate Concurrent Resolution (SCR) 100, approved by the Legislature during the 1988 legislative session, requests the ARB, the SCAQMD, and the California Energy Commission (CEC), to develop and, where feasible, implement a common strategy to achieve the maximum feasible reduction in public exposure to diesel vehicle emissions in a cost-effective manner through a combination of strategies. The strategies, which are to be developed in consultation with engine manufacturers and operators of diesel equipment, include diesel fuel composition specifications and requirements. SCR 100 also requests that the ARB, the SCAQMD, and the CEC report to the appropriate legislative committees on activities and plans to reduce public exposure to diesel emissions. The requested report is due by March 31, 1989.

Assembly Bill No. 2595 (AB 2595), often referred to as "the California Clean Air Act", would specifically require the Board to hold a hearing or hearings to consider adoption of regulations for diesel fuel quality, including aromatic content, along with other measures, before November 15, 1989. This bill is on the Governor's desk as of this writing.

E. FUTURE REQUIREMENTS AND POTENTIAL STRATEGIES

1. Future Standards

As noted earlier, the Board has adopted PM standards for 1991-1993 new on-road heavy-duty diesel-fueled vehicles (HDDV) of 0.25 g/bhphr (0.1 g/bhphr for urban transit buses) and 0.1 g/bhphr for 1994 and subsequent model-year vehicles. These standards were intended to be technology forcing since control technology, which was capable of achieving these standards, had not been demonstrated at the time they were adopted by the EPA and the Board.

2. <u>Potential Control Strategies</u>

In response to these stringent standards, HDDV manufacturers and others are developing technologies that should allow them to meet the new standards. The following potential approaches have evolved from the manufacturers' efforts:

- "Cleaner" Conventional Fuels for Diesel Engines
  - Fuel Sulfur Limitations
  - Fuel Aromatics Limitations
- Engine Design Modifications to Improve Combustion
- Exhaust After-Treatment Devices
  - Particulate Traps
  - Automotive Style Oxidation Catalysts
- Alternative Fuels for Diesel Engines
  - Methanol
  - Compressed Natural Gas
  - Liquid Petroleum Gas

Advances in engine design have substantially lowered particulate emissions, however it is likely that aftertreatment devices will also be necessary to meet the 1994 standards. As discussed in the next section, low sulfur diesel fuel appears necessary for catalytic aftertreatment devices to function effectively. In the absence of cleaner diesel fuel and aftertreatment devices, only the use of alternative fuels such as methanol offer an expectation of compliance.

3. Benefits of Reducing Sulfur Levels

Lower fuel sulfur levels will help manufacturers in their efforts to meet the 1994 PM standards in two ways. The first is by reducing levels of directly emitted sulfate particulate matter. Sulfate particulate matter may account for as much as 80 percent of the mass limit of the 1994 PM standard. The second way is by allowing the use of catalytic exhaust aftertreatment devices which offer the promise of reducing particulate emissions to very low levels. This device must be used with low sulfur diesel fuel since it converts sulfur in the exhaust to sulfates, a form of particulate. When used with high sulfur fuel, the conversion is sufficient to negate much of the device's effectiveness in reducing sooty particulate matter.

In addition to facilitating compliance with upcoming stringent emission standards, low sulfur diesel fuel is one of the few available methods of reducing the emission impact of the current fleet of on- and off-road diesel vehicles. Reduced sulfur in the fuel also helps extend engine life by reducing corrosive wear.

4. Benefits of Reducing Aromatic Hydrocarbon Levels

By lowering the aromatic hydrocarbon content of diesel fuel, fewer particulate and NOx emissions will result from its use. The lower aromaticity modifies the combustion process in a manner that results in less carbonaceous soot being formed. It also results in lower amounts of nitrogen in the fuel, and lower combustion temperatures, both of which contribute to lower NOx formation.

Lower aromatic hydrocarbon content should also reduce the carcinoginicity of diesel exhaust. Lower aromatic fuel contains less benzene and PAHs, and thus less of these compounds will be emitted in their unburned form. Aromatic content is also linked to the formation of benzene, PAH and PAH derivatives in the combustion process. Mutagenicity tests have provided corroborating evidence of the beneficial effect of lower aromatic content.

5. Timeliness of Benefits

Lower levels of sulfur and aromatic hydrocarbons in diesel fuel would reduce NO_x and PM emissions from on-road diesel-fueled vehicles currently in use, thereby achieving significant emission reductions more quickly than the new vehicle emission standards alone. Normally, 10-15 years are needed to realize the full benefit of a control measure that requires full turnover of the fleet. Emission reductions would also be obtained from off-road diesel-fueled vehicles which are not currently subject to any emission standards.

6. Additional Benefits

There are other benefits of reducing the aromatic hydrocarbon content of diesel fuel. The reduction of carbonaceous particulate matter emissions will reduce cancer risks. There will also be economic benefits from reduced soiling and improved visibility. We have not taken credit for these economic benefits in our cost-effectiveness analyses.

II.

EMISSIONS FROM DIESEL-FUELED VEHICLES

A. EMISSIONS ESTIMATES FOR 1990

We estimate that the 1990 population of heavy-duty diesel vehicles in California will be nearly 200,000 vehicles, travelling over 27 million miles per day and consuming diesel fuel at a rate of 6 miles per gallon. These vehicles are significant sources of emissions of SO_2, NO_x, and PM. The tables and figures in this and the following section include emission reductions from those regulations that are now in effect and adopted measures with future effective dates. Table 1 and Figure 1 present the projected statewide emissions for 1990 for diesel-fueled motor vehicles and compare the emissions to the total emissions in California by category. As shown, of the more than 550 tons per day of sulfur dioxide emissions from all sources, nearly 100 tons per day, or more than 17 percent, are from diesel-fueled motor vehicles. Of the 2900 tons per day of NO_x emissions from all sources, over 700 tons per day, or nearly 25 percent, are from diesel-fueled motor vehicles.

Virtually all of the PM from the tailpipes of diesel-fueled motor vehicles lies within the PM_{10} size range. Although the PM_{10} emissions from diesel-fueled motor vehicles appear small

Table 1
Estimated Statewide Emissions of SO_2, NO_x, and PM_{10}
(Tons Per Day)
1990

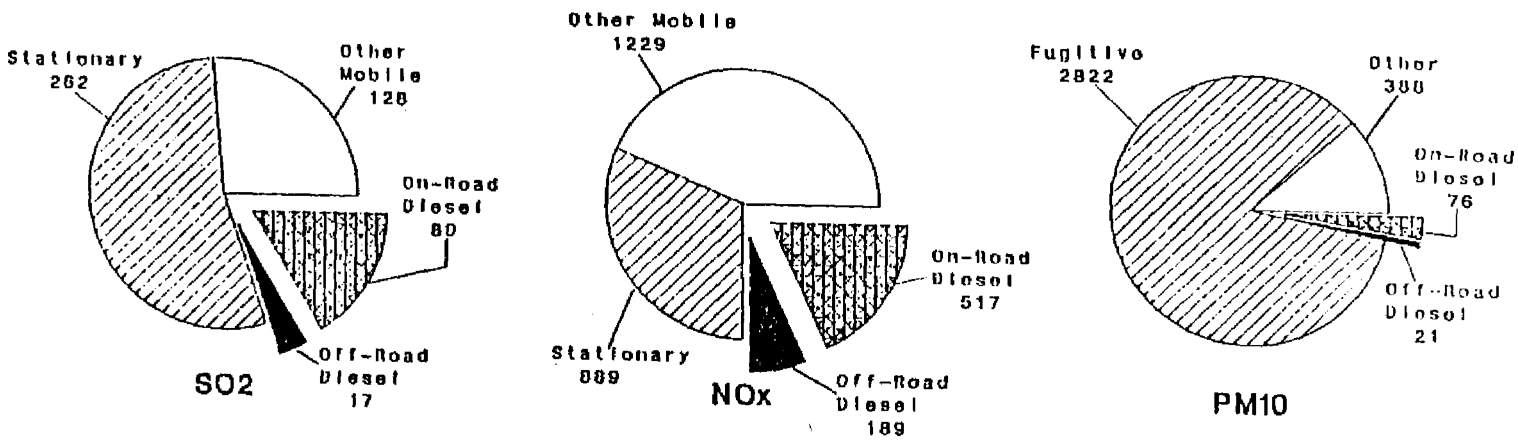
Source Category	Pollutant SO_2	NO_x	PM10 Fugitive	Other*
Total	487	2824	2822	488
Stationary	262	889	2760	339
Mobile	225	1935	62	146
Diesel-fueled vehicles				
Total	97	706	9	97
On-Road	80	517	9	76
Off-Road	17	189	0	21

* "Other" PM_{10} emissions consist of PM_{10} emissions other than road dust, windblown dust, agricultural tillage dust, etc. Fugitive emissions from diesel-fueled vehicles includes tire and brake lining wear.

Source: ARB/SSD/TSD

Figure 1

1990 Projected Statewide Emissions*
Tons per Day



* No controls beyond what exists in 1989.

Source: ARB/SSD/TSD

upon first inspection of the table, these emissions are important when compared to emissions for which control technology is available. Table 1 shows that fugitive emissions are the greatest fraction of the total PM_{10} emissions. These emissions include road dust, dust from agricultural tillage, dust from brake lining wear, and dust from other sources which cannot be readily controlled. When the nearly 100 tons per day of PM_{10} from diesel-fueled motor vehicles is compared with the 489 tons per day of emissions from industrial, mobile, and other "controllable" sources, the importance of the diesel-fueled motor vehicles emissions becomes greater.

B. EMISSIONS PROJECTIONS TO 2010

Figures 2, 3, and 4 present our projected statewide emission estimates for emissions of NO_x, PM_{10}, and SO_2. The projected emissions reflect a statewide growth rate in diesel fuel use of about 25 percent from 1990 to 2010. These figures include the emission reduction effects of regulations that are now in place, including those with future effective dates. Figure 2 shows NO_x emissions increasing throughout the period 1990 to 2010 despite control measures now in place. The increase in NO_x emissions from about 700 tons per day in 1990 to over 900 tons per day in 2010 is largely attributable to expected growth in the number of diesel-fueled motor vehicles and an increase in their

Figure 2

Projected Statewide Inventory of
NOx Emissions from Diesel Motor Vehicles

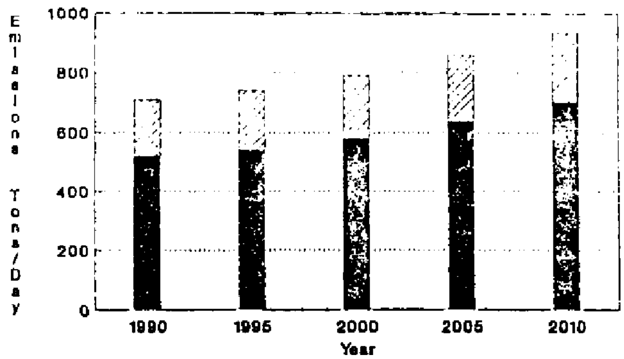


Figure 3

Projected Statewide Inventory of PM10
Emissions from Diesel Motor Vehicles

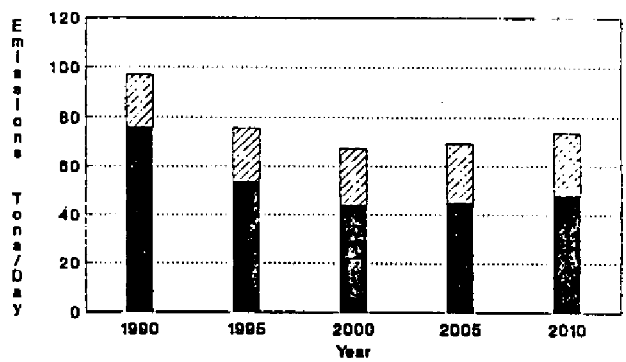
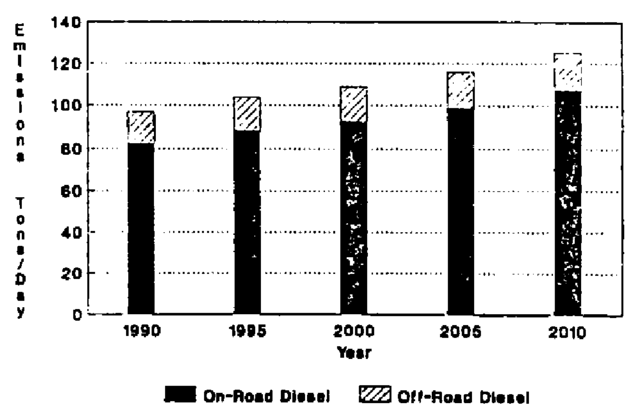


Figure 4

Projected Statewide Inventory of SO2
Emissions from Diesel Motor Vehicles



Source : ARB/SSD/TSD

use. It also reflects that the NO_x emission standard for heavy-duty diesel engines has not changed appreciably over the past decade.

Figure 3 shows projected PM_{10} emissions from diesel-fueled motor vehicles for the same period. The figure shows that from nearly 100 tons per day in 1990, emissions decrease to about 70 tons per day between 2000 and 2005, before beginning to increase. This trend is the result of two factors. The first is lower PM emissions from the introduction into the fleet of cleaner heavy-duty diesels which meet the 1991 and 1994 emission standards. The second is increased emissions due to growth in vehicle use, both on-road and off-road (off-road vehicles are not subject to the standards) throughout the period. The growth in diesel vehicle use eventually results in a net overall increase in PM emissions when growth overwhelms the reductions from fleet turnover.

Figure 4 presents statewide projected SO_2 emissions from diesel-fueled motor vehicles. In developing Figure 4, we assumed a constant sulfur content of 0.28 percent for motor vehicle diesel fuel sold outside the South Coast Air Basin and Ventura County. Because SO_2 emissions depend directly on the amount of fuel used and the sulfur content of the fuel, the steadily increasing emissions are solely due to an increase in fuel use from 1990 to 2010.

III.

EMISSIONS REDUCTIONS FROM DIESEL FUEL MODIFICATIONS

A. SULFUR CONTENT

1. Pollutants Attributable to Sulfur in Diesel Fuel

The sulfur in diesel fuel is responsible for emissions of gaseous sulfur dioxide and particulate sulfates. Each pound of sulfur in diesel fuel is converted, in the combustion process, to two pounds of sulfur dioxide, except for a small percentage that is converted to a sulfate species. However, even though the percentage of sulfur that becomes directly emitted sulfate particulate matter is small, it can be an important fraction of the total exhaust particulate matter. Sulfur dioxide is a pollutant itself and is also converted to particulate sulfate in the atmosphere. The degree of conversion depends on a variety of atmospheric and meteorological conditions.

2. Reductions of Emissions of Sulfur Dioxide

We estimate that the diesel fuel sulfur content for those areas outside the SCAB and Ventura County is 0.28 percent.[1,2/] A reduction in diesel fuel sulfur content to 0.05 percent, or 500 parts per million (ppm), would reduce sulfur dioxide emissions from diesel-fueled motor vehicles by approximately 80 percent. Of course, this reduction is required in the South Coast Air Basin and Ventura County because of previous ARB action.

3. <u>Reductions of Sulfate Particulate</u>

In addition to the reduction of directly emitted particulate sulfate, part of the sulfur dioxide that is emitted is converted in the atmosphere to various particulate sulfate compounds. Sulfate particulate matter lies within the PM_{10} size range. The variation in the conversion of sulfur dioxide to particulate matter has been reported to be 25 percent to 75 percent[3/] depending on atmospheric conditions. To convert sulfur dioxide emissions to equivalent PM_{10} emissions for purposes of this analysis, we used the low end of the range of reported conversion (25 percent) and a "weight gain factor" of 2.3 to account for other chemical species that are added to the sulfate in the atmosphere. This results in an overall equivalency of PM_{10} to sulfur dioxide emissions of about 0.6. This means that for each pound of sulfur dioxide emissions reduced, the equivalent of 0.6 pound of PM_{10} would be reduced.

B. AROMATIC HYDROCARBON CONTENT

A number of investigators have evaluated the effects of fuel quality on emissions from diesel engines. Their studies show that the aromatic hydrocarbon content of diesel fuel affects particulate matter emissions.

1. <u>Coordinating Research Council Tests</u>

The Coordinating Research Council (CRC), an organization of the Motor Vehicle Manufacturers Association and the American Petroleum Institute, is sponsoring a test program to evaluate how fuel composition affects heavy-duty diesel emissions. The ARB participated as minority sponsor in providing funding to expand the scope of the test program. The purpose of the CRC study, being conducted by Southwest Research Institute (SwRI), is to test a number of heavy-duty diesel engines on a number of fuels with varying levels of aromaticity, sulfur content, and volatility. The data generated by this testing is to be analyzed in order to determine how these fuel properties affect emissions of regulated and non-regulated pollutants as well as the toxicity of the exhaust particulate. The study has been underway for two years and testing has been completed on two of the three engines scheduled for testing.

Emission testing of heavy-duty diesel engines is complex and expensive, especially at the level of precision needed to accurately discern changes in emissions due to differences in fuel properties. The emissions tests are labor intensive, and the use of the transient test cycle requires precise computerized equipment to produce the test cycle. Few organizations are equipped to perform such tests. Most of the diesel engine emission testing that has been done by independent parties has been conducted by SwRI. SwRI devoted a considerable amount of time to the blending of the 9 test fuels in order to obtain the desired fuel characteristics. In conjunction with engine testing, a CRC committee managed the project and periodically reviewed the resultant data and recommended further action. The test plan called for 5 types of tests on each of the 9 fuels. With 2 to 3 duplicate tests required to ensure reproducibility, each engine received between 90 and 135 tests. Testing of a third engine was delayed because of a mechanical failure which destroyed the engine. However, testing of a similar engine is currently underway.

The CRC has released to us the raw data from the first two engine tests. We have analyzed the data and developed predictive equations that relate fuel properties to emissions. The CRC takes no responsibility for the analyses presented here although the steering committee for the CRC project, the VE-1 Committee, commented on our analyses. The Committee's comments are appended to the Technical Support Document.

2. <u>Tests by Other Investigators</u>

Although the CRC tests are the most rigorous tests that have been performed to date, other investigators have conducted tests that show the relationship of diesel fuel aromatic hydrocarbon content with PM and NO_x emissions. Those investigators and their findings are listed in Table 2.

Table 2

Summary of Test Results on
the Directional Effect of Reduced Aromatic
Hydrocarbon Content on Diesel Engine Emissions

	Effects of Decreased Fuel Aromatic Hydrocarbon Content on Emissions	
Investigator	PM	NO_x
EPA	Decrease	Decrease
Chevron Research	Decrease	No Effect
Caterpillar/Mobil	Decrease	Decrease
CRC	Decrease	Decrease

3. Emission Reduction Analysis

The two engine tests upon which we based our analyses are the CRC tests on a Cummins NTCC 400 and a Detroit Diesel DDAD 60. These engines had different emission levels and directionally consistent but different responses to changes in fuel quality. We have analyzed the data for each engine separately. The results of our analyses are shown in Table 3.

Table 3 shows the emission responses of the two engines to changes in fuel composition. Particulate matter and NO_x emissions are shown as decreasing in response to reductions in the aromatic hydrocarbon content of the fuel. There are two sets of entries for each engine, one entry for the South Coast Air Basin and one entry for other areas of the state. Separate analyses were done because the predictive equations include

Table 3

Emissions of Particulate Matter and NOx
for the Cummins and DDAD Engines

	Emissions Grams per Horsepower-Hour			
Fuel Aromatic Hydrocarbon Content, % by Volume:	31%	20%	15%	10%
Fuel Sulfur Content, % by Weight:	*	0.05%	0.05%	0.05%
Cummins Engine				
SCAB				
PM	0.494	0.451	0.431	0.412
NOx	4.622	4.483	4.420	4.356
Other Areas				
PM	0.514	0.451	0.431	0.412
NOx	4.622	4.483	4.420	4.356
DDAD Engine				
SCAB				
PM	0.233	0.221	0.215	0.209
NOx	4.746	4.435	4.294	4.152
Other Areas				
PM	0.302	0.221	0.215	0.209
NOx	4.746	4.435	4.294	4.152

* The baseline sulfur content for areas outside the SCAB and Ventura County is 0.20 percent, and the baseline sulfur content for the SCAB and Ventura County is 0.05 percent.

Table 4

Percent Emissions Reduction for NOx and Particulate Matter
for Cummins and DDAD Engines*

	Percent Emissions Reduction		
Fuel Quality Scenario:	20% Aromatics 0.05% Sulfur	15% Aromatics 0.05% Sulfur	10% Aromatics 0.05% Sulfur
Cummins Engine			
SCAB			
PM	9	13	17
NOx	3	4	6
Other Areas			
PM	12	16	20
NOx	3	4	6
DDAD Engine			
SCAB			
PM	5	8	10
NOx	7	10	13
Other Areas			
PM	27	29	31
NOx	7	10	13

* The predictive equations for PM emissions included sulfur variables. Percent emission reductions are based on uncontrolled fuel containing 31 percent aromatic hydrocarbons, with sulfur contents of 0.05 percent in the South Coast Air Basin and Ventura County, and 0.20 percent elsewhere in the state.

Source: ARB/SSD analysis of CRC data.

factors for the sulfur content, and the sulfur content of diesel fuel is different in the South Coast Air Basin than in the rest of the state. Therefore, when analyzing the data for the South Coast Air Basin, we used a baseline sulfur content of 0.05 percent–the maximum allowed by Air Resources Board requirements. For other areas of the state, we used a baseline sulfur content of 0.28 percent.

Table 4 shows the percentage effect of changes in fuel quality on emissions. This table was prepared by comparing the emissions for each lower aromatics/lower sulfur fuel in Table 3 with the emissions for the baseline fuel and converting the differences into percent changes. The table shows that as aromatic hydrocarbon content is reduced, emissions of particulate matter and oxides of nitrogen go down.

C. HOW FUEL AROMATIC HYDROCARBONS AFFECT PARTICULATE EMISSIONS

The aromatic hydrocarbons in diesel fuel play an important role in particulate matter formation. Researchers have theorized that aromatic hydrocarbons, during the combustion process, produce chemical species that contain a high ratio of carbon to hydrogen and that are very unstable. These species, because of their instability, tend to react with each other to agglomerate and produce highly carbonaceous particulate matter. Researchers at General Motors conducted studies on a light-duty vehicle engine that demonstrated that, of the fuel components, aromatic hydrocarbons were the greatest contributors to carbonaceous particle formation.

D. HOW FUEL AROMATIC HYDROCARBONS AFFECT NO_x EMISSIONS

Diesel engines can produce NOx by two different mechanisms. Thermal NOx is produced when the nitrogen in the combustion air combines with oxygen in the air. Fuel NO_x is produced from the nitrogen contained in the fuel and the oxygen in the combustion air. Thermal NO_x is generally regarded as the most important of the two mechanisms. Researchers have shown that for spark-ignited engines in-cylinder temperatures can be lower for a less aromatic fuel than for a more aromatic fuel.[4/] Lower temperatures, in turn, result in less thermal NO_x formation. Regarding fuel NOx, the refining process that would be used to produce lower levels of aromatic hydrocarbons in diesel fuels would also reduce fuel nitrogen concentrations. To the extent that fuel nitrogen contributes to NOx emissions, fuels manufactured to contain low aromatic hydrocarbon concentrations would produce less NOx.

E. EMISSION REDUCTIONS

To evaluate the emission reductions that could be achieved in future years by reducing the sulfur content and the aromatic hydrocarbon content of motor vehicle diesel fuel, we calculated emission inventories for future years using emission factors modified to reflect the results of the CRC tests. To develop these estimates many assumptions had to be made about the mix of future engine technology and the affect of fuel content on emissions from a wide variety of engine technologies. In our analysis the Cummins engine was used to represent existing engine technology, and the DDAD engine future engine technology (1991 and later models). As a means of comparison we also evaluated emission reductions that would be obtained if the estimates were based on the results of all the engine tests shown in Table 2. By averaging the results from those tests, the emission reductions for the fleet are greater than using the CRC tests only. Because we believe that the CRC tests are the most complete, and in order to present a conservative estimate of emission reductions, we used only the CRC test results.

The results of these analyses for future years are shown in Figures 5 and 6. The upper line in each graph represents emissions with no new fuel requirements and the lower line represents emissions with requirements for 0.05 percent sulfur content and 10 percent aromatic hydrocarbon content.

Table 5 presents the emission reductions that could be achieved for a sulfur content of 0.05 percent and different levels of aromatic hydrocarbon content for the years 1995, 2000, 2005, and 2010. The table shows the increasing amounts of PM and NO_x reduced as the aromatic hydrocarbon content is reduced. The emission reductions shown for a sulfur content of 0.05 percent and 10 percent aromatic hydrocarbon content are those presented in Figures 5 and 6.

Figure 5

Projected Statewide PM10 Emissions
from Diesel Motor Vehicles

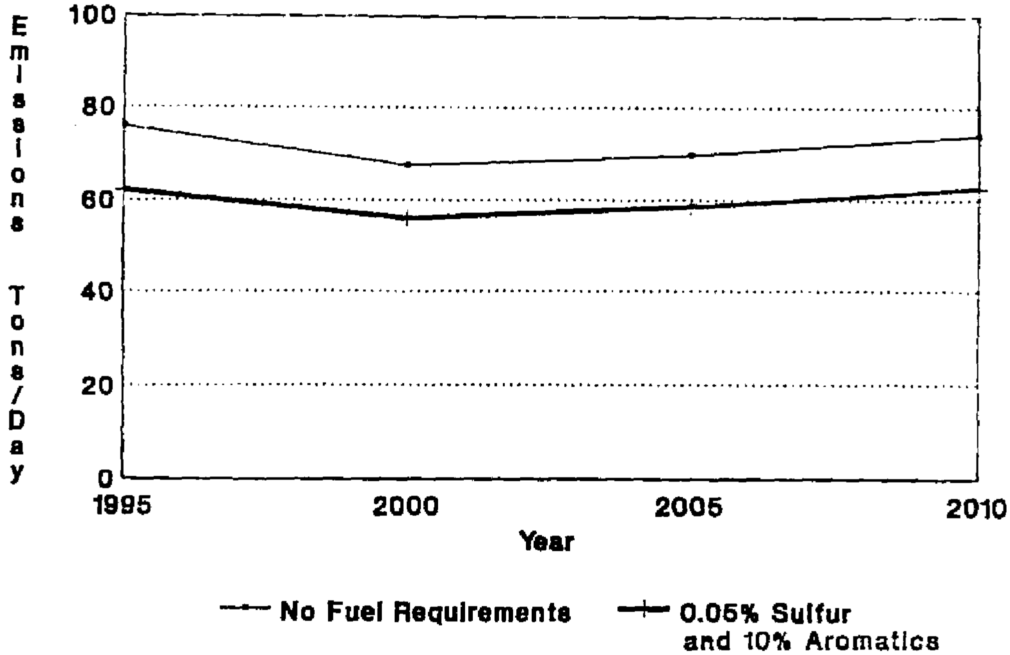
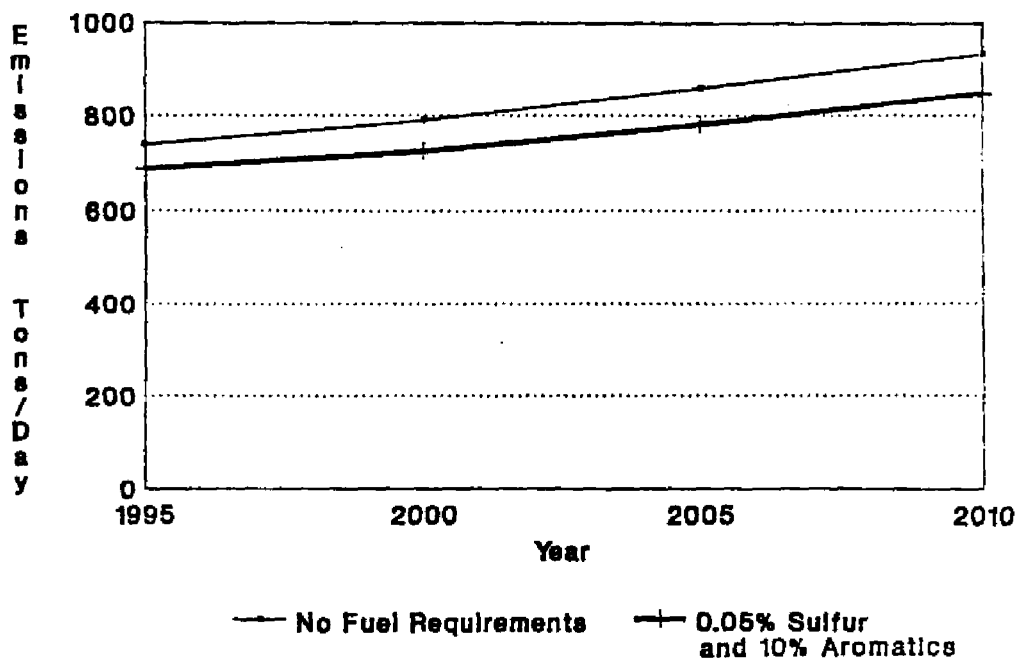


Figure 6

Projected Statewide NOx Emissions
from Diesel Motor Vehicles



Source: ARB/SSD/MSD/TSD

Table 5

Estimated Emission Reductions
for Different Fuel Quality Scenarios

Fuel Quality Scenario	Emissions Reductions (Tons/Day)			
	1995	2000	2005	2010
0.05% Sulfur				
SO_2	80	84	89	96
PM	4	4	5	5
NO_x	0	0	0	0
0.05% Sulfur and 20% Aromatics				
SO_2	80	84	89	96
PM	9	8	8	8
NO_x	27	34	39	44
0.05% Sulfur and 15% Aromatics				
SO_2	80	84	89	96
PM	11	10	10	10
NO_x	40	51	59	65
0.05% Sulfur and 10% Aromatics				
SO_2	80	84	89	96
PM	14	12	11	11
NO_x	53	67	78	87

Source: ARB/SSD

es ... produ ...

... with a sulfur content of 0.05 percent and various ...els of aromatic hydrocarbon content. The bases for our cost estimates are shown in Table 6. In our evaluation, we have used the hydrodearomatization process as the process to reduce the aromatic hydrocarbon content of diesel fuel. Although the aromatic hydrocarbon content of diesel fuel is not now being reduced using this process, it is in commercial use for reducing the aromatic hydrocarbon content of jet fuel. A licensor of such a process has informed us that there should be no technological barrier to using this process to reduce the aromatic hydrocarbon content of diesel fuel. Application of the hydrodearomatization process to reduce aromatic content of diesel fuel to 10 percent will require pilot studies to obtain needed design information. Thus, industry has contended that this technology is not proven for the 10 percent aromatics option.

The basis for our capital investment requirements is the volume of fuel that would be produced to meet the demand for motor vehicle diesel fuel. Refiners have stated that there would be additional costs to segregate the fuel that would be subject to the requirements from the fuel that would not be subject. We have estimated those costs to be less than 0.5 cents per gallon based on new tank and associated equipment costs.

Table 6

Basis for ARB Staff Cost Analysis

<u>All Refiners</u>

- Arthur D. Little Process Unit Costs
- Arthur D. Little Capital Recovery Factor
- Motor Vehicle Diesel Fuel Production Rate Equal to 55 Percent of Distillate Production
- Hydrorefining and Hydrodearomatization Added to Reduce Sulfur and Aromatic Hydrocarbon Content
- Hydrodearomatization Reduces Aromatic Hydrocarbon Content to 7 Percent
- Hydrogen Production Facilities Added to Meet Hydrogen Requirements

<u>Large Refiners</u>

- Modified Arthur D. Little Analysis
  - Methanol-to-Distillate Process Replaced by Hydrodearomatization Process
  - Hydrodearomatization Capacity Equal to 2.5 Times Methanol-to-Distillate Production Capacity
  - No Feedstock Costs

<u>Small Refiners</u>

- Individual Refinery Basis
- Analysis Done Outside the Arthur D. Little Model

Source: ARB/SSD

Because those costs are small, compared to the total cost, we have not included them in the following analyses.

B. COST ANALYSIS RESULTS

Table 7 presents the results of our cost analysis. Included in the table are the cost categories for capital investment, total daily costs, and cost per gallon.

1. Capital Cost

Table 7 shows that the capital cost of the proposal is considerable, over $700 million for the most stringent option. While approximately three quarters of the cost burden falls on large refiners, the capital investment for small refiners is disproportionately high when compared to the volume of diesel fuel they produce. For example, for the case of 0.05 percent sulfur and 20 percent aromatic hydrocarbons, small refiners as a group would need to invest about 140 million dollars to produce the required fuel. This means that small refiners would need to invest 25 to 30 percent of the total required of the industry as a whole, even though they produce only 15 percent of the fuel. For reasons discussed later in this report there are less costly options available to small refiners which they can be expected to pursue if available. These options would reduce the overall cost of the measure and make it more cost-effective than shown in Tables 7 and 8. The analysis that follows is therefore conservative in the view of ARB staff.

At workshops to discuss cost issues, refinery representatives contended that Arthur D. Little's capital cost

Table 7

Cost to Refineries for Diesel Fuel Sulfur and Aromatics Hydrocarbon Content Reduction

Fuel Quality	Capital Investment, $ Million	Total Costs, $ Thousand per Day
0.05% Sulfur		
Small Refiners	100	90
Large Refiners	120	110
0.05% Sulfur and 20% Aromatics		
Small Refiners	140	130
Large Refiners	370	380
0.05% Sulfur and 15% Aromatics		
Small Refiners	150	140
Large Refiners	500	500
0.05% Sulfur and 10% Aromatics		
Small Refiners	170	160
Large Refiners	550	610

Table 8

Incremental Cost Increase to the Price of Diesel Fuel for Reducing the Sulfur and Aromatic Hydrocarbon Content of Motor Vehicle Diesel Fuel

Fuel Composition	Cents per Gallon of Diesel Fuel
0.05%S	
Small refiners	11
Large refiners	2
0.05%S and 20% Aromatics	
Small refiners	16
Large refiners	6
0.05%S and 15% Aromatics	
Small refiners	18
Large refiners	9
0.05%S and 10% Aromatics	
Small refiners	19
Large refiners	11

Source: ARB/SSD

estimates were low. Arthur D. Little's capital equipment costs formed the basis of our capital investment estimates. The refinery representatives proposed that the capital costs should be doubled to more adequately reflect needed capital investment. While we do not concur with these estimates we performed a sensitivity analysis to determine the effect of doubling capital cost on the overall costs, estimated by Arthur D. Little, of producing low sulfur/low aromatic hydrocarbon diesel fuel. For large refiners, doubling the capital cost results in increases in total cost of 50 to 64 percent. For small refiners, doubling the capital cost increases total cost by 24 to 84 percent. Our analysis is presented in the Technical Support Document.

A refining industry representative questioned our capital cost estimates, stating that those estimates were too low. The basis for this statement was that construction costs would escalate by 30 percent and the costs would be increased by 63 percent because new technology has an associated capital cost penalty. Several other industry representatives stated that our costs were understated because we had assumed aromatic hydrocarbon content reductions to levels that would severely increase costs. We recognize the inherent uncertainties of our cost estimates. We have performed sensitivity analyses, such as the one referred to above for the effect of doubling capital costs. The uncertainties in capital costs would fall into the sensitivity range presented above. We have responded more fully to these and other comments on costs in the Technical Support Document.

2. Cost per Gallon

Table 8 shows the cost per gallon of producing diesel fuel with a 0.05 percent sulfur content limit and several aromatic hydrocarbon content limits. The cost per gallon of reducing the sulfur content and the aromatic hydrocarbon content of motor vehicle diesel fuel is obtained by dividing the annual production cost by the annual volume produced. It should be noted that the increase in cost of production cannot be directly related to retail price. Retail price increases could be more or less than the cost shown, depending on many other manufacturing and marketing factors.

3. Cost-Effectiveness

The value for cost-effectiveness is obtained by dividing the cost of a control measure by the emissions reductions from the measure. Table 9 shows the cost-effectiveness of emissions reductions from reducing the sulfur and aromatic hydrocarbon contents of motor vehicle diesel fuel.

Since a number of pollutants are reduced by the proposal, and each is affected somewhat differently, the calculation of cost-effectiveness is necessarily complex and can be viewed in several ways. We have used three methods of presenting cost-effectiveness values: (1) The cost is divided by two and allocated equally between estimated reductions of PM and NO_x emissions considered individually; (2) The total cost is divided by the sum of the PM and NO_x emissions reductions; (3) The total cost is divided by the sum of reductions of PM emissions, NO_x emissions, and SO_2 emissions to obtain the cost-effectiveness of total pollutants reduced.

Table 9 shows that, as would be expected from the higher costs to small refiners, the cost-effectiveness in dollars per pound of emissions reduced is two to six times higher for small refiners than large refiners.

4. Other Perspectives on Cost-Effectiveness

In addition to the perspectives presented above, there are other ways of analyzing cost and effectiveness. At workshops to discuss costs, emission reductions, and cost-effectiveness, refining industry representatives requested that we prepare an analysis of the cost-effectiveness for reducing the aromatic hydrocarbon content of diesel fuel over and above the reduction of diesel fuel sulfur content. Such an analysis is referred to as an "incremental" cost analysis.

The statewide incremental cost-effectiveness can be estimated by using the differences in daily cost for the different fuel quality scenarios, as shown in Table 7, and the differences in emission reductions for those same scenarios as shown in Table 5. The difference in cost divided by the difference in emission reductions provides the incremental cost-effectiveness. Another way of evaluating incremental cost-effectiveness is to consider the situation in the South Coast Air Basin. Because there is already a requirement for low sulfur

Table 9

Cost-Effectiveness of Emission Reduction from
Diesel Fuel Sulfur and Aromatics Hydrocarbon Content Reduction

1995

Regulatory Scenario	Cost (cents/gallon)	Cost-Effectiveness ($/lb of Emissions Reduced) PM	NOx	PM + NOx	Total Pollutants*
0.05% S, No Aromatics Reduction					
small refiners	11	107.5	-	107.5	4.6
large refiners	2	18.8	-	18.8	0.9
0.05% S and 20% Aromatics					
small refiners	16	31.1	10.0	15.2	4.7
large refiners	6	12.6	4.0	6.2	1.9
0.05% S and 15% Aromatics					
small refiners	18	26.9	7.6	11.8	4.6
large refiners	9	13.8	3.8	6.1	2.3
0.05% S and 10% Aromatics					
small refiners	19	24.1	6.3	9.9	4.6
large refiners	11	13.8	3.5	5.6	2.6

* Cost-effectiveness for total pollutants reduced includes dierectly emitted PM, NOx, and sulfur dioxide.

Table 10

Incremental Cost-Effectiveness of Emission Reduction in the South Coast Air Basin from
Reducing Aromatic Hydrocarbon Content When Diesel Fuel Sulfur Content is 0.05 Percent

1995

Regulatory Scenario	Cost (cents/gallon)	Cost-Effectiveness ($/lb of Emissions Reduced) PM	NOx	PM + NOx	Total Pollutants
0.05% S and 20% Aromatics					
small refiners	16	64.8	11.7	19.6	19.6
large refiners	6	26.2	4.7	8.0	8.0
0.05% S and 15% Aromatics					
small refiners	18	48.5	8.7	14.7	14.7
large refiners	9	24.9	4.5	7.6	7.6
0.05% S and 10% Aromatics					
small refiners	19	40.0	7.2	12.2	12.2
large refiners	11	22.6	4.1	6.9	6.9

Source: ARB/SSD

diesel fuel in effect in the SCAB, a cost-effectiveness analysis for reduced aromatic hydrocarbon content of diesel fuel for theSCAB is an incremental analysis. Table 10 shows the cost-effectiveness in the SCAB of adding low aromatic hydrocarbon content requirements to existing sulfur limits.

The table shows that the cost per pound of total emissions reduced is greater than for the state as a whole. While overall costs are less, no SO_2 emission reductions occur as they do for the statewide case. For Table 10, the total emission reductions consist of PM and NO_x emission reductions. The values shown in the tables are the incremental cost-effectiveness values of reducing the aromatic hydrocarbon content of motor vehicle diesel fuel. We also considered the additional indirect benefit that occurs from reducing SO_2 emissions when the emissions lead to the conversion of sulfur dioxide to particulate sulfates or PM_{10}. As previously discussed, we estimate that, conservatively, each pound of sulfur dioxide is converted to 0.6 pound of PM_{10}. Table 11 shows the effect of considering the additional benefits. As in Table 9, half of the costs are assigned to each pollutant reduced. The result is a more cost-effective ratio for particulate matter reduction than shown in Table 9 for directly emitted PM reduction alone.

In evaluating cost-effectiveness, we have not included as a "credit" the economic benefits that would be realized from reduced sulfur and aromatic hydrocarbon content. Those benefits, discussed in more detail elsewhere in this report, include

Table 11

Cost-Effectiveness of Emissions Reductions from Diesel Fuel Sulfur and Aromatics Hydrocarbon Content Reduction When SO_2 Reductions are Included as Sulfates

1995

Regulatory Scenario	Cost (Cents/Gallon)	Cost-Effectiveness ($/lb ofEmissions Reduced) PM	NO_x	Total*
0.05% Sulfur				
Small Refiners	11	7.6	-	7.6
Large Refiners	2	1.3	-	1.3
0.05% Sulfur and 20% Aromatics				
Small Refiners	16	4.9	10.0	6.6
Large Refiners	6	2.0	4.1	2.7
0.05 Sulfur and 15% Aromatics				
Small Refiners	18	5.2	7.5	6.2
Large Refiners	9	2.7	3.9	3.2
0.05 Sulfur and 10% Aromatics				
Small Refiners	19	5.5	6.3	5.9
Large Refiners	11	3.1	3.5	3.3

* Total pollutants reduced includes directly emitted PM, NO_x, and secondary sulfate PM.

Source: ARB/SSD

increased diesel engine life, extended oil change intervals, visibility improvement, and reductions in soiling. Also, our analysis of cost-effectiveness is based only on emissions of criteria pollutants, that is, SO_2, PM, and NO_x. As discussed in Chapter V, there would also be reduced risk from cancers associated with diesel exhaust particulate matter.

To compare the cost-effectiveness of reduced sulfur and aromatic hydrocarbon content as a control measure, below are listed some cost-effectiveness values for measures that have been adopted in recent years.

Source Applicability	Pollutant	Cost-Effectiveness $/Pound of Pollutant Reduced
1986 Light-Duty Diesel Exhaust Standard	PM	2.70 to 10.70
1989 Light-Duty Gasoline Vehicle Exhaust Standard	NO_x	0.65
1991 Heavy-Duty Diesel Exhaust Standard	NO_x	0.25
1991 Heavy-Duty Diesel Exhaust Standard	PM	1.50
1994 Heavy-Duty Diesel Exhaust Standard	PM	3.20
Refinery Boilers and Heaters Emission Limit (SCAQMD Rule 1109)	NO_x	4.40

C. COSTS FOR SMALL REFINERS

The cost to small refiners of producing low-sulfur/low-aromatic hydrocarbon content fuel are projected to be greater than the cost for large refiners on a per gallon basis. This situation has several important implications for small refiners and the overall cost to the refining industry of producing diesel fuel with lower sulfur and lower aromatic hydrocarbon content.

1. Options Available to Small Refiners

There are several ways in which small refiners could respond to the proposed diesel fuel specifications. First, as assumed in the staff analysis, small refiners could install the capital equipment needed to produce diesel fuel of the specified quality. Second, small refiners could choose to withdraw from the California motor vehicle diesel fuel market and invest no funds in new equipment. Third, small refiners could purchase low-sulfur/low-aromatic hydrocarbon content diesel fuel from large refiners and blend that fuel with fuel produced in the small refiners' facilities. The last option would still necessitate fuel desulfurization by small refiners before blending, so this option would require capital investment for equipment.

2. Evaluation of Costs for Small Refiner Options

We have evaluated the differing cost impact on the refining industry of the three options outlined above. The first option, in which all refiners install capital equipment to meet the proposed requirements, has been described in Table 7. The second option, in which all small refiners would choose alternative markets for their diesel fuel, would result in an increase in diesel fuel production by the large refiners to fill the void left in the market from the withdrawal of small refiners. The overall cost to the industry would decrease under this option because of economy of scale for processing diesel fuel in large refineries. While large refiners would benefit from greater motor vehicle diesel fuel sales, there would be adverse economic impacts on small refiners if diesel fuel that is now produced for motor vehicle use has to be sold in other markets that are less profitable. Those markets include marine and locomotive diesel fuel, and fuel used in external combustion applications. The small refiners' fuel could also be sold to major refiners for further processing. During the development in 1985 of the amendments to Section 2252 of the California Code of Regulations, one small refiner reported to us that diesel fuel could be sold as refinery processing feedstock at a loss of 7 to 8 cents per gallon when compared to the price it would command as motor vehicle diesel fuel.[4/]

In the third option, small refiners could purchase low-sulfur/low-aromatic hydrocarbon diesel fuel from large refiners and blend it with diesel fuel produced at the small refiners' facilities to produce a final product that would meet the separate requirements for small refiners. As a practical matter, this option could only be available if there is established a less stringent requirement for small refiners' motor vehicle diesel fuel than for large refiners. For example, a small refiner's diesel fuel containing 30 percent aromatic hydrocarbons could be blended with an equal volume of large refiners' fuel with 10 percent aromatic hydrocarbons to produce diesel fuel containing 20 percent aromatic hydrocarbons. Again however, the small refiner's fuel would have to be desulfurized.

We met with representatives of the small refiners to discuss the options available to them to comply with requirements for the sulfur content and aromatic hydrocarbon content of motor vehicle diesel fuel. At that meeting, the small refiners proposed a separate limit for the aromatic hydrocarbon content of diesel fuel produced by small refiners such that the limit could be met by blending. The small refiners indicated that they would meet such a standard by blending fuel purchased from large refiners with fuel that they produce at their refineries. We have included a provision for a separate limit in our proposal, as discussed further in Chapter VI.

3. Costs of Desulfurization

We have estimated that the cost to small refiners to desulfurize diesel fuel would be about 11 cents per gallon. The cost to large refiners to produce desulfurized diesel fuel with an aromatic hydrocarbon content of 10 percent would be also about 11 cents per gallon. Small refiners have reported to us that they could purchase fuel from large refiners, and transport it, for the large refiners' price plus 2 cents per gallon for transport and testing cost. A small refiner whose diesel fuel contains 30 percent aromatic hydrocarbons could, therefore, produce motor vehicle diesel fuel that contains 500 ppm sulfur and 20 percent aromatic hydrocarbons for a cost of about 12 cents per gallon, the average cost of the two blending stocks.

Table 12 presents a summary of the costs the options available to small refiners. It is important to note that the cost of selling fuel to non-vehicular markets is the estimate of one refiner as made in 1985. If significant numbers of refiners would choose this option, it could depress the price of non-vehicular fuel and cause a greater cost than the 7 to 8 cents per gallon shown in the table.

D. COST TO REFINERS AND THE PRICE OF MOTOR VEHICLE DIESEL FUEL

The basis for our cost estimates is an after tax analysis, that is, what the refiners would have to recover such that the production of a specified motor vehicle diesel fuel would be "revenue neutral". However, as noted earlier, the relationship of the increased cost to the refiner and the retail price is dictated by market forces. For example, the additional cost of producing diesel fuel might be spread to other petroleum products, such as gasoline, so that the full increased cost of

Table 12

Cost to Small Refiners of a Limit on Sulfur Content of 0.05 Percent and a Limit on Aromatic Hydrocarbon Content of 20 Percent for Motor Vehicle Diesel Fuel

Option for Compliance	Capital Investment ($ million)	Cost of Purchased Blendstocks (cents per gallon)	Overall Cost to Small Refiners (cents per gallon)
Install Equipment to Reduce Sulfur and Aromatics Content	$ 140	N/A*	16
Dispose of Fuel to Non-Vehicular Markets	0	0	7 to 8
Install Equipment to Reduce Sulfur Content, Purchase Blendstocks to Reduce Aromatics Content	$ 100	11	12

* N/A = not applicable

Source: ARB/SSD

production might not appear as a passed through cost at the retail level. However, for the purposes of our evaluation of economic impacts, discussed in the next chapter, we have assumed a full cost pass-through.

V.

IMPACTS ASSESSMENT

We are proposing requirements for motor vehicle diesel fuel that would limit the sulfur content to 0.05 percent, and the aromatic hydrocarbon content to 10 percent for large refiners and to 20 percent for small refiners. The impacts of our proposals are presented below. A detailed description of our proposals is presented in the following chapter.

A. EMISSIONS IMPACTS

1. Emissions from Diesel-Fueled Vehicles

The proposed requirements for the sulfur and aromatic hydrocarbon content for motor vehicle diesel fuel would reduce exhaust emissions from diesel-fueled vehicles, based on the projected emission inventory for 1995 as follows:

SO_2 - 80 tons per day (75 percent reduction)
PM - 16 tons per day (22 percent reduction)
NO_x - 50 tons per day (7 percent reduction)

2. Emissions from Refineries

The additional processing and associated operating changes at refineries required to produce the diesel fuel could result in increased emissions of SO_2 and NO_x at those facilities. Emissions from new and modified equipment would be minimized by the air pollution control districts' requirements for best available control technology for such new and modified sources. District rules requiring offsets will also minimize emission increases. Some refiners have indicated concern that off-setting emissions reductions might not be available, creating an obstacle to obtaining needed air quality permits. The ARB is working with the districts affected by the proposal to remove any such obstacles.

B. AMBIENT AIR QUALITY AND HEALTH BENEFITS

The proposed regulations would reduce ambient concentrations of PM_{10}, nitrogen dioxide, ozone, sulfur dioxide, and sulfates. The reduction of motor vehicle diesel emissions would also improve visibility as a result of reducing ambient concentrations of these pollutants. The improvement of air quality related to the emission reductions would depend on the particular area of the state and the contribution of diesel-fueled motor vehicles to air quality degradation in the particular area.

Reductions of directly emitted particulate matter from diesel-fueled motor vehicles would also reduce exposure to known and suspected carcinogens. We have estimated that for the South Coast Air Basin, the increased number of potential lung cancers from exposure to diesel exhaust particulate matter is 299 to 647 for the period 1995 to 2065. We estimate that the reduction of motor vehicle diesel particulate matter emissions in the South Coast Air Basin that would be achieved by the proposed regulations would reduce the increased number of potential cancers by 10 to 17 percent.

C. OTHER ENVIRONMENTAL IMPACTS

The catalysts used to reduce the sulfur content and the aromatic hydrocarbon content of diesel fuel contain metals. These metals may be nickel, molybdenum, cobalt, and some of the so-called "noble metals" such as platinum and palladium. If disposed of improperly, the spent catalysts could have an adverse impact on groundwater quality. However, catalysts are generally sent out for metals reclamation. If recycled, or if disposed of properly, no adverse impacts would result from the increased use of catalysts at refineries.

D. ECONOMIC IMPACTS

The proposed regulations would result in increased costs to the refining industry and to users of motor vehicle diesel fuel. We estimate that the capital investment for large refiners to install the appropriate processing equipment to meet the proposed requirements would be about $550 million. The capital investment for small refiners to meet the small refiners requirements by desulfurizing diesel fuel and purchasing blendstocks from large refiners would be about $140 million. The estimated daily cost of producing motor vehicle diesel fuel that meets the proposed specifications is about $740,000 per day for the entire California refining industry. The increased wholesale price of diesel fuel would be 11 to 12 cents per gallon if the total cost were passed through.

As previously discussed, there are other options available to small refiners. The option that we believe is most likely is that small refiners would desulfurize diesel fuel and purchase low aromatic hydrocarbon diesel fuel from large refiners to use as a blendstock. The small refiners would blend the 10 percent aromatic hydrocarbon fuel with their own fuel to meet an aromatic hydrocarbon content limit of 20 percent. Such a strategy would reduce the small refiners' capital investment requirement. We estimate that for this scenario, for total cost pass through the increased price of diesel fuel would be about 11 cents per gallon.

Refiners have argued that, for various reasons, our cost estimates are too low. We have performed additional cost estimates in response to comments from the refining industry. Those cost estimates are included in the Technical Support Document.

By raising the price of diesel fuel the proposal would also increase trucking costs. We have estimated the cost increase for trucks based on miles traveled by trucks hauling various categories of products. For most categories of goods, the fuel cost increase based upon a complete cost pass-through would average less than two dollars per day of truck operation. More details are included in the Technical Support Document.

California's transit districts would also experience increased costs as a result of the increased price of diesel fuel. We have estimated that a diesel fuel price increase of 11 cents per gallon would increase the total expenses of California transit districts by less than one percent. Public transit fares traditionally provide only about one fourth of transit district revenues, but even if fare increases were used to cover the full cost of the more expensive fuel, the impact would be less than one cent on a one dollar fare.

We have also estimated the impact of increased fuel costs on users of motor vehicle diesel fuel grouped by industrial category. These groups include agriculture, forestry and lumber, construction, manufacturing, and others. Our evaluation shows that none of these categories would see an impact of increased diesel fuel price of greater than 0.50 percent of total sales.

There are also positive economic impacts associated with the proposed regulations. Reduced emissions of particulate matter from diesel engines would improve visibility and reduce soiling. The economic benefits of improved visibility include increased property values, and benefits to tourism. Reduced soiling means reduced requirements for washing and painting the interiors and exteriors of buildings, the laundering and cleaning of materials, and the washing of motor vehicles.

We estimate that the benefits of improved visibility and reduced soiling that would result from the proposed diesel fuel requirements would have a value exceeding $40 million per year in the SCAB and $60 million per year statewide. Our analyses of the economic benefits of reduced soiling and improved visibility are presented in the Technical Support Document.

E. OTHER IMPACTS

In addition to the impacts discussed above, there would be other impacts related to the proposed motor vehicle diesel fuel specifications. For example, a reduction in the sulfur content of motor vehicle diesel fuel would reduce engine wear, extend engine life, and increase the intervals between overhauls and oil changes. As discussed in Chapter I, fuel sulfur content reduction would also allow the use of catalytic after-treatment devices by engine manufacturers in their efforts to meet the 1994 exhaust PM standards.

Because diesel fuel in California is expected to cost more than in neighboring states, vehicles that enter the state to make a delivery and subsequently leave California have an incentive to purchase as little fuel as possible while in California. We have estimated that 18 percent of the vehicle miles traveled in California are attributable to vehicles with a route pattern that would allow them to maximize use of out-of-state fuel. To the extent that out-of-state purchases do occur, the effectiveness of the proposed requirements would be reduced and California retailers will lose sales. In our estimate of emission reductions, we assumed that all motor vehicle diesel fuel consumed in California would meet the proposed requirements. Since some consumption of out-of-state fuel will clearly occur, our simplifying assumption results in an over-estimation of benefits. However, the same assumption also results in an over-estimation of costs to the trucking industry.

Although the requirements of the proposals would affect only motor vehicle diesel fuel, the production of low sulfur or low-sulfur/low-aromatic hydrocarbon content diesel fuel would also allow air pollution control districts to more easily adopt requirements for the use of such fuel in stationary sources. If this occurs, the additional low sulfur, low aromatic fuel needed to meet the additional demand could be accomplished at a much lower cost than the average cost of the proposed.

F. COMPLIANCE WITH OTHER REGULATIONS

The modification of equipment, addition of new equipment, or an increase in throughput at refineries require new permits from the air pollution control disticts, local building authorities, fire districts, and other permitting authorities. The ability of refiners to comply with the proposed diesel fuel specifications depends on their ability to obtain the needed permits.

G. INDUSTRY CONCERNS

During consultation meetings to discuss the basis for the proposed regulations, representatives of the refining industry voiced their concerns on the following topics:

- Accuracy of emission reduction estimates
- Availability of technology to reduce aromatic hydrocarbon concentrations
- Cost of technology to reduce aromatic hydrocarbon concentrations
- Aromatic hydrocarbon content test method

In response to industry's concerns, we did additional studies and calculations regarding costs and emissions. We believe that our adjusted estimates of emission reductions, costs, and technology availability are sufficiently accurate to propose sulfur content and aromatic hydrocarbon content requirements for motor vehicle diesel fuel. Detailed responses to the industry's concerns are in the Technical Support Document.

Regarding the aromatic hydrocarbon content test method, we are aware of the limitations of the proposed method ASTM D 1319-84. The proposed method is used to determine the aromatic hydrocarbon content of diesel fuel. At present, it is the only accepted method that is in widespread use in the refining industry. The proposed method was used to determine the aromatic hydrocarbon content of the diesel fuels used in studies referenced in this report.

The reproducibility of the test method at the aromatic hydrocarbon levels we are proposing is about 25 percent which is poorer than the reproducibility of other fuel specification test methods. Also, the scope of the ASTM method states that it does not apply to fuels with final boiling temperatures greater than 600 degrees Fahrenheit. Although most California diesel fuels have final boiling temperatures greater than 600 degrees Fahrenheit, we propose that ASTM Method D 1319-84 be applicable as the method for the purposes of the proposed requirement. However, we have included in proposed Section 2256 an option for the use of other methods that could be used upon an equivalency determination by the ARB Executive Officer. We are investigating other methods that we would propose when such methods are validated.

VI.

DESCRIPTION OF THE PROPOSED REGULATIONS

We are proposing two new regulations governing the composition of motor vehicle diesel fuel for inclusion in Title 13 of the California Code of Regulations. The first proposed regulation is Section 2255-Sulfur Content of Motor Vehicle Diesel Fuel. The text of the proposal is shown in Attachment B. The second proposed regulation is Section 2256-Aromatic Hydrocarbon Content of Diesel Fuel. The text of the proposal is shown in Attachment C. We are also proposing that Section 2252, the existing regulation governing the sulfur content of diesel fuel in the South Coast Air Basin and Ventura County, be amended so that it does not apply to diesel fuel sold after the effective date of the new sulfur in diesel fuel regulation. The text of these amendments are set forth in Attachment D.

The proposed regulations would apply statewide. We believe statewide regulation is appropriate because nearly all areas in California have air quality problems to which diesel vehicles contribute. A group representing the petroleum and engine manufacturing industries recently proposed to the Environmental Protection Agency that the sulfur content of on-highway motor vehicle diesel fuel should be controlled nationwide at a level of 0.05 percent. We believe that in most cases it is appropriate for vehicle fuel regulations to apply nationally or statewide to provide air quality benefits to the greatest number of people and to reduce the use of non-complying fuel.

Our proposals are regulations to limit the sulfur content of motor vehicle diesel fuel to 0.05 percent and the aromatic hydrocarbon content to 10 percent. As of the date of publication of this report, we are continuing to investigate the appropriateness of other limits for the aromatic hydrocarbon content. Other limits for the aromatic hydrocarbon content are available as control options.

A. PROPOSED SECTION 2255--SULFUR CONTENT OF MOTOR VEHICLE DIESEL FUEL

1. <u>The Sulfur Content Limit.</u>

The regulation would impose a statewide sulfur content limit on motor vehicle diesel fuel of 500 ppm. As discussed elsewhere in this report, a 500 ppm limit is technologically feasible and would result in significant emissions reductions. A 500 ppm limit is already being met in the SCAB and Ventura County. Standard refinery processes can reduce the sulfur content of diesel fuel by 90 percent. The current Division of Measurement Standards (DMS) limit for the sulfur content of motor vehicle diesel fuel outside the SCAB and Ventura County is 5,000 ppm. A 90 percent reduction of the sulfur content of diesel fuel containing 5,000 ppm would result in diesel fuel containing 500 ppm sulfur.

2. Applicability to All Producers and Importers.

The regulation would apply to all motor vehicle diesel fuel in the state, regardless of who produced or imported the fuel. We believe this is the most equitable approach and will result in the greatest emissions reductions.

The existing regulation for the SCAB and Ventura County has included an exemption for small refiners. In 1985 the Board eliminated the exemption effective January 1, 1989. We believe that the reasons for eliminating the existing small refiner exemption also support not having such an exemption in a statewide regulation. The cost-effectiveness of applying the basic standard to small refiners compares favorably with other measures. An exemption results in substantially greater emissions because the DMS standard permits ten times the sulfur content as our proposed 500 ppm standard. An exemption would also result in an unintended economic advantage for small refiners. Because of the nature of refinery operations, an intermediate sulfur content standard for small refiners does not appear to be a practical option.

3. Compliance Date.

The proposed regulation would require compliance with the 500 ppm sulfur content limit as of January 1, 1993. This compliance date would provide leadtime generally comparable to that provided by previous fuels regulations, and would allow adequate time for large and small refiners to plan and install necessary new refinery equipment or develop alternative markets for diesel fuel.

Section 2252 originally provided three and one-half years for large refiners to comply with the low sulfur requirement for diesel fuel in the SCAB and Ventura County. The 1985 amendments similarly provided small refiners three and one-half years leadtime. Our proposed limits on the aromatic hydrocarbon content of diesel fuel would require somewhat more time because of greater capital equipment requirements for aromatic hydrocarbon content reduction compared to sulfur content reduction. Since many refiners would be expected to use the same refinery processes to comply with both the sulfur and aromatic hydrocarbon limits, it is advisable for both regulations to have the same date for final compliance. We believe that a January 1, 1993, effective date for both regulations would be consistent with the need for expeditious emission reductions and the need of refiners to have sufficient time to plan, design, and have necessary equipment installed.

4. <u>High-Altitude Winter Diesel Fuel.</u>

During the workshop process, some refiners indicated that it is necessary to blend quantities of higher sulfur jet fuel into diesel fuel sold at higher elevations during the wintertime in order to have an acceptable cloud point (the temperature at which wax crystals begin to appear in the fuel). This could make compliance with a 500 ppm sulfur content standard much more dificult.

The proposed regulation provides that the 500 ppm standard does not apply where two conditions are met: (1) the person selling the diesel fuel demonstrates that he or she has taken reasonable precautions to assure that the diesel fuel will be dispensed to vehicles only at altitudes of 3000 feet above sea level and only between November 1 and March 31, and (2) the sulfur content of the diesel fuel does not exceed 1500 ppm. We believe this will allow the use of sufficient amounts of jet fuel as a blend component, while having a minimal impact on the overall emissions reductions resulting from the regulation.

4. Compliance Mechanism.

(a) Flat Limit Applicable to All Motor Vehicle Diesel Fuel.

We propose that the 500 ppm sulfur content standard be a flat limit applicable to all batches of motor vehicle diesel fuel. We believe that this approach has distinct advantages over a regulation which permits averaging or offsetting different sulfur contents of different batches. The flat limit approach is also similar to that taken in almost all of the Board's other fuels regulations, including the existing limits on the sulfur content of motor vehicle diesel fuel in the SCAB and Ventura County.

With a flat limit, the regulation can be much more straightforward than if averaging or offsetting are allowed. Enforcement can be more effective and less costly because enforcement personnel can sample diesel fuel in the field instead of having to conduct audits of producers' records. A program dependent on the accuracy and integrity of tests and reports submitted by the regulated community has too great a potential for unreported violations. Additionally, the ability of staff to verify compliance through direct sampling minimizes the need for industry to submit reports to staff. Since the proposed 500 ppm sulfur content limit will apply to all batches and there will be no separate limit for small refiners, we do not believe that producers or importers need be required to maintain records of sulfur content tests as they have been in the existing regulation for the SCAB and Ventura County.

(b) <u>Applying the Limit Throughout the Distribution Network.</u>

Like the Board's other fuels regulations, the sulfur content limit would apply throughout the diesel fuel distribution network. This enables the enforcement staff to conduct tests and document violations at various points in the distribution process. For instance, "upstream" inspections at refineries can effectively identify large batches of noncomplying fuel before they leave the refinery. "Downstream" samples can help identify the presence of high sulfur diesel fuel originally intended for nonvehicular sources.

(c) <u>Prohibited Transactions.</u>

The proposed regulation prohibits the "sale, offer for sale, or supply" of vehicular diesel fuel exceeding the standard. A definition of "supply" would clarify that the term means to provide or transfer a product to a physically separate facility, vehicle, or transportation system. Because a supply can occur without relinquishment of the product to a separate entity, wholesale purchaser-consumers who fuel their own vehicles would be engaging in a supply. Thus there is no need to have a separate provision on wholesale purchaser-consumers dispensing fuel into their vehicles.

(d) Definition of "Vehicular Diesel Fuel."

The sulfur content standard would apply to "vehicular diesel fuel." The regulation only applies to motor vehicle diesel fuel because the Board has the direct authority to regulate the composition only of those fuels used in motor vehicles. (Western Oil and Gas Association v. Orange County APCD, 14 Cal. 3d 411 (1975)).

The regulation would contain a definition of "vehicular diesel fuel" identical to the existing Section 2252(f)(4) definition of "diesel fuel for use in motor vehicles in the south coast control area" except for changes in the geographic references. Diesel fuel which meets any of three tests would be included in the definition: (1) The fuel is not conspicuously identified as a fuel that may not lawfully be dispensed to motor vehicles in the control area; (2) the seller or supplier knows the diesel fuel will be used in motor vehicles in California, or (3) the seller or supplier reasonably should know the diesel fuel will be so used and s/he has not received a declaration stating that the purchaser or recipient will not sell the fuel for dispensing, or dispense it, into motor vehicles in California. The prohibitions on sales, offers or supplies would apply to diesel fuel which at the time of the transaction is "vehicular diesel fuel."

The proposed definition is intended to help assure that sellers of higher sulfur diesel fuel take reasonable precautions against subsequent use of the fuel in California vehicles. If they do not do so, we believe the sale should be subject to the regulation. At the same time, the definition assures that a person taking appropriate precautions is not liable where a subsequent party misuses the fuel.

(e) <u>Presumed Sulfur Content of Diesel Fuel Represented as Being for Nonvehicular Use</u>.

Diesel fuel will generally be represented as being for nonvehicular use only if it exceeds the ABB's specifications. However, direct test results of the sulfur content may not be available, and one of the elements in demonstrating a violation is proving that the diesel fuel was in fact above the limit. We are therefore proposing that where fuel has been represented as not for use in California motor vehicles, it shall be deemed to exceed the 500 ppm sulfur content limit unless it has been tested and shown to be in compliance.

(f) <u>Sales Attributed to Upstream Vendors.</u>

The regulation would provide that each retail sale of diesel fuel for use in a motor vehicle, and each supply of diesel fuel into a motor vehicle fuel tank, is also deemed a sale by any person who previously sold the fuel in violation of the substantive standards. This provision would help assure that Health and Safety Code Section 43016 "per vehicle" penalties will apply to persons who sell noncomplying diesel fuel to distributors, service stations or bulk purchaser-consumers. It is based on essentially identical language in Section 2252(d)(6).

5. Test Method.

The test method for determining the sulfur content of diesel fuel would be American Society for Testing and Materials (ASTM) Method D 2622-82, or any other method determined by the Executive Officer to give equivalent results. This is identical to the test method provisions in Section 2252.

6. Variances.

The regulation would authorize the issuance of variances in essentially the same manner as presently authorized in Section 2252. We believe that a variance provision is necessary to mitigate, in appropriate instances, extraordinary hardship that could result from application of the sulfur content standards.

In order to monitor progress towards compliance by January 1, 1993, we propose that the regulation require each producer to submit a compliance schedule. The schedule would be due at the beginning of 1990, with annual updates for the next two years. A variance based on a compliance plan involving the installation of major additional equipment could not be issued if installation of the equipment had not been included in the compliance schedule and updates. We do not believe a variance is appropriate in the absence of timely activity during the available leadtime period.

7. Other.

The proposed regulation includes various other provisions intended to make it more effective and practicable. These provisions are generally patterned after the terms of Section 2252, and have proven to be useful and appropriate.

B. PROPOSED AMENDMENTS TO SECTION 2252--SULFUR CONTENT OF DIESEL FUEL IN THE SOUTH COAST AIR BASIN AND VENTURA COUNTY

In order to avoid potential conflicts between the proposed new Section 2255 and the exisiting limits in Section 2252 on the sulfur content of diesel fuel sold for use in the SCAB and Ventura County, we propose adding a new Section 2252(o) stating that the section does not apply to diesel fuel sold, offered for sale, or transferred on or after January 1, 1993. We also propose a change in the title of the section to reflect the effect as amended.

C. PROPOSED SECTION 2256--AROMATIC HYDROCARBON CONTENT OF MOTOR VEHICLE DIESEL FUEL

1. The Basic Aromatic Hydrocarbon Content Limit.

The regulation would impose a basic statewide aromatic hydrocarbon limit on motor vehicle diesel fuel of 10 percent by volume (a less stringent limit would apply to small refiner diesel fuel as discussed below). The emission reduction and attendant health effects benefits of the 10 percent aromatic hydrocarbon content limitation are the greatest of the limits that we examined. Further emission reductions could be achieved with lower levels of aromatic hydrocarbons, but the technology to reduce the aromatic hydrocarbon contents may not be adequate to achieve much lower levels. As discussed elsewhere in this Report, we believe that a 10 percent aromatic hydrocarbon content limit is technologically feasible and cost-effective measure that will achieve the maximum emission reductions.

2. <u>Less Stringent Aromatic Hydrocarbon Limit for Small Refiners</u>

(a) <u>20 Percent Aromatic Hydrocarbon Limit.</u>

We recommend that vehicular diesel fuel produced by small refiners be subject to a less stringent 20 percent limit on aromatic hydrocarbon content. The less stringent limit would only apply the small refiner's historic production volume; any diesel produced beyond that amount would be subject to the basic 10 percent limit.

We propose an aromatic hydrocarbon content limit of 20 percent for small refiners so that small refiners can effectively and fairly compete in the motor vehicle diesel fuel market and still reduce emissions. The "unit" or per gallon cost for small refiners to produce motor vehicle diesel fuel by desulfurizing the diesel fuel produced in the small refiner's refinery, and purchasing 10 percent aromatic hydrocarbon content diesel fuel to "blend down" to 20 percent aromatic hydrocarbon content, is about the same as for large refiners' per gallon costs to produce 10 percent aromatic hydrocarbon content diesel fuel.

(b) Definition of "Small Refiner."

The proposed small refiner definition is based on the existing definition in Section 2252, with some modifications. Parallel to the treatment in the current regulation for the SCAB and Ventura County, a small refiner's California refinery could not have a capacity of more than 50,000 barrels per stream day (bpsd) at any time since January 1, 1978. The limit on past capacity prevents a "downsized" large refinery from qualifying for the less stringent limit. The refinery could not at any time since September 1, 1988 (the month we advised industry of this proposal) be owned or controlled by a refiner that at the same time controls California crude capacity over 50,000 bpsd or U.S. crude capacity exceeding 137,500. We believe that refiners not meeting these criteria are likely to have a sufficient ability to integrate operations and to provide financial resources so that they should be subject to the basic 10 percent standard.

(c) Annual Volume of Diesel Fuel Subject to the Less Stringent Limit.

We recommend that an annual cap be imposed on the amount of vehicular diesel fuel a small refiner could produce under the less stringent limit. This would help limit the amount of diesel fuel sold with a higher aromatic hydrocarbon content. The proposed regulation would set the annual limit at a volume equal to 55 percent of the average of the highest three year annual production volumes of distillate fuel in 1983-1987 at the small refiner's refinery, as reported in required annual reports to the California Energy Commission (CEC). On an industry-wide basis, 55 percent of the distillate fuel produced in California is sold as motor vehicle diesel fuel in the state. Such a cap would allow small refiners access to the less stringent 20 percent aromatic hydrocarbon limits at their historic production levels. Using the volumes in the CEC reports has the advantage of providing fixed, preexisting figures that cannot modified to maximize production under the volume allowance for the less stringent limit.

(d) <u>Administration of Small Refiner Limit.</u>

The provisions on administration of the small refiner aromatic hydrocarbon limit are patterned very closely after the provisions in Section 2252.

A refiner seeking to be subject to the 20 percent limit would have to submit an application containing information necessary for the ARB to evaluate whether the refiner qualifies. The Executive Officer would be required to grant or deny the application within 90 days of receipt. The lower 10 percent limit would immediately apply whenever the refiner ceases to meet the small refiner definition.

All vehicular diesel fuel consecutively produced in a calendar year would be counted against the small refiner's cap until the annual cap volume is reached, whether or not some batches have an aromatic hydrocarbon content not exceeding 10 percent. The definition of "produce" would be the same as in Section 2252; that definition has proven workable.

As is the case in Section 2252, we propose that the basic 10 percent aromatic hydrocarbon limit apply to diesel fuel supplied from a small refiner's refinery in any quarter where less than 25 percent of the diesel fuel supplied from the refinery was produced from distillation of crude oil at the refinery. The purpose of the less stringent limit for small refiners is to allow small refiners to produce diesel fuel from their refineries, not to allow production of diesel fuel that meets less stringent requirements through blending of all purchased blendstocks.

Small refiners would be required to submit periodic reports similar to those required under Section 2252. The data required to be reported is necessary to help enable the ARB to verify compliance with the regulation. Failure to submit the required data will create a presumption that the diesel fuel was sold in violation of the regulation.

3. Compliance Date.

We propose that the diesel fuel aromatic hydrocarbon content standard become applicable beginning January 1, 1993, for the reasons set forth in the discussion of the compliance date for the sulfur content limits.

4. Compliance Mechanism.

(a) Designated Alternative Limits and Offsetting.

(i) General Approach.

As indicated above, we believe that flat limits are generally preferable to schemes involving averaging and self-reporting. However, we have concluded that imposition of a flat limit for the 10 percent hydrocarbon standard would not allow adequate flexibility for refiners to meet the standard in a cost-effective manner. Thus we are recommending that producers and importers be allowed the option of varying the aromatic hydrocarbon content of batches of vehicular diesel fuel above and below 10 percent.

The proposed approach would allow refiners to sell diesel fuel that is somewhat out of specification and thus operate closer to manufacturing tolerances. Refiners have stated that such an approach could significantly reduce their costs. They would not have to reblend as many batches to bring them into compliance. We believe that our proposed approach will provide a cost-effective means of compliance with the 10 percent aromatic hydrocarbon content limit.

We considered a "pure" averaging mechanism under which compliance with the standard would be determined solely on the basis of the average aromatic hydrocarbon content over some time-period such as a calendar quarter. We do not recommend such an approach as it would be entirely dependent on self-reporting and verification of the accuracy and completeness of the reported data would be extremely difficult. We are recommending a "hybrid" approach which is based on a mechanism in the ARB's lead content of leaded gasoline regulation (Section 2253.2(c), Title 13, California Code of Regulations). A producer or importer would be permitted to sell batches of diesel fuel with a "designated alternative limit" exceeding 10 percent aromatic hydrocarbon content as long as the batch is reported to the ARB and the producer within 90 days before or after transfers sufficient quantities of diesel fuel with lower "designated alternative limits" to offset fully the higher aromatic content. Unless a designated alternative limit is assigned to a batch, the basic 10 percent limit would apply.

(ii) Reporting and Offsetting Designated Alternative Limit Batches.

Producers and importers would be permitted to assign designated alternative limits to final blends they have produced or imported. The designated alternative limit could not be less than aromatic hydrocarbon content as shown by the testing required to be conducted.

The producer or importer would have to notify the Executive Officer of the final blend's designated alternative limit and volume. In administering the offset provisions in the lead in gasoline regulation, compliance staff set up a 24-hour system for telephonic notification. Such a system would similarly be made available for notifications under of designated alternative limits.

The notification would have to be received before the start of physical transfer of the diesel fuel from the production or importation facility, and in no case less than 12 hours before the producer either completes physical transfer or commingles the blend. The ARB needs to be notified in sufficient time to have the opportunity to verify compliance by sampling some part of the blend before it has left the facility. At the same time, it would be unduly burdensome for refiners to have to hold a final blend for a substantial period before it is shipped out. We believe that the proposal strikes an appropriate balance between these two objectives. Notifications of designated alternative limit batches would be permitted after the specified time periods if the Executive Officer determines the delay was not caused by the intentional or negilegent conduct of the producer or importer.

As in the lead in gasoline regulation, the 90-day offset period would run from the start of physical transfer of the high aromatic hydrocarbon blend to the completion of physical transfer of the low aromatic hydrocarbon blend. These events are reasonable and readily identifiable.

The regulation would expressly authorize the use of protocols between the Executive Officer and an individual producer or importer to specify how the designated alternative limit requirements are applied to the producer's or importer's operations. Terms of the protocol would be limited to specification of alternative events from which notification and offset periods are measured, and allowing flexibility in the deadlines for reporting batches with designated alternative limits to accomodate normal business hours. Essentially identical provisions in the lead in gasoline regulation have proven useful and workable.

(iii) Prohibited Activities Regarding Designated Alternative Limit Batches.

The proposed regulation would prohibit the sale, offer for sale, or supply of vehicular diesel fuel which has been reported pursuant to the designated alternative limit provisions if the aromatic hydrocarbon content exceeds the designated limit, or if the excess aromatic hydrocarbon content is not fully offset. The regulation would prohibit selling vehicular diesel fuel in a blend with a designated alternative limit of more than 10 percent aromatic hydrocarbon if the total volume of the blend sold exceeds the volume reported. It would similarly prohibit selling vehicular diesel fuel in a blend with a designated alternative limit of less than 10 percent aromatic hydrocarbon if the total volume of the blend sold is less than the volume reported. These provisions would protect against misreporting volumes of diesel fuel to which a designated alternative limit has been assigned.

(b) Required Testing and Recordkeeping.

The proposed regulation includes requirements for testing and recordkeeping patterned closely after the requirements in Section 2252(i) and (j). Producers and importers would be required to sample and test each final blend of vehicular diesel fuel for aromatic hydrocarbon content, and maintain for two years records of sample date, product sampled, vessel sampled, final blend volume, and aromatic hydrocarbon content. Producers and importers would be required to provide the records to the ARB within 20 days of a written request. We believe that these provisions are necessary to enable ARB staff to conduct compliance audits, particularly since the designated alternative limit and small refiner provisions make field testing potentially less effective.

Diesel fuel not tested would be deemed to have an aromatic hydrocarbon content exceeding 10 percent, unless the producer or importer demonstrates to the contrary. This assures that producers and importers could not benefit from failing to test noncomplying fuel.

Producers and importers would be authorized to enter into protocols with the Executive Officer to specify alternative sampling, recordkeeping, or small refiner reporting requirements. This would afford flexibility to tailor the requirements to special operational needs.

(c) Other Compliance Mechanisms.

The other compliance mechanisms in the regulation would be identical to those described above in subsection 4 (b)-(f) of the discussion of the sulfur content regulation.

5. <u>Test Method.</u>

The test method for determining the aromatic hydrocarbon content of diesel fuel would be ASTM Test Method D 1319-84, or any other method determined by the Executive Officer to give equivalent results. We are proposing this method even though the scope of the method states that it is not applicable to fuels with final boiling points greater than 600 degrees Farenheit, which is the case with most diesel fuels. We recommend this method because the historical information on diesel fuel aromatic hydrocarbon content is largely composed of measurements using this method. We are continuing to investigate better test methods for diesel fuel aromatic hydrocarbon content and will propose that such methods be used when they are validated.

6. <u>Waivers for Diesel Fuel Containing Certain Additives.</u>

The 10 percent aromatic hydrocarbon limit could be waived by the Executive Officer for a blend of diesel fuel containing an additive if the Executive Officer determines, upon application, that the blend results in no greater emissions of any criteria pollutant, criteria pollutant precursor, or toxic air contaminant than vehicular diesel fuel meeting the 10 percent limit. At workshops on our proposals, some parties requested that the use of additives be allowed as an alternative to aromatic hydrocarbon content reduction. The proposal will allow this as long as it is assured the additives will result in equivalent emissions reductions.

7. Variances.

We propose that the regulation have variance provisions identical to those in the proposed sulfur content regulation.

8. Other.

As in the sulfur content regulation, the proposed aromatic hydrocarbon regulation would include various other provisions intended to make it more effective and practicable. The provisons are generally patterned after the terms in Section 2252.

REFERENCES

REFERENCES

1. Stationary Source Division, Status Report: Diesel Engine Emission Reductions Through Modification of Motor Vehicle Diesel Fuel Specifications, Sacramento, CA: California Air Resources Board, October 1984.

2. Arthur D. Little, Inc., Cost of Reducing Aromatics and Sulfur Levels in Motor Vehicle Fuels, California Air Resources Board, Contract No. A6-199-32, August 5, 1988.

3. Ingham, M.C., Warden R.B., Cost-Effectiveness of Diesel Fuel Modifications for Particulate Control, SAE Paper # 870SS6, February 23-27, 1987.

4. Sawyer, R.F., Starkman, E.S. et al., Alternative Fuels for Control of Engine Emission, Journal of the Air Pollution Control Association, Volume 20, No. 2, February, 1970.

5. Stationary Source Division, Public Hearing to Consider Amendments to Regulation Limiting the Sulfur Content of Motor Vehicle Diesel Fuel in the South Coast Air Basin and Ventura County and Limiting the Sulfur Content of Unleaded Gasoline, Sacramento, CA: California Air Resources Board, March 11, 1985.