SUMMARY OF BOARD ITEM

ITEM # 03-6-2: PUBLIC HEARING TO CONSIDER PROPOSED AMENDMENTS TO THE CALIFORNIA DIESEL FUEL REGULATIONS

STAFF RECOMMENDATION: The staff recommends that the Air Resources Board (ARB) approve the proposed amendments to the regulations pertaining to the composition of commercial motor vehicle diesel fuel, and the composition of diesel fuel used to certify light- and medium-duty vehicles and engines, and the adoption of an Airborne Toxic Control Measure (ATCM) for nonvehicular diesel fuel standards. The amendments would do the following: (1) reduce the maximum permissible sulfur content in vehicular diesel fuel from 500 ppmw to 15 ppmw starting in 2006; (2) revise the requirements for certification of alternative diesel fuel formulations; (3) adopt new specifications for equivalency to the aromatic hydrocarbon limit for California diesel fuel; (4) establish standards for diesel fuel lubricity; (5) revise the sulfur specification for certification diesel fuel for light- and medium-duty vehicles; (6) adopt an ATCM to require the use of vehicular diesel fuel in all nonvehicular diesel engines except engines used to power locomotives and marine vessels; and (7) make other changes to provide flexibility and to help ensure effective enforcement of the regulations.

DISCUSSION: In November 1988, the Board approved the California diesel fuel regulations that since 1993 have limited the allowable sulfur content of motor vehicle diesel fuel to 500 ppm by weight and the aromatic hydrocarbon content to 10 percent by volume with a 20 percent limit for small refiners. The regulation limiting the aromatic hydrocarbon content allows refiners to comply through certified alternative formulations that must be demonstrated through testing to result in the same emission benefits as the 10-percent aromatic standard (or in the case of small refiners, the 20-percent standard). Most refiners have taken advantage of the regulation's flexibility to produce alternative diesel formulations that provide the required air quality benefits at a lower cost.

The proposed new sulfur content limit of 15 ppmw would generally align the California requirements with the U.S. Environmental Protection Agency's (U.S. EPA) standard for on-road diesel fuel, but the ARB requirements would apply to diesel fuel used in off-road motor vehicles as well. The sulfur content limit is needed to ensure the effective performance of after-treatment technologies in heavy-duty diesel engines and vehicles designed to meet 2007 model-year federal and California exhaust emission standards for particulate matter (PM), oxides of nitrogen (NOx), and non-methane hydrocarbons (NMHC). Low sulfur diesel will also be required by new and retrofitted diesel engines that must meet the diesel PM reduction targets proposed in California's Risk Reduction Plan (RRP) to Reduce Particulate Matter Emissions from Diesel-Fueled Engines.

The proposed 15-ppmw sulfur content limit would be phased in during mid-2006 using a schedule substantially the same as the schedule in the federal regulations.

The proposed new "equivalent limits" option for complying with the 10-percent aromatic hydrocarbon standard would provide additional flexibility for refiners or importers and potentially allow more diesel fuel to be imported into the California market.

Natural fuel lubricity is expected to be reduced by the more severe hydrotreating that will be used to reduce the sulfur content of diesel. Therefore, staff is proposing that the Board adopt a diesel fuel lubricity standard to ensure that California diesel fuel provides adequate lubrication for fuel systems of existing and future diesel engines to protect them from excessive wear that would reduce engine life and increase exhaust emissions. The proposed standard is a maximum wear scar diameter (WSD) of 520 microns based on the high frequency reciprocating rig method and would be phased in starting August 1, 2004. Staff is also recommending that the Board direct that a technology review be conducted by staff to determine by 2005 whether the 520 microns WSD standard is adequate for the more advanced high-pressure fuel injection systems or should be replaced with a more protective standard. These systems, which are expected to become more prevalent within the next few years, will require even higher lubricity levels than conventional systems.

Staff is proposing adoption of a new ATCM for nonvehicular diesel fuel that would facilitate the implementation of the RRP for nonvehicular diesel engines by enabling the use of high-efficiency, PM emission-control devices that would not be effective with higher sulfur levels. There would be an exception for diesel fuel used in locomotives and marine vessels.

Additional amendments proposed by staff include revisions to the alternative diesel formulation provisions, adoption of a new sulfur content range for diesel fuel used in certifying 2007 and later model-year light- and medium duty vehicles that is identical to U.S. EPA's (the sulfur requirements for heavy-duty diesel engine certification fuel have already been aligned), improvements to the sulfur test method, and other changes to provide flexibility and to help ensure effective enforcement of the regulations.

SUMMARY AND IMPACTS:

Reducing the sulfur content of diesel fuel from the statewide average of 140 ppmw to less than 15 ppmw would reduce sulfur oxide emissions by about 90 percent or by about 6.4 tons per day from 2000 levels and direct diesel PM emissions by about four percent, or about 0.6 tons per day for engines not equipped with advanced PM emissions control technologies. The lower sulfur diesel makes much more significant emissions reductions possible by facilitating the implementation of the RRP and the introduction of the new on-road, heavy-duty diesel engine emission standards – two programs that will significantly reduce emissions of ozone precursors (NOx and NMHC) and diesel PM. The consequent reduction of ambient levels of ozone and primary and secondary diesel PM would reduce Californians' exposure to ozone and diesel PM and the associated health risks. There should be no significant negative impacts on air quality.

There should be no additional impact on surface water, groundwater, or soil compared to the current diesel fuel. The lower sulfur content limit provides a direct benefit through reduction of atmospheric deposition of sulfuric acid and sulfates in water bodies. In addition, the NOx and PM emissions reductions achieved with the use of low sulfur diesel and after-treatment technologies would result in a decrease in atmospheric deposition of nitrogen and airborne diesel particles as well as the toxic compounds typically found in diesel exhaust.

The proposed amendments are not expected to have any impact on the ability of California to produce and supply adequate quantities of diesel fuel to the California market.

Staff estimates that the overall cost of reducing the sulfur content of diesel fuel and meeting the minimum lubricity specifications will be about 2 to 4 cents per gallon of diesel with about 0.6 cents per gallon of this cost attributed to the lubricity standard. Most of these costs will be incurred as a result of the low sulfur diesel fuel regulations already adopted by the U.S. EPA and the South Coast Air Quality Management District.

The cumulative cost impact of the proposed regulations is expected to be increased fuel costs for diesel end users in California by up to about $110 million per year in 2007. This is not expected to have a significant impact on the overall California economy.

TITLES 13 and 17. CALIFORNIA AIR RESOURCES BOARD

NOTICE OF PUBLIC HEARING TO CONSIDER AMENDMENTS TO THE CALIFORNIA DIESEL FUEL REGULATIONS

The Air Resources Board (ARB or Board) will conduct a public hearing at the time and place noted below to consider amendments to the regulations pertaining to the composition of commercial motor vehicle diesel fuel, and the composition of diesel fuel used to certify light-, medium-, and heavy-duty vehicles and engines, and to consider adoption of an airborne toxic control measure (ATCM) for non-vehicular diesel fuel standards. Proposed amendments would reduce the maximum permissible sulfur content in vehicular diesel fuel from 500 parts per million weight (ppmw) to 15 ppmw, revise the requirements for certification of alternative diesel fuel formulations, adopt new equivalent limits for diesel fuel properties, establish standards for diesel fuel lubricity, and make other changes, including improvements to the sulfur test method and a revision of the definition of "diesel fuel." Proposed amendments to the requirements for diesel engine certification fuel would revise the sulfur specification to make it consistent with the proposed sulfur standard for commercial motor vehicle diesel fuel. The proposed ATCM would adopt requirements for non-vehicular diesel fuel identical to the regulations for vehicular diesel fuel.

DATE: July 24, 2003

TIME: 9:00 a.m.

PLACE: California Environmental Protection Agency
Air Resources Board
1001 I Street
Auditorium, Second Floor
Sacramento, CA 95814

This item will be considered at a two-day meeting of the Board, which will commence at 9:00 a.m. on July 24, 2003, and may continue at 8:30 a.m. on July 25, 2003. This item may not be considered until July 25, 2003. Please consult the agenda for the meeting, which will be available at least 10 days before July 24, 2003, to determine the day on which this item will be considered.

If you have special accommodation or language needs, please contact ARB's Clerk of the Board at (916) 322-4011 or amalik@arb.ca.gov as soon as possible. TTY/TDD/Speech-to-Speech users may dial 7-1-1 for the California Relay Service.

INFORMATIVE DIGEST OF PROPOSED ACTION AND POLICY STATEMENT OVERVIEW

Sections Affected: Proposed amendments to sections 2281, 2282 and 2701(a), and adoption of sections 2284 and 2285, title 13, California Code of Regulations (CCR); amendments to section 1956.8(b) and the incorporated "California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines" as last amended December 12, 2002, and sections 1961(d) and 1962 and the incorporated "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles" as last amended July 30, 2002, title 13, CCR. Adoption of the ATCM for nonvehicular diesel fuel, section 93114, title 17, CCR.

Background

The ARB administers regulations that since 1993 have limited statewide the allowable sulfur content of motor vehicle diesel fuel to 500 ppm and the aromatic hydrocarbon content to 10 percent with a 20 percent limit for small refiners. The regulation limiting aromatic hydrocarbon content allows refiners to comply by selling a certified alternative formulation that has an aromatic hydrocarbon content greater than the basic limits. Most refiners have taken advantage of the regulation's flexibility to produce alternative diesel formulations that provide the required air quality benefits at a lower cost.

In order to be certified, an alternative formulation must be shown to result in the same emission benefits as the 10 percent aromatic standard (or in the case of small refiners, the 20 percent standard). The regulation requires the determination of the values of five properties – sulfur, aromatic hydrocarbon, polycyclic aromatic hydrocarbon, and nitrogen contents, and cetane number – of the candidate fuel submitted by a refiner for certification. The values for the candidate then become the required specifications for the alternative formulation. Candidate fuel formulations are tested in a laboratory engine for emission equivalency against a defined reference fuel. They must be shown to be equivalent or better than the reference fuel. In comparing emissions, a statistical margin of safety is required but an allowable tolerance is provided so that a truly emission-equivalent candidate fuel will always qualify.

ARB regulations also establish test procedures for evaluating whether new motor vehicles and engines may be certified as meeting the California motor vehicle emission standards. These test procedures identify the specifications of the "certification fuel" to be used in exhaust emission testing. The ARB's current specifications for diesel certification fuel specify an allowable range of sulfur content from 100 ppmw to 500 ppmw and specifies limits or allowable ranges for other fuel properties, including an aromatic hydrocarbon content of 8-12 volume percent (vol.%). Manufacturers may also certify California diesel engines using certification fuel meeting the federal certification fuel specifications established by the U.S. Environmental Protection Agency (U.S. EPA) and incorporated into the ARB's test procedures.

There is currently no government or industry standard controlling diesel fuel lubricity in the United States. Refiners in California have maintained a voluntary minimum lubricity level consistent with the recommendation of a 1994 Governor's Task Force that was created during the statewide introduction of 500-ppm sulfur California reformulated diesel. This voluntary level is a Ball-on-Cylinder Lubricity Evaluator (BOCLE) scuffing load (SL) of 3,000 grams or higher. The American Society for Testing and Materials (ASTM) has been working since 1993 to develop a lubricity specification for its D-975 specifications for diesel fuel but to date has not been successful.

The California diesel fuel regulations are a necessary part of the state's strategy to reduce air pollution through the use of clean fuels and lower emitting motor vehicles and off-road equipment. The most recent proposed and adopted regulations to reduce diesel exhaust emissions, exposure, and risk will require the use of low sulfur diesel fuel to be effective.

In October 2001, the ARB adopted the new stringent exhaust emissions standards that were adopted in January 2001 by the U.S. EPA for 2007 and subsequent model year heavy-duty highway diesel engines and vehicles. The new emission standards represent a 90% reduction of emissions of oxides of nitrogen (NOx), a 72% reduction of emissions of non-methane hydrocarbon (NMHC), and a 90% reduction of emissions of particulate matter (PM) compared to the emission standards that apply starting in the 2004 model year. The new emissions standards will require the use of catalyzed diesel particulate filters, NOx after-treatment and other advanced after-treatment based technologies that could not achieve the required efficiency with diesel fuel sulfur levels higher than 15 ppm.

In August 1998, the ARB identified particulate matter emitted from diesel engines (diesel PM) as a Toxic Air Contaminant (TAC) and in September 2001, approved the Diesel Risk Reduction Plan to reduce public exposure to diesel PM. The plan identified air toxic control measures and regulations that will set more stringent emissions standards for new diesel-fueled engines and vehicles, establish retrofit requirements for existing engines and vehicles where determined to be technically feasible and cost-effective. The sulfur content of diesel fuel must not exceed 15 ppm because at higher concentrations, the effectiveness of the emissions control systems is so reduced that the desired emissions reductions for NOx and PM cannot be achieved.

Although the ARB's vehicular diesel fuel regulations do not apply to diesel fuel used in stationary engines, complying "CARB diesel" is used in the great majority of stationary engines because of California's single fuel distribution network. Also, several districts have established best available control technology requirements for diesel-fueled stationary engines that specify the use of CARB diesel. Portable engines registered under ARB's Statewide Portable Equipment Registration program are required to use CARB diesel. In practice, transportation refrigeration unit (TRU) diesel engines, fueled in California, are normally fueled with California vehicular diesel fuel, but this is not required by existing law. Locomotive and most marine diesel engines are examples of other applications that are not required to use California vehicular diesel fuel.

Locomotive diesel engines fueled in California primarily burn diesel fuel complying with the U.S. EPA sulfur content regulation (≤ 500 ppmw) for diesel fuel used in on-road engines. Passenger-fleet, marine diesel engines are required by statute to use California vehicular diesel fuel. It is believed that high-sulfur (≤ 5000 ppmw) diesel fuel is burned in most of the rest of the marine diesel engines fueled in California.

Comparable Federal Regulations

Since 1993, a U.S. EPA regulation – 40 CFR ∍ 80.29 – has imposed a maximum sulfur content limit of 500 ppmw on diesel fuel sold or supplied for use in on-road motor vehicles. In addition, the regulation requires on-road motor-vehicle diesel fuel to have a cetane index of at least 40 or have an aromatic hydrocarbon content of no greater than 35 percent by volume (vol. %). Diesel fuel not intended for on-road motor-vehicle use must contain dye solvent red 164.

On January 18, 2001, the U.S. EPA published a final rule requiring refiners, beginning June 1, 2006, to produce highway diesel fuel that meets a maximum sulfur standard of 15 ppmw. (66 F.R. 5002; 40 C.F.R. §§ 80.500 et seq.). All 2007 and later model year diesel-fueled vehicles must be fueled with this new low sulfur diesel. The federal regulations contain temporary compliance options and flexibility provisions not offered in the ARB's proposed amendments. The temporary federal compliance option, which includes an averaging, banking and trading component, begins in June 2006 and lasts through 2009, with credit given for early compliance before June 2006. Under this temporary compliance option, up to 20 percent of highway diesel fuel may continue to be produced at the existing 500 ppmw sulfur maximum standard. Highway diesel fuel marketed as complying with the 500 ppmw sulfur standard must be segregated from 15 ppmw fuel in the distribution system, and may only be used in pre-2007 model year heavy-duty vehicles. The federal regulation also provides additional hardship provisions that the U.S. EPA believes will minimize the economic burden of the small refiners in complying with the 15-ppm sulfur standard.

The Proposed ARB Amendments

15-ppmw sulfur limit for vehicular diesel fuel starting in 2006. Staff proposes an amendment that would reduce the maximum allowable sulfur content of vehicular diesel fuel from 500 ppmw to 15 ppmw. This fuel sulfur requirement would apply to diesel fuel sold for use in both on-road and-off-road motor vehicles. The 15-ppmw sulfur limit would apply to all diesel supplied from production and import facilities starting no later than June 1, 2006. The limit would apply 45 days later – starting July 15, 2006 – to all downstream facilities except bulk plants, retail outlets, and bulk purchaser-consumer facilities. After another 45 days – starting September 1, 2006 – the 15-ppm sulfur limit would apply throughout the distribution system. These phase-in dates are substantially identical to those in the U.S. EPA regulation.

The 15-ppm sulfur content limit is proposed for two primary reasons: to enable the effective use of the emissions control technology that will be required by heavy-duty diesel vehicles and engines that must meet the new PM and NOx emission standards adopted by the U.S EPA and ARB; and to enable the use of the exhaust gas treatment technologies that will be required by new and retrofitted diesel engines to meet the diesel PM reduction targets proposed in the diesel risk reduction plan. Current sulfur levels in diesel fuel will prevent effective operation of both the NOx and PM emissions control technologies.

Revising the procedures for certifying alternative diesel formulations. Staff is proposing the following amendments to the procedures for new certifications of alternative formulations to the 10-percent aromatic hydrocarbon standard: (1) requiring that the reference and candidate fuels meet the proposed 15-ppm sulfur standard, starting August 2004; (2) requiring that the candidate fuel properties meet the same property ranges and limitations as those required for the reference fuels and be within half the range of each reference fuel property; (3) reducing the allowable tolerance values for each pollutant by half its current value; and (4) eliminating a provision which reduces candidate fuel particulate matter emissions by the lesser of a calculated indirect sulfate difference or the actual measured sulfate content of the emissions.

Various studies have shown that the emissions characteristics of diesel fuel blends may be affected by diesel fuel properties, such as density, that are not among the five specified for alternative fuel formulations. This means that an applicant has been is permitted to blend a candidate fuel that has a property such as density that is significantly different from that of the reference fuel. The difference between the two fuels could contribute to an improved emissions performance by the candidate fuel even though there is no assurance that the value of that property in diesel fuels produced commercially under the alternative formulation would be comparable to that of the candidate fuel. The proposed revisions of the alternative diesel formulation provisions are needed to ensure that certified alternative formulations results in equivalent emissions to the candidate fuel formulations tested in the laboratory.

Add a new "equivalent limits" compliance mechanism in the regulation limiting the aromatic hydrocarbon content of vehicular diesel fuel. Staff is proposing an amendment that would add a new alternative compliance mechanism as an option to meeting the 10 vol.% aromatic hydrocarbon limit. A refiner using this mechanism for a batch of diesel fuel would have to meet the following specifications:

Property	Equivalent Limit
Aromatic Content (% by wt.)	≤ 21.0
PAH Content (% by wt.)	≤ 3.5
API Gravity	≥ 36.9
Cetane Number	≥ 53
Nitrogen Content (ppmw)	≤ 500
Sulfur (ppmw)	≤ 160 before 6/1/06 ≤ 15 starting 6/1/06

This new compliance mechanism would provide additional flexibility for refiners or importers and potentially allow more diesel fuel to be imported into the California market. The proposed new equivalent limits are based on the average properties of certified formulations and should therefore preserve the actual emission benefits of California diesel fuel.

Revising the sulfur specification for diesel engine certification fuel. Staff is proposing a sulfur content range of 7 to 15 ppmw by weight for California diesel certification fuel for all classes of on-road diesel motor vehicles, starting in the 2007 model year. This would be identical to the sulfur content of federal certification fuel. The specifications for the other fuel properties would not change. Manufacturers would retain the options to certify diesel engines using certification fuel meeting the federally established certification fuel specifications or an alternative certification test fuel provided they can demonstrate that this test fuel will be the predominant in-use fuel. The new sulfur content range will be representative of the in-use commercial fuel, and as noted above the stringent new standards for 2007 and subsequent model vehicles are predicated on the ability to operate on fuel with the reduced sulfur content.

Adoption of a diesel fuel lubricity standard. Staff is proposing that the Board adopt a fuel lubricity standard that would be phased in for all California motor vehicle diesel fuel starting August 1, 2004. The proposed standard is a High Frequency Reciprocating Rig (HFRR) maximum wear scar diameter (WSD) of 520 microns which will become effective August 1, 2004. Staff recommends that the Board direct that a technology review be conducted by staff to determine whether a more stringent standard – HFRR maximum WSD of 460 microns – should be implemented on the same schedule as the proposed 15-ppm sulfur limit for diesel fuel.

Staff believes that a diesel fuel lubricity standard is necessary to ensure that California diesel fuel provides adequate lubrication for fuel systems of existing and future diesel engines. Fuel lubricity levels are expected to be reduced by the more severe hydrotreating that will be needed to lower the sulfur content of diesel fuel to meet the proposed 15-ppm sulfur limit. Fuels of low lubricity do not provide adequate lubrication and will contribute to excessive wear resulting in reduced equipment life and performance. A more stringent second-phase standard may be needed to protect the advanced high-pressure fuel injections systems that will become more prevalent within the next few years.

ATCM for nonvehicular diesel fuel. Staff is proposing adoption of a new ATCM which would ultimately require that California nonvehicular diesel fuel meet the same ARB standards as California vehicular fuel, once air districts have had the opportunity to adopt their own ATCM on the subject. There would be an exception for diesel fuel used in locomotives and marine vessels. The ARB's new ATCM would complement and enable the use of high-efficiency, PM emission-control devices for non-vehicular diesel engines.

Other Amendments: The staff is proposing additional amendments to clarify the requirements of the diesel fuel regulations and to ensure that the regulations work effectively. One amendment would replace the current x-ray fluorescence test method for determining sulfur (ASTM D2622-94) with an ultraviolet fluorescence method (ASTM D5453-93) that will provide a more suitable detection limit and better precision. An exemption from the diesel fuel requirements would be established for diesel fuel used in qualifying military vehicles, closely paralleling provisions in the U.S. EPA regulations. Another amendment would revise the definition of "diesel fuel" to include any mixture of predominately liquid hydrocarbons that is sold or represented as suitable for use in internal combustion, compression ignition (diesel cycle) engines. This will clarify the applicability of the diesel fuel regulations and make the definition functionally consistent with the definition for fuel for internal combustion, spark ignition (gasoline) engines. A conforming amendment would also be made to the definition of diesel fuel in the verification procedure and in-use compliance requirements for in-use strategies to control emissions from diesel engines. This amendment would assure that the current effect of the requirements for the verification procedure regulation will not be changed by the expansion of the definition of diesel fuel.

AVAILABILITY OF DOCUMENTS AND AGENCY CONTACT PERSONS

The ARB staff has prepared a Staff Report: Initial Statement of Reasons (ISOR) for the proposed regulatory action, which includes a summary of the environmental and economic impacts of the proposal and supporting technical documentation. The report is entitled "Proposed Amendments to the California Diesel Fuel Regulations."

Copies of the ISOR and the full text of the proposed regulatory language, in underline and strikeout format to allow for comparison with the existing regulations, may be accessed on the ARB's web site listed below, or may be obtained from the Public Information Office, Air Resources Board, 1001 I Street, Visitors Environmental Services Center, First Floor, Sacramento, CA 95814, (916) 322-2990 at least 45 days prior to the scheduled hearing (July 24, 2003).

Upon its completion, the Final Statement of Reasons (FSOR) will also be available and copies may be requested from the agency contact persons in this notice, or may be accessed on the ARB's web site listed below.

Inquiries concerning the substance of the proposed regulations may be directed to the designated agency contact persons: Mr. Steven Brisby, Manager, Fuels Section, (916) 322-6019, or Mr. Dean C. Simeroth, Chief, Criteria Pollutants Branch, Stationary Source Division, at (916) 322-6020.

Further, the agency representative and designated back-up contact persons to whom nonsubstantive inquiries concerning the proposed administrative action may be directed are Artavia Edwards, Manager, Board Administration & Regulatory Coordination Unit, (916) 322-6070, or Amy Whiting, Regulations Coordinator, (916) 322-6533. The Board staff has compiled a record for this rulemaking action, which includes all the information upon which the proposal is based. This material is available for inspection upon request to the contact persons.

If you are a person with a disability and desire to obtain this document in an alternative format, please contact the Air Resources Board ADA Coordinator at (916) 323-4916, or TDD (916) 324-9531, or (800) 700-8326 for TDD calls outside the Sacramento area.

This notice, the ISOR and all subsequent regulatory documents, including the FSOR, when completed, are available on the ARB Internet site for this rulemaking at http://www.arb.ca.gov/regact/ulsd2003/ulsd2003.htm.

COSTS TO PUBLIC AGENCIES AND TO BUSINESSES AND PERSONS AFFECTED

The determinations of the Board's Executive Officer concerning the costs or savings necessarily incurred by public agencies, private persons and businesses in reasonable compliance with the proposed regulations are presented below.

Pursuant to Government Code sections 11346.5(a)(5) and 11346.5(a)(6), the Executive Officer has determined that the proposed regulatory action will not create costs or savings to any state agency or in federal funding to the state, costs or mandate to any local agency or school district whether or not reimbursable by the state pursuant to Part 7 (commencing with section 17500), Division 4, Title 2 of the Government Code, or other nondiscretionary savings to state or local agencies.

In developing this regulatory proposal, the ARB staff evaluated the potential economic impacts on representative private persons or businesses. The ARB is not aware of any cost impacts that a representative private person or business would necessarily incur in reasonable compliance with the proposed action.

The Executive Officer has made an initial determination that the proposed regulatory action will not have a significant statewide adverse economic impact directly affecting businesses, including the ability of California businesses to compete with businesses in other states, or on representative private persons.

With the exception of the proposed amendments that establish a 15-ppmw diesel fuel sulfur limit, establish a diesel fuel lubricity standard, and set "equivalent limits" in the regulation limiting the aromatic hydrocarbon content of vehicular diesel fuel, the proposed amendments are not expected to have any economic impact.

It is not expected that the proposed amendments will modify existing diesel production and consumption patterns in California. Implementation of the proposed amendments and the federal and SCAQMD regulations for diesel fuel are estimated to increase the costs of producing diesel fuel in California by about 3 cents per gallon. It is estimated that the proposed lubricity standard represents about 0.6 cents per gallon of this cost. However, these costs may be reduced by some unquantifiable amount by the additional flexibility provided to refiners and importers using the "equivalent limits" provision in the aromatic hydrocarbon content regulation. Nationally, the federal low sulfur requirement is expected to increase the cost of diesel fuel by about 4 to 5 cents per gallon. The difference between the California costs and the federal costs is due to California refineries being more complex than national refineries, and therefore in less need of modifications to produce low sulfur diesel fuel. While the California diesel fuel standards will also apply to off-road and some stationary engine applications, fuel costs for these users have historically been comparable to surrounding states even though diesel fuel in those states has not had to meet the same standards as California diesel fuel.

The economy-wide impacts of the production of low sulfur diesel fuel were estimated using a computable general equilibrium (CGE) model of the California economy. Based on staff's analysis, the cumulative impact of these regulations could be expected to increase fuel costs to diesel end users in California by up to about $110 million per year in 2007. This is not expected to have a significant impact on the overall California economy.

The specific economic impacts to the petroleum, transportation, and agricultural sectors of the California economy were also evaluated. For the refinery sector, the production of low sulfur diesel fuel will likely require capital investments of from $170 to $250 million dollars for equipment. For the agricultural sector, the use of low sulfur diesel fuel could increase operating costs by 0.05 percent. For the transportation sector, the use of low sulfur diesel fuel could increase typical truck operating costs by 0.6 percent. These are not expected to be significant adverse economic impacts.

In accordance with Government Code section 11346.3, the Executive Officer has determined that the proposed regulatory action will not affect the creation or elimination of jobs within the State of California, the creation of new businesses or elimination of existing businesses within the State of California, or the expansion of businesses currently doing business within the State of California. A detailed assessment of the economic impacts of the proposed regulatory action can be found in the Staff Report (ISOR).

The Executive Officer has also determined, pursuant to title 1, CCR, section 4, that the proposed regulatory action will affect small businesses. The proposed amendments lowering the sulfur limit of commercial diesel fuel are expected to result in an increase in the cost of producing diesel fuel. However, most of this cost would have been incurred even without action by the ARB because of the federal requirements for on-road diesel fuel. No negative economic impacts on small businesses are expected.

In accordance with Government Code sections 11346.3(c) and 11346.5(a)(11), the ARB's Executive Officer has found that the reporting requirements of the proposed regulatory actions which apply to businesses are necessary for the health, safety, and welfare of the people of the State of California.

Before taking final action on the proposed regulatory action, the Board must determine that no alternative considered by the agency or that has otherwise been identified and brought to the attention of the agency would be more effective in carrying out the purpose for which the action is proposed or would be as effective and less burdensome to affected private persons than the proposed action.

SUBMITTAL OF COMMENTS

The public may present comments relating to this matter orally or in writing at the hearing, and in writing or by e-mail before the hearing. To be considered by the Board, written submissions not physically submitted at the hearing must be received **no later than 12:00 noon, July 23, 2003**, and addressed to the following:

Postal mail is to be sent to:

Clerk of the Board
Air Resources Board
1001 I Street, 23rd Floor
Sacramento, California 95814

Electronic mail is to be sent to: ulsd2003@listserv.arb.ca.gov and received at the ARB **no later than 12:00 noon, July 23, 2003.**

Facsimile transmissions are to be transmitted to the Clerk of the Board at (916) 322-3928 and received at the ARB **no later than 12:00 noon, July 23, 2003.**

The Board requests, but does not require, that 30 copies of any written statement be submitted and that all written statements be filed at least 10 days prior to the hearing so that ARB staff and Board Members have time to fully consider each comment. The ARB encourages members of the public to bring to the attention of staff in advance of the hearing any suggestions for modification of the proposed regulatory action.

STATUTORY AUTHORITY AND REFERENCES

This regulatory action is proposed under that authority granted in sections 39002, 39003, 39500, 39600, 39601, 39650-39675, 39658, 39659, 39666, 40000, 43000, 43000.5, 43011, 43013, 43013.1, 43018, 43101, 43104, 43105, 43600 and 43700, Health and Safety Code, and *Western Oil and Gas Ass'n.* v. *Orange County Air Pollution Control District*, 14 Cal.3d 411, 121 Cal.Rptr. 249 (1975). This regulatory action is proposed to implement, interpret, and make specific sections 39000, 39001, 39002, 39003, 39010, 39500, 39515, 39516, 39650-39675, 39650, 39658, 39659, 39666, 41511, 43000, 43009.5, 43013, 43013.1, 43016, 43018, 43101, 43104. 43105. 43106, 43107, 43204-43205.5, Health and Safety Code; title 17, CCR section 93000; and *Western Oil and Gas Ass'n.* v. *Orange County Air Pollution Control District*, 14 Cal.3d 411, 121 Cal.Rptr. 249 (1975).

HEARING PROCEDURES

The public hearing will be conducted in accordance with the California Administrative Procedure Act, Title 2, Division 3, Part 1, Chapter 3.5 (commencing with section 11340) of the Government Code.

Following the public hearing, the Board may adopt the regulatory language as originally proposed or with nonsubstantial or grammatical modifications. The Board may also adopt the proposed regulatory language with other modifications, if the text as modified is sufficiently related to the originally proposed text that the public was adequately placed on notice that the regulatory language as modified could result from the *proposed regulatory action. Potential modifications include, but are not limited to, the* identification of instances in which a certified alternative formulation not meeting the new engine test requirements will at a future date be deemed no longer certified. In the event that such modifications are made, the full regulatory text with the modifications clearly indicated, will be made available to the public for written comment at least 15 days before it is adopted.

The public may request a copy of the modified regulatory text from the ARB's Public Information Office, Air Resources Board, 1001 I Street, Visitors and Environmental Services Center, 1st Floor, Sacramento, CA 95814, (916) 322-2990.

CALIFORNIA AIR RESOURCES BOARD

Catherine Witherspoon
Executive Officer

Date: May 27, 2003

The energy challenge facing California is real. Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs see our Web –site at www.arb.ca.gov.

State of California
California Environmental Protection Agency
AIR RESOURCES BOARD
Stationary Source Division

**STAFF REPORT: INITIAL STATEMENT OF REASONS
PROPOSED AMENDMENTS TO THE CALIFORNIA
DIESEL FUEL REGULATIONS**

Public Hearing to Consider Amendments to the California Diesel Fuel Regulations Including Reduction of the Maximum Permissible Sulfur Content of Motor Vehicle Diesel Fuel

Date of Release: June 6, 2003
Scheduled for Consideration: July 24, 2003

Location:

California Air Resources Board
Central Valley Auditorium, Second Floor
1001 I Street
Sacramento, California 95814

Acknowledgments

This report was prepared with the assistance and support from the other divisions and offices of the Air Resources Board. In addition, we would like to acknowledge the assistance and cooperation that we have received from many individuals and organizations.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

APPENDICES

A. Proposed Regulation Order for Proposed Amendments to the California Diesel Fuel Regulations

B. California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines

C. Diesel Fuel Aromatic Content and Exhaust Emissions of Polycyclic Aromatic Hydrocarbons

D. Staff Review of the Emission Benefits of California's Diesel Fuel Program

E. Staff Analysis of Future Emission Benefits of California's Diesel Fuel Program

F. Effects of Changes in Diesel Fuel Properties on Emissions

G. Diesel Fuel Lubricity: Pump Wear Data

H. Refining Technology for Low Sulfur Diesel Production

I. Diesel Engine Lubricating Oils

J. Effects of Low Sulfur Diesel Fuel on Greenhouse Gas Emissions

K. Low Sulfur Diesel Fuel and Water Quality

L. Questionnaires Presented to California Refiners Producing Diesel Fuel

M. Economic Impacts of Proposed Regulations on the Agricultural Sector

N. Impact of Fuel Taxes on Fuel Purchases of Out-of-State Diesel Fuel

O. References

I. INTRODUCTION AND SUMMARY

A. Introduction

In November 1988, the Air Resources Board (ARB) approved regulations limiting the allowable sulfur content of motor vehicle diesel fuel to 500 parts per million by weight (ppmw) statewide and the aromatic hydrocarbon content to 10 percent with a 20 percent limit for small refiners. These diesel fuel regulations, which became effective in 1993, are a necessary part of the state's strategy to reduce air pollution through the use of clean fuels and lower emitting motor vehicles and off-road equipment. The regulation limiting the aromatic hydrocarbon content of diesel fuel has included provisions that enable diesel fuel producers and importers to comply through alternative diesel formulations that may cost less. The alternative specifications must result in the same emission benefits as the 10 percent aromatic standard (or in the case of small refiners, the 20 percent standard).

The California diesel fuel regulations have resulted in significant reductions in emissions from diesel powered vehicles and equipment: greater than 80 percent for sulfur dioxide (SO_2), 25 percent for particulate matter, and 7 percent for oxides of nitrogen (NOx). California diesel fuel also results in reductions of emissions of several toxic substances, other than diesel particulate matter, including benzene and polynuclear aromatic hydrocarbons.

This report is the initial statement of reasons to support proposed amendments to the California diesel fuel regulations. One of the proposed amendments would reduce the sulfur content limit from 500 ppmw to 15 ppmw for diesel fuel sold for use in California in on-road and off-road motor vehicles starting in mid-2006. The lower sulfur limit would align the California requirement with the on-road diesel sulfur limit adopted by the United States Environmental Protection Agency (U.S. EPA). However, the California sulfur requirement would apply to on and off-road motor vehicle diesel fuel. The new sulfur standard will enable the use of the emissions control technology required to ensure compliance with the new emissions standards adopted by the U.S. EPA for 2007 and subsequent model-year heavy-duty engines and vehicles. We are also proposing establishment of another compliance option to the aromatics regulation to provide further flexibility to fuel producers. Under the proposed option, producers could choose to meet a set of specific diesel fuel properties that would achieve emissions benefits equivalent to those provided by the original specification for aromatic hydrocarbons approved by the Board 15 years ago. Staff is also proposing improved procedures for certifying emission-equivalent alternative formulations. In addition, we are proposing adoption of standards for diesel fuel lubricity. Also, to implement requirements of ARB's risk reduction plan for diesel PM emissions, staff is proposing the adoption of an airborne toxic control measure (ATCM) making the diesel fuel requirements applicable to nonvehicular diesel fuel.

B. What is California Diesel Fuel?

California diesel fuel used in motor vehicles must meet specifications adopted by the ARB in 1988 limiting sulfur and aromatic contents. The requirements for "CARB diesel," which became applicable in 1993, consists of two basic elements:

- A limit of 500 ppmw on sulfur content to reduce emissions of both sulfur dioxide and directly emitted particulate matter.
- A limit on aromatic hydrocarbon content of 10 percent for large refiners and 20 percent for small refiners to reduce emissions of both particulate matter and NOx.

The regulation limiting aromatic hydrocarbons also includes a provision that enables producers and importers to comply with the regulation by qualifying a set of alternative specifications of their own choosing. The alternative formulation must be shown, through emissions testing, to provide emission benefits equivalent to that obtained with a 10 percent aromatic standard (or in the case of small refiners, the 20 percent standard). Most refiners have taken advantage of the regulation's flexibility to produce alternative diesel formulations that provide the required emission reduction benefits at a lower cost.

C. Why are Amendments to the California Diesel Fuel Regulations Necessary?

1. Lower Sulfur Limit

A lower sulfur limit is needed to ensure the emissions performance of heavy-duty diesel engines and vehicles designed to meet 2007 model-year federal and California exhaust emission standards and to help reduce the exposure and risk from diesel particulate matter emissions as required by the ARB Diesel Risk Reduction Plan.

a) 2007 Model-Year Emission Standards for Heavy-Duty Diesel Engines

In January 2001, the U.S. EPA adopted emission standards for 2007 and subsequent model-year heavy-duty diesel engines. These emission standards represent a 90% reduction of NOx emissions, 72% reduction of non-methane hydrocarbon (NMHC) emissions, and 90% reduction of particulate matter (PM) emissions compared to the 2004 emission standards. In October 2001, the ARB approved amendments that aligned the California exhaust emission standards for heavy-duty diesel engines with those promulgated by the U.S. EPA.

The U.S. EPA's Final Rule sets heavy-duty engine emissions standards that will necessitate the use of catalyzed diesel particulate filters, NOx after-treatment and other advanced after-treatment based technologies. However, current commercial diesel fuel sulfur levels would inhibit the performance of these technologies. In the same January 2001 rulemaking, the U.S. EPA adopted new diesel fuel quality standards limiting the sulfur content of on-road diesel fuel to no more than 15 ppmw to enable the effective performance of the advanced engine emission control technologies. The average sulfur content of California diesel is about 140 ppmw with about 20 percent of production already meeting the proposed 15-ppmw limit.

b) The Diesel Risk Reduction Plan

Diesel-powered vehicles (on-road and off-road) account for a disproportionate amount of pollutants emitted by motor vehicles. They represent about 4 percent of California motor vehicles but produce about 40 percent of the NOx and 60 percent of directly emitted particulate matter from California on- and off-road vehicles.

In August 1998, the ARB identified particulate matter emitted from diesel engines (diesel PM) as a Toxic Air Contaminant (TAC). Because of the considerable potential health risks posed by exposure to diesel PM, ARB staff recommended a comprehensive plan, the diesel RRP, to further reduce diesel PM emissions and the health risks associated with such emissions. This plan seeks to reduce Californians' exposure to diesel particulate matter and associated cancer risks from baseline levels in 2000 by 85 percent by 2020.

In October 2000, the diesel RRP was approved by the ARB. The plan identified air toxic control measures and regulations that will set more stringent emissions standards for new diesel-fueled engines and vehicles, establish retrofit requirements for existing engines and vehicles where determined to be technically feasible and cost-effective, and require the sulfur content of diesel fuel to be reduced to no more than 15 ppmw.

The proposed maximum fuel sulfur standard of 15 ppmw is needed for the effective performance of the emissions control technologies proposed in the diesel RRP for new and retrofitted engines. At diesel sulfur concentrations higher than 15 ppmw, the effectiveness of the emissions control systems is sufficiently reduced that the desired emissions reductions for NOx and particulate matter cannot be achieved. These reductions in hydrocarbons, NOx, carbon monoxide (CO), and particulate matter are essential to the achievement of California's air quality goals.

2. New Equivalent Limits for Diesel Fuel Properties

Staff is proposing a new option for compliance with the aromatic hydrocarbon specification. The proposed option is a set of specified limits that provide an alternative formulation that would provide equivalent environmental benefits to the 10 percent aromatic hydrocarbon limit. The proposed new equivalent limits are based upon the average properties of existing certified formulations to preserve the actual emission benefits of California diesel fuel.

This proposal provides producers or importers of diesel fuel another compliance option that should facilitate the importation of diesel fuel into California.

3. Diesel Fuel Lubricity Standard

Staff is proposing a diesel fuel lubricity standard to ensure that California diesel fuel provides adequate lubrication for fuel systems of existing and future diesel engines. Diesel fuel lubricity can be defined as the ability of diesel fuel to provide surface contact lubrication. Adequate levels of fuel lubricity are necessary to protect the internal contact points in fuel pumps and injection systems to maintain reliable performance.

The levels of natural lubricity agents in diesel fuel are expected to be reduced by the more severe hydrotreating needed to lower the sulfur content of diesel fuel to meet the proposed 15-ppmw sulfur limit. Lubricity additives are available to increase the lubricity of fuels that have had their natural lubricity agents depleted.

Several types of diesel fuel injection equipment rely on the fuel for lubrication of the moving parts. Fuels of low lubricity do not provide adequate lubrication and will contribute to excessive wear resulting in reduced equipment life and performance. New fuel injector systems, developed to further reduce exhaust emissions, use extremely high pressures and require even higher levels of fuel lubricity than conventional systems. Excessive wear in these systems is expected to increase emissions due to compromised pump performance.

The American Society for Testing and Materials (ASTM) has been working to develop lubricity standards for its D-975 diesel fuel specifications since the introduction of low sulfur diesel fuel in 1993. To date, ASTM has not been successful in adopting a lubricity standard. As diesel fuel sulfur levels continue to be reduced, equipment manufacturers and consumers have expressed concern regarding the lack of a lubricity standard.

Staff believes that a lubricity standard is necessary due to the reduction of natural diesel fuel lubricity that is expected to occur with the implementation of the proposed 15-ppmw sulfur limit. Adequate diesel fuel lubricity must be maintained to protect both existing and future diesel engine fuel systems from excessive wear that would reduce engine life and increase exhaust emissions.

4. *Certified Alternative Diesel Fuel Formulations*

Staff is proposing several technical amendments to the portion of the regulation addressing certification of alternative formulations – Title 13, California Code of Regulations (CCR), Section 2282 (g).

a) Consistency With the Proposed Sulfur limit

For consistency with the proposed new sulfur content limits in section 2281, we are proposing that the Board amend section 2282(g) to require that both the candidate fuels and the reference fuels meet a sulfur limitation of 15 ppmw. Also, fuel produced under the existing certified formulations will independently have to meet the 15-ppmw sulfur limit when it becomes effective in 2006.

b) Emission Equivalency of Candidate Fuels to In-Use Fuels

Studies have shown that emissions from diesel engines are affected by fuel properties other than the five minimum specifications of certified alternative formulations. The effects of other properties on emissions do not change the applicability of section 2282(g) for certifying emission-equivalent California diesel fuel formulations. However, if there are large differences in properties between a reference fuel and a candidate fuel and between the candidate fuel and the fuel produced under the certification, the emission equivalency of the fuel produced for sale is in doubt. To eliminate doubts about the emission equivalency of fuel produced for sale, we are proposing that section 2282(g)(2) be amended by adding additional required specification ranges for candidate fuels, applicable for all new alternative formulations certified on or after August 1, 2004.

c) Emission Equivalency of Candidate Fuels to Reference Fuels

To determine whether the average emissions of NOx, particulate matter, and the soluble organic fraction (SOF) during testing with the candidate fuel do not exceed the average emissions of the comparable compounds during testing with the reference fuel, an arithmetic criterion is applied to the average emissions of each pollutant. The arithmetic criterion includes a margin of safety, based on the pooled standard deviation of the emissions, as well as a tolerance to ensure that truly emission-equivalent fuels will qualify. We have evaluated the results of the test programs for sixteen 10-percent equivalent formulations and have determined that the allowable tolerances for each pollutant are too large. Therefore, we are recommending that the tolerances for each pollutant be reduced by half.

d) Elimination of Sulfate Credit.

The provisions on certifying alternative formulations currently allow a sulfate credit for the candidate fuel when calculating particulate matter emissions. The sulfate credit was provided to encourage refiners to reduce sulfur in diesel fuel below the 500-ppmw limit, since fuel-originated secondary sulfates in the environment would significantly outweigh the sulfate portion in the primary PM emissions. Because ARB staff did not want an unlimited credit to be provided, the sulfate credit was capped at the primary sulfate level. For future certifications, the staff proposes to eliminate the sulfate credit, because the proposed sulfur level of 15 ppmw practically eliminates the possibility of a sulfate credit for future applicants.

D. What are the Proposed Amendments?

1. Reduce the Maximum Allowable Sulfur Content of Diesel Fuel

Staff is proposing that the Board amend the California diesel fuel regulations to reduce the maximum sulfur content of motor vehicle diesel fuel from 500 ppm by weight to 15 ppm by weight. Staff is proposing that the new sulfur limit for diesel fuel become effective at the refinery June 1, 2006 – the same effective date as the U.S. EPA's 15 ppmw sulfur limit for diesel fuel. The proposed change is expected to reduce the sulfur level in California diesel fuel from its current average of 140 ppmw to about 10 ppmw.

2. Change the Allowable Sulfur Content of Diesel Engine Certification Fuel

Staff is proposing an amendment that would change the sulfur content specification for certification fuel used to certify diesel vehicles and engines. Staff is proposing a range of sulfur content of 7 to 15 ppmw to replace the current range of 100 to 500 ppmw. This change is necessary to be consistent with the maximum permissible sulfur content of 15 ppmw being proposed for commercial diesel fuel in this rulemaking. The proposed sulfur content of the certification fuel will not exceed levels compatible with the effective operation of diesel engines and vehicles equipped with sulfur sensitive emissions control technologies.

3. Adopt New Alternative Equivalent Limits for California Diesel

We are proposing that the Board approve new equivalent limits which can be used by diesel fuel producers and marketers as an alternative means of complying with the 10-percent aromatic standard. Table I-1 presents the proposed new equivalent limits.

Table I-1: Proposed New Equivalent Limits for California Diesel Fuel

Property	Equivalent Limit[1]	Test Method
Aromatic Content (% by wt.)	≤ 21.0	ASTM D5186-96
PAH Content (% by wt.)	≤ 3.5	ASTM D5186-96
API Gravity	≥ 36.9	ASTM D287-82
Cetane Number	≥ 53	ASTM D613-84
Nitrogen Content (ppmw)	≤ 500	ASTM D4629-96
Sulfur (ppmw)	≤ 160[2]	ASTM D2622-94

[1] ≤ means "less than or equal to"
≥ means "greater than or equal to"
[2] Becomes ≤ 15 ppmw beginning June 1, 2006.

4. Adopt a Diesel Fuel Lubricity Standard

Staff is proposing that the Board approve a two phase plan to institute a fuel lubricity standard that will apply to all diesel fuel sold or supplied in California.

The proposed initial phase will be to immediately adopt a standard that is at least as protective as the current voluntary standard to protect current in-use engines. The proposed standard is a High Frequency Reciprocating Rig (HFRR) maximum wear scar diameter (WSD) of 520 microns. The HFRR ASTM test method, D6079-02, would be incorporated by reference. Staff is proposing that this standard be implemented on a 90-day phase-in schedule, commencing August 1, 2004.

The proposed second phase would be to determine a 2006 lubricity standard protective of advanced technology fuel systems via a technology assessment. Staff proposes that a place holder be included in the regulation for the 2006 standard and that the Board's resolution direct staff to conduct a technical assessment, to be completed in 2005, to determine an appropriate 2006 standard. The Board's resolution would further direct staff to return to the Board in 2005 with a proposed 2006 lubricity standard if the technology assessment determines that a HFRR maximum WSD of 460 microns at 60 degrees C, or a more appropriate standard, should be implemented on the same schedule as the proposed 15-ppmw sulfur limit for diesel fuel.

5. Revise the Requirements for Certifying Alternative Diesel Formulations.

We are proposing four types of technical amendments to subsection 2282(g): 1) for consistency with section 2281; 2) to ensure equivalent emissions performance of fuels sold as certified formulations to candidate fuels; 3) to ensure equivalent emissions performance of candidate fuels to reference fuels; and, 4) to eliminate a provision for sulfate credit in determining equivalency of the candidate fuel.

a) Consistency With the Sulfur Standard in Section 2281

Since we are proposing under section 2281 that all California diesel fuel meet a 15-ppmw sulfur limitation starting in mid-2006, for consistency and to improve the effectiveness of subsection 2282(g) we are also proposing that reference and candidate fuels also meet the 15-ppmw sulfur limitation for all alternative formulations certified after July 31, 2004. In addition, fuels produced under existing certified formulations will have to meet the 15 ppmw limit when it becomes applicable.

b) Emission Equivalency of Candidate Fuels to In-Use Fuels

To ensure that future candidate fuels tested in the laboratory are fully characterized, we are proposing that the reporting requirements for candidate fuel properties be expanded to include all the properties that must be reported for reference fuels. We are also proposing that the Board require that the same property limitations and ranges apply to candidate fuels as reference fuels, except for the four specified certified-formulation properties, and that candidate fuel properties be within half the range of reference fuel properties. For new formulations, a candidate fuel property will be permitted to be outside applicable ranges only if the property is specified in the formulation in the Executive Order certifying the formulation. This would prevent the applicant from changing other candidate fuel properties that could affect emissions unless the applicant is willing to accept that specifications for those properties be included in the certified formulation.

c) Emission Equivalency of Candidate Fuels to Reference Fuels

For a candidate fuel to qualify an alternative formulation, the average emissions of NOx, PM, and SOF during testing with the candidate fuel cannot exceed the average emissions of NOx, PM, and SOF during testing with the reference fuel. A statistical margin of safety, based on the pooled standard deviation of the tests with the candidate and reference fuels, is required for each pollutant. Tolerances are allowed for each pollutant to make sure that a truly emission-equivalent fuel will always pass. Based on sixteen fuels qualified in the same laboratory, we have found that the standard deviations and calculated safety margins warrant that the tolerances be lowered. Therefore, we are proposing that the tolerances be lowered from 2, 4, and 12 percent to 1, 2, and 6 percent of the average emissions of NOx, PM, and SOF, respectively, during testing with the reference fuel.

d) Elimination of Sulfate Credit

In the interest of updating the certified alternative formulation provisions of subsection 2282(g) to be applicable to fuels with the proposed 15-ppmw sulfur content limitation, we are proposing that the Board amend the regulation to eliminate the two provisions for sulfate credit under subsection 2282(g)(5)(B) for all new certified formulations. The proposed limit for sulfur content of 15 ppmw makes this provision obsolete as there could not practically be any significant difference between the sulfur levels in the reference and candidate fuels. Existing formulations would not be affected.

6. Adopt Diesel Fuel Standards for Nonvehicular Diesel Engine Applications

Staff is proposing that the Board adopt, as a new section of title 17 of the California Code of Regulations, an Airborne Toxic Control Measure (ATCM) for nonvehicular diesel fuel standards. The new diesel fuel requirements would be identical to the California Diesel Fuel Regulations except that the applicability would be to fuel used in nonvehicular diesel engines, other than those powering locomotives or marine vessels. The proposed ATCM would facilitate the implementation of the Diesel Risk Reduction Plan for nonvehicular diesel engines.

7. Other Amendments

The staff is proposing the following amendments to clarify the requirements of the regulations and to ensure that the regulations work effectively.

The sulfur regulation currently requires that sulfur in diesel fuel be determined by x-ray spectrometry using ASTM D2622-94. The detection limit and repeatability for this method are not acceptable for determining sulfur at the levels expected in diesel fuels produced to comply with the proposed sulfur limit of 15 ppmw. Therefore, staff is proposing to replace this method with ASTM D5453-93, an ultraviolet fluorescence method that will provide a more suitable detection limit and better precision than the current method, when the new sulfur standard becomes applicable.

Staff is proposing a revision of the definition of "diesel fuel" to clarify the applicability of the diesel fuel regulations and make the definition consistent with the definition for fuel for internal combustion, spark ignition engines. The revised definition will include any predominantly hydrocarbon, liquid fuel that is used or intended for use or represented for use in internal combustion, compression ignition (diesel cycle) engines.

Staff is also proposing a conforming amendment to the definition of diesel fuel in the verification procedure and in-use compliance requirements for in-use strategies to control emissions from diesel engines. This amendment would assure that the current effect of the requirements for the verification procedure regulation will not be changed by the expansion of the definition of diesel fuel.

Also, staff is proposing that an exemption from the diesel fuel requirements be established for diesel fuel used in qualifying military vehicles, closely paralleling provisions in the U.S. EPA regulations.

E. What Alternatives Were Considered?

Staff evaluated alternatives to the proposed new sulfur standard and concluded that there were no alternative means of complying with the emission standards for 2007 and subsequent model year diesel engines. Staff also found that there were also no alternative means of facilitating the implementation of the Diesel Risk Reduction Plan. Discussions of the alternatives considered by staff are contained in the chapters of this report that describe the individual proposed amendments.

F. Do the Proposed Amendments Satisfy the Commitments in the State Implementation Plan?

The proposed amendment to reduce the sulfur content of diesel fuel will have a direct benefit for the State Implementation Plan (SIP) by reducing particulate sulfate PM_{10} emissions. Most importantly, the proposed diesel fuel sulfur standard is central to the success of the 2007 heavy-duty diesel vehicle emission standards in providing benefits that help the state meet SIP emission reduction obligations. The lower sulfur diesel fuel will be an enabling fuel for the advanced emission control technologies needed to achieve the emissions reductions required by the 2007 heavy-duty diesel engine emission standards.

G. What Are the Emission Impacts of the Proposed Amendments?

Sulfur oxides and particulate sulfate are emitted in direct proportion to the sulfur content of diesel fuel. Reducing the sulfur content of diesel fuel from the statewide average of 140 ppmw to less than 10 ppmw would reduce sulfur oxide emissions by about 90 percent or by about 6.4 tons per day from 2000 levels. Direct diesel particulate matter emissions would be reduced by about 4 percent, or about 0.6 tons per year in 2010 for engines not equipped with advanced particulate emissions control technologies. These emissions reductions would be obtained with low sulfur diesel used in mobile on-road and off-road engines, portable engines, and those stationary engines required by district regulations to use CARB diesel. In addition, NOx emissions would be reduced by 7 percent or about 80 tons per year for those engines not currently using CARB diesel, assumed to be about 10 percent of the stationary engine inventory.

The lower sulfur diesel makes much more significant emissions reductions possible by enabling the effective use of advanced emission control technologies on new and retrofitted diesel engines. With these new technologies, emissions of diesel particulate matter and NOx can be reduced by 90 percent. Significant reductions of non-methane hydrocarbons and carbon monoxide can also be achieved with these control devices.

H. What are the Environmental Impacts of the Proposed Amendments?

1. Air Quality

Sulfur in diesel fuel contributes to ambient levels of fine particulate matter through the formation of sulfates both in the exhaust stream of the diesel engine and later in the atmosphere. Therefore, reducing the sulfur limit of California diesel to 15 ppmw will have a positive air quality impact by reducing ambient levels of particulate matter. The proposed diesel sulfur limit of 15 ppmw will also help to improve air quality by enabling the effective performance of advanced diesel exhaust emissions control technologies that reduce emissions of ozone precursors (NOx and NMHC) and diesel PM. As ozone precursor emissions are reduced, ozone levels will also be reduced. In addition, reducing ozone precursor emissions will help to reduce secondary particulate matter formation – whether nitrate or organic compound aerosols. Reductions in emissions of diesel PM mean reduced ambient levels of the toxic air contaminants found in diesel exhaust and reduced public exposure to those TACs.

2. *Water Quality.*

The proposed amendment to lower the sulfur content limit of California diesel fuel to 15 ppmw should have no significant adverse impacts on water quality. With a lower sulfur content, emitted sulfur oxides and sulfates would be lower and consequently there would be a reduction of atmospheric deposition of sulfuric acid and sulfates in water bodies. The low sulfur diesel will enable the use of emissions control devices to reduce NOx and diesel PM emissions. As a result, there should be a decrease in atmospheric deposition of nitrogen compounds such as nitrates and airborne diesel particles as well as the associated heavy metals, PAHs, dioxins, and other toxic compounds typically found in diesel exhaust.

The release of diesel fuel to surface water and groundwater can occur during production, storage, distribution or use. The refining process to reduce the sulfur content of diesel to 15 ppmw is not expected to result in a significant change in the chemical composition of the fuel. There should also be no significant change in the physical or chemical properties that affect the activity of the fuel in soil and water. Therefore, any release of low sulfur diesel fuel to the environment should have no additional impact on water quality compared to the current diesel fuel.

The other proposed amendments to the California diesel regulation should not have any significant adverse impacts on water quality.

3. *Greenhouse Gas Emissions*

Implementation of the proposed amendment to reduce the sulfur content of diesel fuel could have a small effect on global warming. The production of low sulfur diesel is expected to increase emissions of greenhouse gases. Emissions of CO_2 from refineries will increase due to the increased demand for energy for additional hydrogen production and additional processing to produce low sulfur diesel. Emissions from refineries of other greenhouse gases like methane and nitrous oxide will be very small compared to the additional carbon dioxide emissions.

4. *Refinery Modifications*

Implementation of the proposed amendment to the diesel fuel sulfur standard will require changes in processing that could affect emissions from the refinery.

Refiners have indicated that they will meet the proposed sulfur limit by increasing their hydrotreating capability. The additional energy needs for this additional processing could mean increases in combustion derived emissions such as NOx, PM, CO, and SO_2 from sources such as heaters and boilers that must increase their operation to meet the additional energy demands. The impact of these process changes on air quality will be limited by the requirements of the California Environmental Quality Act (CEQA) and by new source review or BACT requirements of the air quality management districts.

I. What is the Cost of the Proposed Amendments?

The staff's estimates of the costs of the proposed amendments are based on information provided by California refiners, the major California common carrier pipeline operator, specialty fuel suppliers, California Energy Commission (CEC) staff, and documents prepared by the U.S. EPA, U.S. DOE, and the SCAQMD.

1. Overall Costs.

The ARB staff estimates that the costs of reducing the sulfur content of diesel fuel and requiring the fuel to meet minimum lubricity specifications will be about 2 to 4 cents per gallon of diesel. The cost estimates include: capital expenditures of about $170 to $250 million; operating and maintenance costs of $50 to $60 million per year; distribution system costs of about $8 million due to downgrading of transmix to federal off-road diesel standards; a fuel economy penalty of about 0.5 cents per gallon; and the cost of the proposed lubricity standard which could range from 0.2 to 0.6 cents per gallon of diesel.

Most of these costs to refiners to reduce diesel fuel sulfur levels will be incurred as a result of the U.S. EPA and the SCAQMD regulations[a] that have already been adopted. Staff's proposed amendments would extend the applicability of these regulations to the 25 percent of state's total diesel fuel consumed by California off-road diesel vehicles outside the SCAQMD.

The U.S. EPA estimated the cost of its national program to be between 4 cents and 5 cents per gallon. The cost of the national program is expected to be higher than the estimated cost of 2 to 4 cents for California's because the California refining industry is already producing a lower sulfur on-road diesel fuel than most refineries in other regions of the country, and is therefore better positioned to produce low-sulfur diesel fuel. About 20 percent of the diesel fuel produced in California has sulfur levels below 15 ppmw.

2. Fuel Supply and Price.

With respect to diesel prices, it is very difficult to predict what will occur in the marketplace. California diesel prices are heavily influenced by supply and demand, crude oil prices, and competitive market considerations. However, it is reasonable to assume that over time, the refiners will recover the increased costs of production in the marketplace. With this assumption and the staff's estimate that the long-term production cost of low-sulfur diesel fuel will be from 2 to 4 cents per gallon, it is reasonable to assume that this increase in production cost will, on average, be reflected in diesel fuel prices.

It is very difficult to predict the stability of diesel prices. However, the proposed amendments regulation should not affect the ability of California refiners to supply sufficient quantities of diesel fuel to the California market. The recent ARB refinery survey suggests that sufficient diesel refinery capacity already exists. In addition, the implementation of the federal on-road low sulfur diesel regulations, adoption of the California diesel fuel regulations by the state of Texas, and the ability of out-of-state refiners to produce diesel fuel meeting California standards should provide even greater assurance of diesel fuel availability to the State. Further, the flexibility provided by the proposed equivalent limits should enhance the ability of producers

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[a] SCAQMD Rule 431.2. Sulfur Content of Liquid Fuels limits the sulfur content in diesel to 15 ppm by weight. The limit applies to diesel produced for both stationary and motor vehicle sources but excluding ships and trains. The rule is described in Section VI.C below.

outside California to provide fuel to California. Therefore, the overall diesel production system – consisting of California refineries and imports – should not be impacted after the implementation of the proposed amendments.

J. What are the Economic Impacts?

The proposed amendments should have only a very small relative economic impact on the California economy or the diesel fuel consuming sectors of the economy investigated by staff. Staff estimated potential impacts for the petroleum industry, the agricultural sector, and the transportation sector using a computable general equilibrium (CGE) model of the California economy. This model is a modified version of the California Department of Finance's Dynamic Revenue Analysis Model (DRAM) developed by researchers at the University of California, Berkeley. The ARB model called E-DRAM describes the economic relationships between California producers, consumers, government, and rest of the world. The analysis predicted very minor changes in various economic outputs. Staff also found that there should be no significant additional adverse effect on small businesses because of the cost impacts of the regulations.

K. What Future Activities Are Planned?

The staff will continue its investigation of a statistical regression model that enables users to predict how diesel emissions are affected by changes in fuel properties. If successful, such a model could be used by refiners and importers to certify alternative formulations, like the California Predictive Model is used for gasoline, and could provide the same type of flexibility for diesel fuel production. Such a model would allow refiners and importers to quickly certify alternative formulations for sale in California without having to conduct engine emissions tests. This should also allow more diesel fuel outside of California to qualify for sale in California.

This effort will involve working with the U.S. EPA's staff and other stakeholders to conduct a comprehensive review and analysis of available data to quantify the exhaust emission effects of diesel fuel parameters including cetane number, aromatic content, 90 percent distillation temperature, sulfur content, and fuel density. The adequacy of available test data to construct a model will be an important consideration.

Also, staff will participate in the Coordinating Research Council (CRC) Diesel Performance Group lubricity panel and the associated lubricity testing of advanced technology fuel injection systems. Staff will conduct a technology assessment of the lubricity level required by advanced technology fuel injection systems in 2005, considering the CRC research results as well as additional data as it becomes available. If necessary, staff will propose a 2006 lubricity standard of a HFRR maximum WSD of 460 microns, or a more appropriate value as determined by the technology assessment.

II. Recommendations

The staff recommends that the Board adopt the proposed amendments to the California diesel regulations as contained in Appendix A. These amendments will do the following:

1. Reduce the maximum permissible sulfur content in vehicular diesel fuel from 500 ppmw to 15 ppmw;
2. Adopt an Air Toxics Control Measure to require the use of vehicular diesel fuel in all nonvehicular diesel engines;
3. Revise the sulfur specifications for diesel certification fuel used to determine whether diesel engines comply with California's emission standards for heavy-duty diesel engines;
4. Revise the requirements for certification of alternative diesel formulations to require that both the candidate and reference fuels used in the certification procedure meet a sulfur limit of 15 ppmw;
5. Establish additional requirements for certification of alternative diesel formulations to ensure that the diesel fuel produced commercially under the alternative formulation has comparable emissions performance to the candidate fuel used to certify the formulation;
6. Adopt new specifications for equivalency to the aromatic hydrocarbon limit for California diesel fuel to provide another compliance option while maintaining the benefits of the existing regulations;
7. Adopt standards for diesel fuel lubricity to ensure that California diesel fuel provides adequate lubrication for the fuel systems of existing and future diesel engines; and
8. Make other changes, including improvements to the sulfur test method and a revision of the definition of "diesel fuel," to ensure that the regulation works effectively.

III. BACKGROUND

This chapter contains general information about the source of the air pollution problems being addressed in this rulemaking and the current air pollution impacts of diesel fuel use.

A. Sources of Diesel Sulfur

The primary sources of sulfur in diesel fuel are the sulfur-containing compounds which occur naturally in crude oil. The sulfur content can vary widely depending on the source of the crude oil. For crude oil refined in the U.S. outside of California, the sulfur content can range from 0.4 percent to 2.8 percent with an average content of about 1.3 percent.[1] The range for crude oil refined in California is 0.4 percent to 3.3 percent while the average is about 1.3 percent.[1]

Most of the sulfur in crude oil is in the heaviest boiling fractions. Since most of the refinery blendstocks used to manufacture diesel fuel come from the heavier boiling components of crude oil, they contain substantial amounts of sulfur.

B. Current Levels of Sulfur in California Diesel Fuel

Almost all of the diesel fuel sold to final users in California is Grade Low Sulfur No. 2-D [2] which complies with the requirements of the Clean Air Act and 40 CFR section 80.29 regarding sulfur content. About 90 percent of the diesel fuel sold or supplied in California meets the "CARB diesel" requirements for sulfur and aromatic hydrocarbons which apply to diesel fuel used in on-road and off-road vehicular sources and are described later in the report. Only stationary sources, marine vessels and locomotives are currently exempt from the CARB diesel requirements.[a]

Table III-1 shows average values for sulfur and four other fuel properties for motor vehicle fuel sold in California before and after the current diesel fuel regulation became effective in 1993. Before 1993, the average fuel sulfur content of 400 ppm for the Los Angeles area was considerably lower than the 3000-ppmw average for the rest of the state. This difference was due to the ARB's 500-ppmw limit on diesel fuel sulfur that had been in effect in the South Coast Air Basin since 1985. The corresponding national averages are shown for the same properties for on-road diesel only since the U.S. EPA sulfur standard does not apply to off-road or nonvehicular diesel fuel.

[a] Most stationary engines use CARB diesel because of the state's single fuel distribution network and because of districts' BACT requirements that specify CARB diesel. Also, South Coast Air Quality Management District's rule 431.2 will require CARB diesel for all stationary engines in 2004, excluding engines in locomotives and ships.

Table III-1: Average Properties of Reformulated Diesel Fuel

Property	California		U.S.(1)
	Pre-1993	1999	1999
Sulfur, ppmw	440(2)	140(3)	360
Aromatics, vol.%	35	19	35
Cetane No.	43	50	45
PNA, wt.%	NA	3	NA
Nitrogen, ppmw	NA	150	110

1 AAMA National Surveys for on-road vehicles only.
2 For Los Angeles area only, greater than 3000 ppmw in rest of California.
3 About 20 % of total California volume is less than 15 ppmw.

C. Diesel-Fueled Engines

A diesel-fueled engine is defined as any internal combustion, compression-ignition (diesel-cycle) engine. The benefits of the proposed amendment to lower the California diesel sulfur limit will result from the use of diesel fuel in the categories of engines listed in Table III-2.

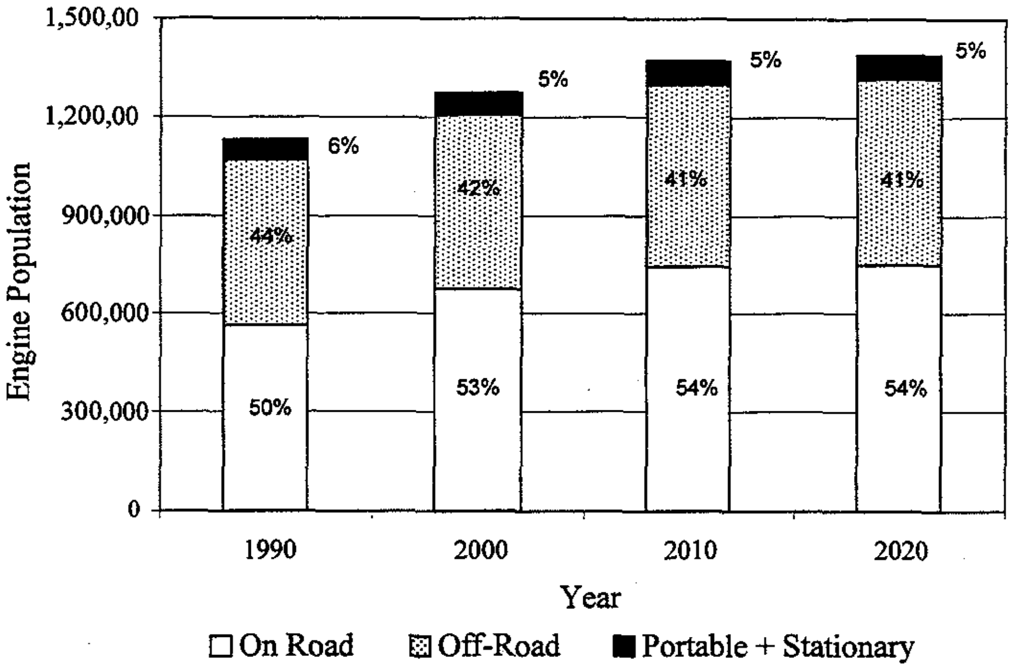
Table III-2 and Figure III-1 present population estimates for the different categories of diesel-fueled engines in California. An increase in the engine population is predicted for all of the diesel engine categories. The statewide population of on-road engines is predicted to increase by about 9 percent between 2000 and 2010 and by about 1 percent between 2010 and 2020. In 2000, 54 percent of the on-road diesel-fueled vehicles fell into one of the heavy-duty classes. There were approximately 700,000 on-road diesel-fueled vehicles in use in the state with the majority in the heavy-duty vehicle class with a gross vehicle weight rating greater than 14,000 pounds. This population is predicted to increase by about 12 percent between 2000 and 2010.[3]

Table III-2: Estimates of Statewide Diesel Engine Population[1]

Engine Category	Engine population			
	1990	2000	2010	2020
On-road	567,000	679,000	742,000	751,000
Off-road	504,000	528,000	556,000	563,000
Portable	48,000	49,000	54,000	55,000
Stationary	15,000	16,000	17,000	18,000
Total	1,134,000	1,272,000	1,369,000	1,387,000

1 From ARB's Risk Reduction Plan[3,4,] except for on-road and off-road estimates which were revised based on EMFAC 2002, version 2.2.

Figure III-1: Statewide Diesel Engine Population in California



D. Pollutants Emitted From Diesel Engines

Diesel exhaust is a complex mixture of inorganic and organic compounds that exist in gaseous, liquid, and solid phases. The composition of this mixture will vary depending on engine type, operating conditions, fuel, lubricating oil, and whether or not an emission control system is present. Many of the individual exhaust constituents remain unidentified.

The primary gas or vapor phase components of diesel exhaust include typical combustion gases and vapors such as carbon monoxide (CO), carbon dioxide (CO_2), oxides of sulfur (SO_X), oxides of nitrogen (NOx), reactive organic gases (ROG), water vapor, and excess air (nitrogen and oxygen). Table III-3 shows the contributions of emissions of PM_{10}, NOx, SOx, and reactive organic gases (ROG) from diesel engines to the statewide total emissions of those pollutants in 2000. Diesel engines contributed 3 percent to the statewide total PM_{10}, of which 85 percent is attributed to area sources. Diesel engines are significant sources of SOx, and NOx, accounting for 44 percent and 43 percent respectively of total statewide emissions. They account for 24 percent of the statewide total emissions of ozone precursors (NOx+ROG). A later chapter discusses the need for further reductions of these emissions to reach attainment of the federal ambient air quality standards for ozone.

The emissions from diesel-fueled engines also contain potential cancer-causing substances such as arsenic, nickel, benzene, formaldehyde, and polycyclic aromatic hydrocarbons. Diesel exhaust includes over 40 substances that are listed by the U.S. EPA as hazardous air pollutants (HAPS) and by the ARB as toxic air contaminants (TACs).

Table III-3: Contribution of Diesel Engines to Statewide Emissions of PM_{10}, NOx, SOx, and ROG in 2000

Pollutant	Emissions (tons per year)		Percent of Statewide total
	Diesel engines	Statewide total[1]	
PM_{10}	28,000	878,000	3.2%
SOx	52,000	117,000	44%
NOx	570,000	1,340,000	43%
ROG	44,000	1,210,000	4%
NOx+ROG	614,000	2,550,000	24%

[1] Data from California Emissions Forecasting System, year 2000. (run date: 5/14/01)

E. Particulate Matter Emissions from Diesel-Fueled Engines

In 1998, the ARB identified diesel particulate matter as a toxic air contaminant. Approximately 98 percent of the particles emitted from diesel engines are smaller than 10 microns in diameter.[4] Diesel particulate matter consists of both solid and liquid material and can be divided into three primary constituents: the elemental carbon fraction; the soluble organic fraction (SOF), and the sulfate fraction. The elemental carbon fraction, which makes up the largest portion of the total DPM, is the result of incomplete combustion in locally fuel-rich regions. The SOF consists of unburned organic compounds in the small fraction of the fuel and atomized and evaporated lube oil that escape oxidation. These compounds condense into liquid droplets or are adsorbed onto the surfaces of the elemental carbon particles. Several components of the SOF have been identified as individual toxic air contaminants. The sulfates with associated water are the result of oxidation of fuel-borne sulfur in the engine's exhaust.

Table III-4 and Figure III-2 present estimates of the statewide inventory for diesel PM emissions for 1990, 2000, 2010, and 2020. These estimates take into account growth in the engine population due to population and economic growth and emission reductions due to both federal and state regulations in effect at the time of the inventory estimate.

As shown in Table III-4 and Figure III-2, mobile diesel-fueled engines (on-road and off-road) are responsible for the majority of the diesel PM emissions in California. These two categories contribute approximately 94 percent of the total diesel PM emissions (Figure III-2). The estimated statewide PM emissions from on-road diesel motor vehicles was 7,600 tons in 2000 while the off-road estimate was 18,600 tons for the year. Emissions from off-road mobile sources far exceed emissions from all other categories. In 2000, off-road mobile sources accounted for 66% of the total diesel PM emissions, on-road sources for 27 percent, portable equipment for 5 percent and stationary sources the remaining 2 percent.

Emissions from stationary engines are expected to remain relatively stable while emissions from portable engines show a significant decrease. This reduction is due to replacement of older engines with new low emission engines.[4]

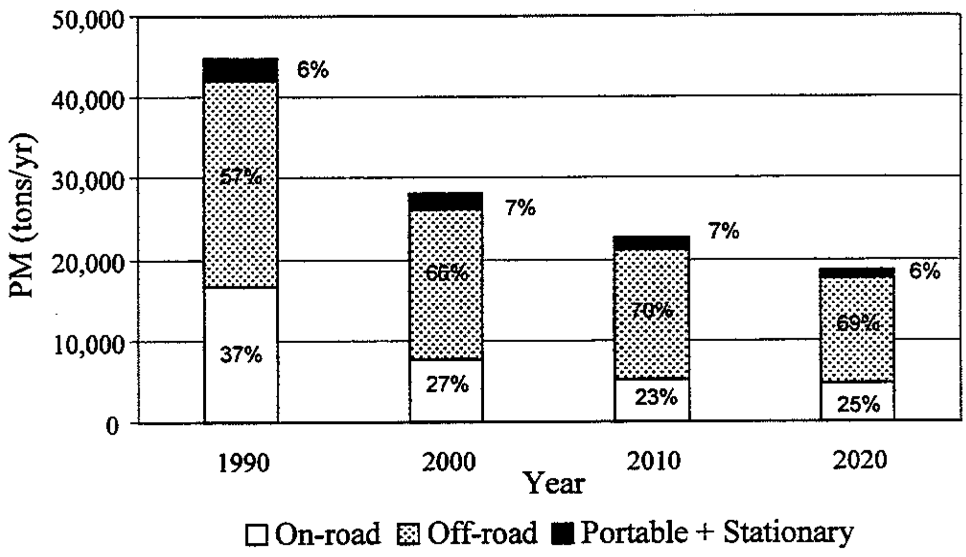
Figure III-2 shows a downward trend in PM emissions from mobile diesel engines even as the number of diesel engines increases (Table III-2 and Figure III-1). These reductions are due to improvements in engine design and emission control technology, currently adopted on-road standards, fleet turn-over as new vehicles with controls replace older vehicles with less effective controls, and the use of reformulated diesel fuels. However, without further controls, the effect of these emissions reduction measures will be to some extent offset by continued growth in vehicle use.

Table III-4: Statewide Diesel PM Emissions (tons per year)[1]

Engine Category	PM emissions (tons per year)			
	1990	2000	2010	2020
On-road	17,000	7,600	5,100	4,700
Off-road	25,000	18,600	16,000	12,800
Portable	2,200	1,400	1,100	660
Stationary	500	600	500	500
Total	44,700	28,200	22,700	18,660

[1] From ARB's Risk Reduction Plan, except for the on-road estimates that were revised based on EMFAC 2.02.

Figure III-2: Statewide Diesel PM Emissions



F. Effect of California Diesel Fuel Regulations on Emissions from Diesel Engines

In the 1988-1989 rulemaking establishing the California diesel fuel regulations, ARB staff estimated the emissions impacts based on transient-cycle testing of two engines and the results of earlier studies. The staff estimated that the diesel fuel specifications in the California diesel fuel regulations result in significant reductions in emissions from diesel powered vehicles and equipment: greater than 80 percent for sulfur dioxide (SO_2), 25 percent for particulate matter, and 7 percent for NOx. California diesel fuel also reduces emissions of several toxic substances other than diesel particulate matter, including benzene and polynuclear aromatic hydrocarbons. Appendix C contains a discussion of how diesel fuel aromatics content affects the emissions of PAHs and PAH derivatives in diesel exhaust.

ARB staff has analyzed the results of 35 different emission studies, involving 300 fuels and 73 engines, which have been conducted since the original estimates of the emission benefits were made in 1988. The staff's analysis show that ARB's original estimates continue to be valid, and are in close agreement with the estimates from the currently available emission studies.

In each study and for every engine configuration analyzed, emissions were predicted to decrease when fuel complying with the California diesel fuel regulations was used instead of conventional diesel fuel. These studies indicate that reducing sulfur content, aromatic hydrocarbon content, and specific gravity and increasing cetane number reduces PM emissions. They also show that reducing aromatic hydrocarbon content and specific gravity and increasing cetane number reduces NOx emissions from diesel engines.

The California diesel fuel regulations reduce emissions of PM and NOx because they limit the sulfur and aromatic hydrocarbons content of diesel or require changes to other properties that produce equivalent emission benefits. The studies reviewed confirm that this flexibility is possible because emission benefits accrue not only from the reduction in the content of sulfur and aromatic hydrocarbons in diesel fuel, but also from the lower specific gravity and higher cetane number of complying alternative diesel fuel formulations. This interrelationship of multiple diesel fuel properties that affect emissions enables fuel producers to employ considerable flexibility in formulating California diesel fuel, so long as their alternative formulations provide the same environmental benefits as defined reference fuels. Appendix D contains a draft report on the current emissions benefits of California's diesel fuel program while Appendix E supplements this report with an analysis of how future emissions benefits will be affected by fleet turnover.

IV. NEED FOR EMISSIONS REDUCTIONS

California's mobile source and fuels programs, more than any other pollution control effort, have helped to move the state's nonattainment areas closer to meeting federal and state air quality standards. The combination of fuels and vehicle emissions regulations provide significant statewide reductions in emissions of CO, PM_{10}, SOx, and ozone precursors - NOx and reactive organic gases or ROG (also called volatile organic compounds or VOCs). Nevertheless, significant additional reductions in mobile source emissions are essential if the state is to attain the state and national ambient air quality standards.

The ARB has published a series of new measures in a proposed new control strategy to reduce emissions of VOC, NOx, and particulate matter statewide.[5] The measures were initially proposed in the draft state and federal element of the South Coast Implementation Plan, but appropriate measures from the list will be incorporated where they are needed in regional ozone and PM_{10} attainment SIPs.

U.S. EPA regulations are needed to effectively reduce emissions from locomotives, aircraft, heavy –duty vehicles used in interstate commerce, and other sources such as off-road engines that are either preempted from state control or best regulated at the national level. Therefore, the reduction of PM_{10} and ozone precursor emissions will require cooperation with the U.S. EPA.

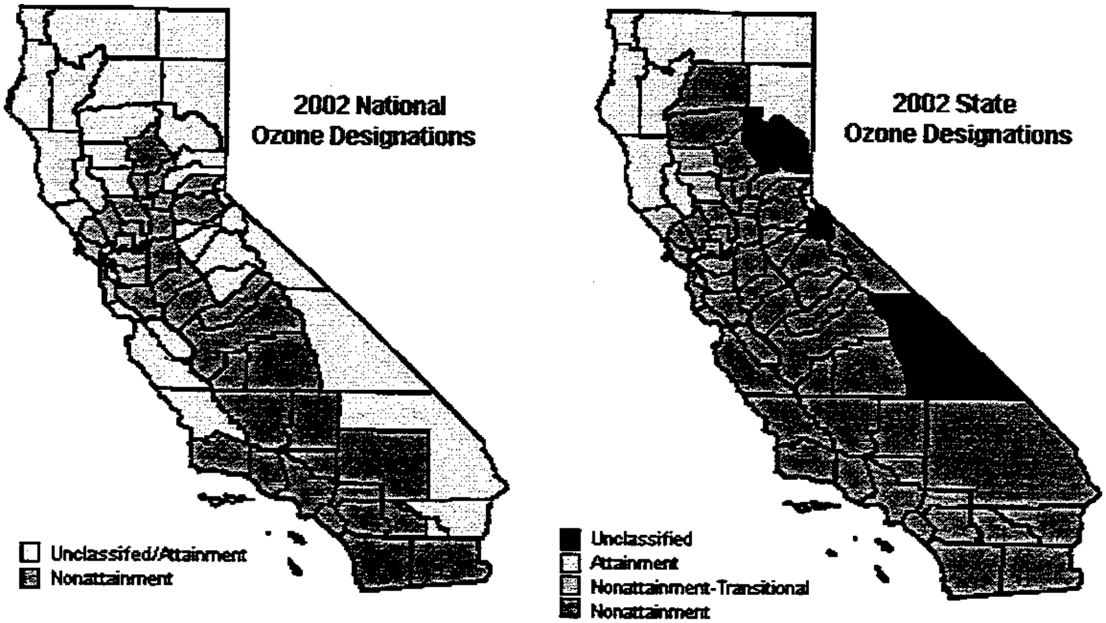
A. Criteria Pollutants

1. Ozone

As shown in Figure IV-1, most of the state does not meet the state or federal ozone standards. The areas that violate the national ozone standard are pursuing a strategy that reduces the emissions of precursors of ozone. Lowering ozone precursor emissions will also help reduce secondary particulate matter formation.

California's plan for achieving the federal ozone standard is contained in the California State Implementation Plan (SIP) that was approved by the Board in 1994. A significant part of the emission reductions in the SIP is achieved by controlling vehicles and their fuels. Mobile source emissions, both on-road and off-road, account for about 70 percent of ozone precursor emissions in California with diesel engines contributing 24 percent to the statewide total in 2000, as shown in Table III-3. Further reductions from the current emissions levels of NOx and ROG are essential if California is to reach attainment for ozone. ARB's strategy for obtaining further mobile source emissions reductions include improved technology measures. The largest new emissions reductions are expected from on-road and off-road diesel engines equipped with technology developed to meet emissions standards for on-road heavy-duty diesel trucks.

Figure IV-1: Federal and State Area Designations for Ozone



The greatest reductions are needed in the South Coast Air Basin. The South Coast Air Quality Management District (SCAQMD) revised its part of the Ozone SIP in 1997 and again in 1999. The U.S. EPA approved the South Coast's 1999 Ozone SIP revision in 2000. The SCAQMD has proposed a 2003 revision to the ozone SIP because of the need for additional reductions beyond those incorporated in the 1997/1999 plan. These additional reductions are need to offset increased emissions from mobile sources and meet all federal criteria pollutant standards within the time frames allowed under the Clean Air Act. The South Coast Air Basin is required to demonstrate attainment of the federal 1-hour ozone standard by 2010.

Significant reductions will also be needed in the San Joaquin Valley Air Basin (SJVAB) which has been classified as severe nonattainment for ozone effective December 10, 2001. The SJVAB is required to attain the ozone standards as expeditiously as possible, but no later than November 15, 2005. The SJVAB cannot attain the one-standard by the required date but the District must reduce emissions by 3 percent per year on average and must continue to make progress toward attainment.[6] Heavy –duty engines are a major source of NOx emissions in the SJVAB. The benefits of low sulfur fuel diesel as an enabling fuel for advanced diesel engine aftertreatment technologies will not come in time for the required timeframe for the SJVAB plan. However the District is developing fleet rules comparable the SCAQMD rules that could require the use of low sulfur diesel in retrofitted engines.[6]

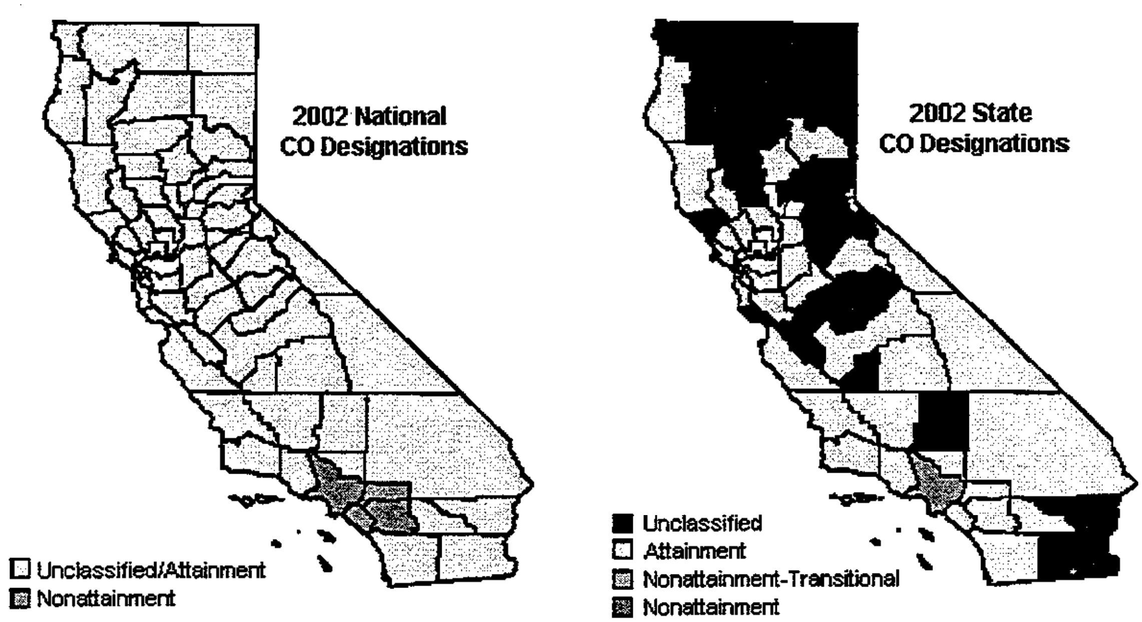
2. *Carbon Monoxide*

All of California, with the exception of the South Coast Air Basin, has attained the state and federal CO standards. Violations of these standards are now limited to a small region in the Los

Angeles area and Calexico in Imperial county. Based on projected emissions, the South Coast Air Quality Management District predicts Los Angeles County will attain the national CO standards sometime after the year 2005.

Reductions in CO levels are largely the result of the implementation of ARB mobile source and clean fuels regulations. These reductions have been achieved despite significant increases in the number of vehicle miles traveled each day. California's on-going mobile source programs will continue to provide new reductions in CO emissions to keep pace with the increases in population and vehicle usage. The aftertreatment technology that would be used to meet the 2007 heavy-duty diesel vehicle emissions standards for NOx and PM would result in a per-vehicle reduction in excess of 90 percent CO from baseline levels.[7] Additional emission reductions will come from continued fleet turnover, expanded use of low emission vehicles, and measures to promote less polluting modes of transportation. In addition, the introduction of zero and near zero emission vehicles will play an increasingly important role in the coming years.

Figure IV-2: Federal and State Area Designations for Carbon Monoxide

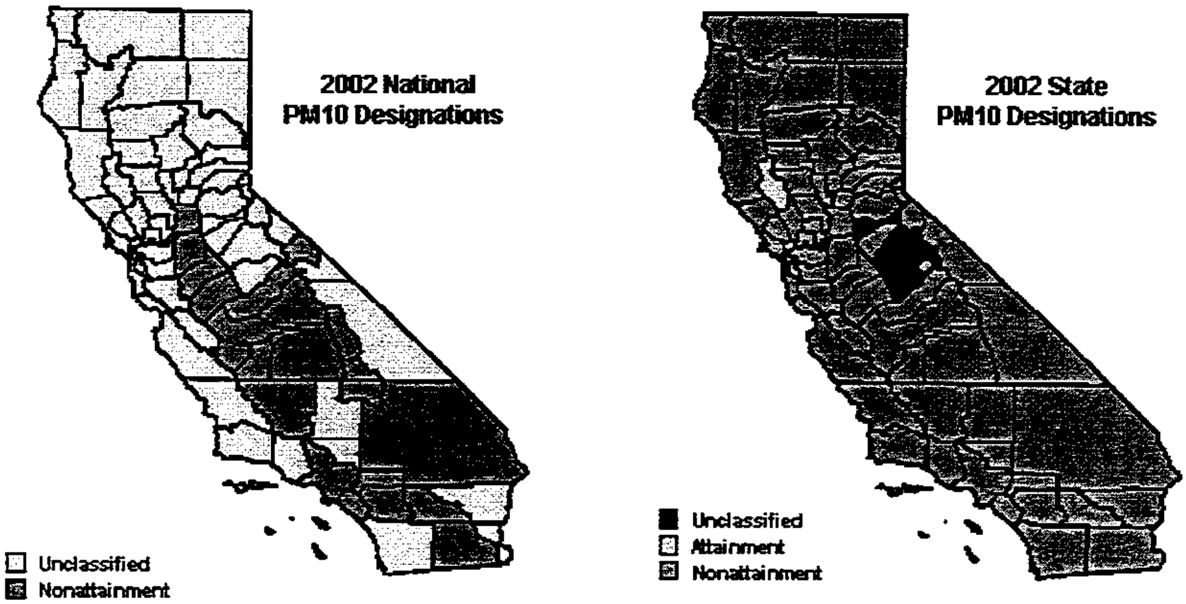


3. Particulate Matter

Particulate pollution is a problem affecting much of California. The majority of California is designated as non-attainment for the state and federal PM_{10} standards as shown in Figure IV-3. Only the Lake County Air Basin is designated as attainment in California and three counties in the northern half of the state remain unclassified. The nonattainment areas with serious problems will require substantial reductions of directly emitted PM_{10} pollutants and PM_{10} precursors. Also control of the emissions of ozone precursors may provide some small benefit due to the reduction in condensible PM_{10} emissions from the organic ozone precursors. Control of oxides of nitrogen would also be effective in controlling ambient nitrate concentrations.

Motor vehicles and equipment under state and federal jurisdiction are responsible for a considerable amount of PM_{10} air pollution but they also contribute the majority of the emissions reductions needed for attainment. As indicated above, appropriate measures from the list proposed in the ARB's control strategy will be incorporated where they are needed in regional PM_{10} attainment SIPs. Included in the list are measures to clean up existing and new truck and bus fleets by reducing PM emissions.

Figure IV-3: Federal and State Area Designations for PM_{10}.



B. Toxic Air Contaminants

1. Components of Diesel Exhaust

Diesel exhaust is a complex mixture of inorganic and organic compounds that exist in gaseous, liquid, and solid phases. The composition of this mixture will vary depending on engine type, operating conditions, fuel, lubricating oil, and whether an emission control system is present.

Diesel engines operate with excess air (around 25-30 parts air to 1 part fuel). Consequently, the primary gas or vapor phase components of whole diesel exhaust are nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O). Diesel exhaust also contains substances such as carbon monoxide, oxides of nitrogen, sulfur dioxide, hydrocarbons, particulate matter, aldehydes, ketones, sulfates, cyanides, phenols, metals, and ammonia. These substances are unburned fuel and lubricant components, products of combustion, or are a result of engine wear or trace contaminants in the fuel and lubricating oil.[8] Other gas phase components of diesel exhaust, are low-molecular mass PAH and nitro-PAH derivatives. Atmospheric reactions of these gas phase PAH and nitro-PAH derivatives may lead to the formation of several mutagenic nitro-PAH, and nitro-PAH compounds, including nitrodibenzopyranones, 2-nitroflouranthene and 2-nitropyrene.[9, 10]

Diesel exhaust contains over 40 substances that have been listed as TACs by the state of California and as hazardous air pollutants by the U.S. EPA. Fifteen of these substances are listed by the International Agency for Research on Cancer (IARC) as carcinogenic to humans, or as a probable or possible human carcinogen. The list includes the following substances: formaldehyde, acetaldehyde, 1,3-butadiene, antimony compounds, arsenic, benzene, beryllium compounds, bis(2-ethylhexyl)phthalate, dioxins and dibenzofurans, inorganic lead, mercury compounds, nickel, POM (including PAHs); and styrene.[11]

Almost all of the diesel particle mass is in the fine particle (PM_{10}) fraction. Approximately 95 percent of the mass of these particles is less than 2.5 microns in diameter. The particles have a very large surface area per unit mass which makes them excellent carriers for many of the organic compounds and metals found in diesel exhaust.

2. Potential Cancer Risk

In 1990, ARB staff[12] reported the statewide population-weighted annual outdoor average diesel PM concentration as 3.0 $\mu g/m^3$. Using this 1990 value for ambient concentrations, and assuming that the ratio of ambient concentration to statewide emissions remained constant, ARB staff[13] calculated ambient diesel PM concentrations for 2000, 2010, and 2020. Estimates of statewide annual average ambient PM concentration are presented in Table IV-1 along with the corresponding percent reduction from the 1990 ambient concentration. Table IV-1 also shows estimates of the risks of contracting cancer from exposure to the indicated ambient diesel PM concentrations. The methodology for estimating these cancer risks is described in the ARB's diesel Risk Reduction Plan.[13]

Diesel PM is a major contributor to potential ambient risk levels. In 2000, the average potential cancer risk associated with diesel PM emissions was estimated at over 500 potential cases per million. This diesel PM cancer risk accounted for approximately 70 percent of the ambient air toxics cancer risk (Figure IV-4).

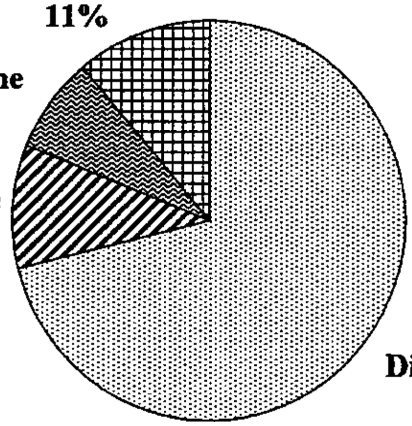
The SCAQMD Multiple Air Toxics Exposure Study II (MATES II) estimated that the average potential cancer risk in the South Coast Air Basin from diesel PM was about 1000 excess cancers per million people, or 71 percent of the average cancer risk from all air toxics in the South Coast Air Basin. Localized or near-source exposures to diesel exhaust, such as might occur near busy roads and intersections, will present much higher potential risks.

Reducing the risk from diesel PM is essential to reducing overall public exposure to air toxics. The control measures proposed in the diesel Risk Reduction Plan will result in an overall 85 percent reduction in the diesel PM inventory and the associated cancer risk by 2020.

Table IV-1: Statewide Population-Weighted Annual Outdoor Average Diesel PM Concentration for 1990, 2000, 2010, and 2020[13]

	1990	2000	2010	2020
Outdoor Ambient Concentration ($\mu g/m^3$)	3.0	1.8	1.5	1.2
Percent Reduction in Diesel PM from 1990 Concentration	N/A	40%	50%	60%
Risk (cancers/million)	900	540	450	360

Figure IV-4:
State Average Potential Cancer Risk from Outdoor Ambient Levels of Toxic Pollutants for the Year 2000[a,b]



a. ARB Risk Reduction Plan[14].

b. Diesel exhaust PM_{10} potential cancer risk based on 2000 emission inventory estimates. All other potential cancer risks based on air toxics network data. Used 1997 data for para-dichlorobenzene. Used 1998 monitoring data for all others.

Assumes measured concentrations are equivalent to annual average concentrations and duration of exposure is 70 years, inhalation pathway only.

c. Includes carbon tetrachloride (4%), formaldehyde (2..5%), hexavalent chromium (2.2%), para-dichlorobenzene (1.2%), acetaldehyde (0.7%), perchloroethylene (0.7%), and methylene chloride (0.3%).

V. HEALTH BENEFITS OF DIESEL EMISSIONS REDUCTIONS

This chapter discusses the health effects of the pollutants emitted by diesel engines and the health benefits of the emissions reductions that would result from the use of low sulfur diesel fuel in diesel engines. There would be health benefits from the sulfate PM emissions reductions that result from the lowering of the sulfur limit of California diesel to 15 ppmw. In addition, there would be major health benefits from the reductions of emissions of ozone precursors (NOx and NMHC), diesel PM and other toxic air contaminants through the use of low sulfur fuel in diesel engines equipped with exhaust aftertreatment systems.

A. Diesel Exhaust

Diesel exhaust is a complex mixture of inorganic and organic compounds that exist in gaseous, liquid, and solid phases. The composition of this mixture will vary depending on engine type, operating conditions, fuel, lubricating oil, and whether or not an emission control system is present. The primary gas or vapor phase components of diesel exhaust include typical combustion gases and vapors such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (CO_2), oxides of nitrogen (NOx), reactive organic gases (ROG), water vapor, and excess air (nitrogen and oxygen). The emissions from diesel-fueled engines also contain potential cancer-causing substances such as arsenic, nickel, benzene, formaldehyde, and polycyclic aromatic hydrocarbons. Diesel exhaust includes over 40 substances that are listed by the U.S. EPA as hazardous air pollutants (HAPS) and by the ARB as TACs. Fifteen of these substances are listed by the International Agency for Research (IARC) as carcinogenic to humans, or as a probable or possible human carcinogen. The list includes the following substances: formaldehyde, acetaldehyde, 1,3-butadiene, antimony compounds, arsenic, benzene, beryllium compounds, bis(2-ethylhexyl)phthalate, dioxins and dibenzofurans, inorganic lead, mercury compounds, nickel, POM (including PAHs), and styrene.

1. Diesel Particulate Matter

Diesel particulate matter is either directly emitted from diesel-powered engines (primary particulate matter) or is formed from the gaseous compounds emitted by a diesel engine (secondary particulate matter). Diesel particulate matter consists of both solid and liquid material and can be divided into three primary constituents: the elemental carbon fraction (ECF); the soluble organic fraction (SOF), and the sulfate fraction.

Many of the diesel particles exist in the atmosphere as a carbon core with a coating of organic carbon compounds, or as sulfuric acid and ash, sulfuric acid aerosols, or sulfate particles associated with organic carbon.[15] The organic fraction of the diesel particle contains compounds such as aldehydes, alkanes and alkenes, and high-molecular weight PAH and PAH-derivatives. Many of these PAHs and PAH-derivatives, especially nitro-PAHs, have been found to be potent mutagens and carcinogens. Nitro-PAH compounds can also be formed during transport through the atmosphere by reactions of adsorbed PAH with nitric acid and by gas-phase radical-initiated reactions in the presence of oxides of nitrogen.[11] Fine particles may also be formed secondarily from gaseous precursors such as SO2, NOx, or organic compounds. Fine particles can remain in the atmosphere for days to weeks and travel through the atmosphere for hundreds to thousands of kilometers, while coarse particles deposit to the earth within minutes to hours and within tens of kilometers from the emission source.

Almost all of the diesel particle mass is in the fine particle range of 10 microns or less in diameter (PM_{10}). Approximately 94 percent of the mass of these particles are less than 2.5 microns in diameter ($PM_{2.5}$). Because of their small size, the particles are readily respirable and can effectively reach the lowest airways of the lung along with the adsorbed compounds, many of which are known or suspected mutagens and carcinogens.[16] They are easily distinguished from noncombustion sources of $PM_{2.5}$ by the high content of elemental carbon with the adsorbed organic compounds and the high number of ultrafine particles (organic carbon and sulfate).

The soluble organic fraction (SOF) consists of unburned organic compounds in the small fraction of the fuel and atomized and evaporated lubricating oil that escape oxidation. These compounds condense into liquid droplets or are adsorbed onto the surfaces of the elemental carbon particles. Several components of the SOF have been identified as individual toxic air contaminants.

B. Health Impacts of Exposure to Diesel Exhaust

In addition to its contribution to ambient PM inventories, diesel exhaust is of specific concern because it poses a lung cancer hazard for humans as well as a hazard from noncancer respiratory effects such as pulmonary inflammation.[17] More than 30 human epidemiological studies have investigated the potential carcinogenicity of diesel exhaust. On average, these studies found that long-term occupational exposures to diesel exhaust were associated with a 40% increase in the relative risk of lung cancer.[18] However, there is limited specific information that addresses the variable susceptibilities to the carcinogenicity of diesel exhaust within the general human population and vulnerable subgroups, such as infants and children and people with pre-existing health conditions. The carcinogenic potential of diesel exhaust was also demonstrated in numerous genotoxic and mutagenic studies on some of the organic compounds typically detected in diesel exhaust.[18] Diesel exhaust was recently listed as a TAC by ARB after an extensive review and evaluation of the scientific literature by OEHHA[19] and subsequent review by the Scientific Research Panel (SRP). Using the cancer unit risk factor developed by OEHHA for the TAC program, it was estimated that for the year 2000, exposure to ambient concentrations of diesel (1.8 $\mu g/m^3$) could be associated with a health risk of 540 excess cancer cases per million people exposed over a 70-year lifetime. This estimated risk is equivalent to about 270 excess cases of cancer per year for the entire State, which is several times higher than the risk from all other identified TACs combined. Another highly significant health effect of diesel exhaust exposure is its apparent ability to act as an adjuvant in allergic responses and possibly asthma.[20, 21, 22] However, additional research is needed at diesel exhaust concentrations that more closely approximate current ambient levels before the role of diesel exhaust exposure in the increasing allergy and asthma rates is established.

C. Health Impacts of Exposure to Diesel PM

The U.S. EPA discussed the epidemiological and toxicological evidence of the health effects of ambient PM and diesel PM in the regulatory impact analyses for on-road and nonroad diesel engine emission standards.[17] The key health effects categories associated with ambient particulate matter include premature mortality, aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), aggravated asthma, acute respiratory symptoms, including aggravated coughing and difficult or painful breathing, chronic bronchitis, and decreased lung function that can be experienced as shortness of breath.

Health impacts from exposure to the fine particulate matter ($PM_{2.5}$) component of diesel exhaust have been calculated for California, using concentration-response equations from several epidemiologic studies. Both mortality and morbidity effects could be associated with exposure to either direct diesel $PM_{2.5}$ or indirect diesel $PM_{2.5}$, the latter of which arises from the conversion of diesel NOx emissions to $PM_{2.5}$ nitrates. It was estimated that 2000 and 900 premature deaths resulted from long-term exposure to either 1.8 $\mu g/m^3$ of direct $PM_{2.5}$ or 0.81 $\mu g/m^3$ of indirect $PM_{2.5}$, respectively, for the year 2000.[23] The mortality estimates are likely to exclude cancer cases, but may include some premature deaths due to cancer, because the epidemiologic studies did not identify the cause of death. Exposure to fine particulate matter, including diesel $PM_{2.5}$ can also be linked to a number of heart and lung diseases. For example, it was estimated that 5400 hospital admissions for chronic obstructive pulmonary disease, pneumonia, cardiovascular disease and asthma were due to exposure to direct diesel $PM_{2.5}$. An additional 2400 admissions were linked to exposure to indirect diesel PM.[23]

D. Health Impacts of Exposure to Ozone

Ozone is formed by the reaction of VOCs and NOx in the atmosphere in the presence of heat and sunlight. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities on clear summer days. This pollutant is a powerful oxidant that can damage the respiratory tract, causing inflammation and irritation, which can result in breathing difficulties. Currently there are no quantitative data available regarding the health impacts associated with ozone.

Studies have shown that there are impacts on public health and welfare from ozone at moderate levels that do not exceed the 1-hour ozone standard. Short-term exposure to high ambient ozone concentrations have been linked to increased hospital admissions and emergency visits for respiratory problems.[24] Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate pre-existing respiratory diseases, such as asthma. Prolonged (6 to 8 hours), repeated exposure to ozone can cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

The subgroups most susceptible to ozone health effects include individuals exercising outdoors, children and people with pre-existing lung disease such as asthma, and chronic pulmonary lung disease. Children are more at risk from ozone exposure because they typically are active outside, during the summer when ozone levels are highest. Also, children are more at risk than adults from ozone exposure because their respiratory systems are still developing. Adults who are outdoors and moderately active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.

E. Health Benefits of Reductions of Diesel Exhaust Emissions

1. Reduced Ambient PM Levels

Studies have shown that there are public health and welfare effects from PM at concentrations that do not constitute a violation of the National Ambient Air Quality Standard (NAAQS) for PM. The emission reductions obtained with low sulfur diesel and diesel engines equipped with aftertreatment systems will result in lower ambient PM levels and significant reductions of exposure to primary and secondary diesel PM. In contrast to ozone, which is a product of complex photochemical reactions and therefore difficult to directly relate to precursor emissions, ambient PM_{10} concentrations are more directly influenced by emissions of particulate matter and can therefore be correlated more meaningfully with emissions inventories. Lower ambient PM levels and reduced exposure mean reduction of the prevalence of the diseases attributed to diesel PM, reduced incidences of hospitalizations, and prevention of premature deaths.

2. Reduced Ambient Ozone Levels

Emissions of NOx and VOC are precursors to the formation of ozone in the lower atmosphere. Ozone can have adverse health impacts at concentrations that do not exceed the 1-hour NAAQS.. Heavy-duty vehicles contribute a substantial fraction of ozone precursors in any metropolitan area. Therefore, reduction of heavy-duty diesel vehicle emissions of NOx and VOCs through the use of low sulfur diesel fuel and exhaust aftertreatment systems would make a considerable contribution to reducing exposures to ambient ozone. Controlling emissions of ozone precursors would reduce the prevalence of the types of respiratory problems associated with ozone exposure and would reduce hospital admissions and emergency visits for respiratory problems.

VI. EXISTING DIESEL FUEL REGULATIONS

This chapter presents a summary of state, federal, and local diesel fuel regulations that affect the quality of diesel fuel consumed by diesel engines in California.

A. California Diesel Fuel Regulations

"CARB diesel" is diesel fuel that meets the Air Resources Board's regulations controlling the sulfur and aromatic contents of diesel fuels used in motor vehicles. The California Division of Measurement Standards requires that motor vehicle diesel fuel meet ASTM D-975 specifications and have a minimum cetane number of 40. About 90 percent of the diesel fuel sold or supplied in California meets "CARB Diesel" requirements. Only diesel fuel for stationary engines, locomotives, and marine vessels is currently exempt from the California diesel fuel regulations. The requirements of the CARB diesel fuel regulations are summarized in Table VI-1 along with the EPA diesel fuel requirements.

1. Sulfur Standard

Section 2281 of Title 13, CCR regulates the sulfur content of vehicular diesel fuel sold or supplied in California. The regulation was approved by the ARB in 1988 originally as section 2255 and was implemented in 1993 statewide. All diesel fuel sold or supplied in California for motor-vehicle use must have a sulfur content no greater than 500 ppmw. The sulfur content of motor vehicle fuel in the South Coast Air Basin and Ventura County had been limited to 500 ppmw since 1985 for large refiners and 1989 for small refiners.

2. Aromatic Hydrocarbon Standard

Section 2282 of Title 13, CCR regulates the aromatic hydrocarbon content of vehicular diesel fuel sold or supplied in California. The regulation was approved by the ARB about 15 years ago in 1988 originally as section 2256 and was implemented in 1993. The aromatic hydrocarbon content of vehicular diesel sold or supplied in California must not exceed 10 percent by volume for large refiners. Small refiners are allowed to meet a less stringent 20 percent limit on aromatic hydrocarbons. The regulation allows alternatives to the aromatic hydrogen concentration if a refiner can demonstrate that the alternative formulation provides emission reductions equivalent to that obtained with specified 10- or 20-percent aromatic reference fuels, as determined through a series of engine emission tests. In 1990, the ARB adopted amendments to the aromatic hydrocarbon fuel regulation to provide more reasonable safeguards that an inferior performing alternative fuel would not be certified as equivalent to a 10- or 20-percent aromatic diesel fuel.

Most refiners have taken advantage of the regulation's flexibility to produce alternative diesel formulations. The ARB has certified a total of 25 alternative formulations. Five have been authorized for full public disclosure. Under the provisions for alternative formulations, the ARB has certified CARB diesel fuel for use in California that typically has a lower sulfur content than 500 ppmw and a higher aromatic content than 10 percent. The average sulfur content of California diesel fuel sold in California has been about 140 ppmw (Table III-1). Excluding the small refiners' fuel production, the average has been about 120 ppmw. About 20 percent of the motor vehicle diesel fuel currently produced in California has a sulfur content of 15 ppmw or less.

Table VI-1: Requirements of Motor Vehicle Diesel Fuel Regulations

	EPA	CARB
1. Applicability	On-road	On-and Off-road
2. Specifications		
a) Maximum Sulfur Content[1] (ppm by weight)	500	500
b) Maximum Aromatic Hydrocarbon Content[2] (% by volume)		
– Independent and Large Refiners	35% or Cetane No. ≥40	10%
– Small Refiners		20%
3. Allows for Certification of Alternative Formulations	NO	YES[3]

≥ means "greater than or equal to"

1 Required in South Coast Air Basin and Ventura County for large refiners since 1985, for small refiners since 1989.

2 Averaging of aromatic hydrocarbon content allowed over a period of 90 days.

3 Requires demonstration of equivalency to the appropriate 10% or 20% aromatic reference fuel.

3. Diesel Engine Certification Fuel Quality Standards

In 1994, the Board adopted regulations pertaining to the composition of diesel fuel used in the certification of diesel engines to ensure that the certification fuel represents California commercial diesel fuel. In order to ensure repeatable and reliable engine test results, the fuel was set to more narrow specifications than commercial fuel. The current regulation specifies an allowable range of sulfur content from 100 ppmw to 500 ppmw and limits or allowable ranges for other fuel properties as indicated in Table VI-2. Manufacturers may also certify diesel engines using certification fuel meeting the federally established certification fuel specifications. In addition, manufacturers have the option to use an alternative certification test fuel provided they can demonstrate that this test fuel will be the predominant in-use fuel.

Table VI-2: Current Diesel Certification Fuel Specifications

Fuel Property	Units	Fuel Specifications
Cetane Number		47-55
Cetane Index		
Distillation Range IBP	°F	340-420
10% point	°F	400-490
50% point	°F	470-560
90% point	°F	550-610
EP	°F	580-660
API Gravity	-	33-39
Total Sulfur	% (wt.)	0.01-0.05
Nitrogen Content (maximum)	ppmw	100-500
Hydrocarbon Composition Total Aromatics	% (vol.)	8-12
Polycyclic Aromatic Hydrocarbons (maximum)	% (wt.)	1.4
Flash Point (minimum)	°F	130
Viscocity @ 40°F	centistokes	2.0-4.1

B. Federal Fuel Regulations

Current federal U.S.EPA regulations establish fuel registration and formulation requirements.

1. Registration of Fuels and Fuel Additives

The U. S. EPA requires that diesel fuels, Grades 1-D and 2-D, and fuel additives for on-road motor-vehicle use be registered in accordance with 40 CFR Part 79 – Registration of Fuels and Fuel Additives. The registration requirements for diesel fuels apply to fuels composed of more than 50 percent diesel fuel by volume and their associated fuel additives. As provided in 40 CFR §79.56, manufacturers may enroll a fuel or fuel additive in a group of similar fuels and fuel additives through submission of jointly-sponsored testing and analysis, conducted on a product which is representative of all products in that group. The general grouping categories are baseline, non-baseline, and atypical.

The baseline diesel fuel category is comprised of a single group, represented by diesel base fuel specified in 40 CFR §79.55(c). Fuel additives are categorized as mixed with diesel base fuel. The baseline category is defined as fuels possessing the characteristics of diesel fuel as specified by ASTM D 975-93 and derived only from conventional petroleum, heavy oil deposits, coal, tar sands, or oil sands. Baseline category fuels may contain no elements other than carbon, hydrogen, oxygen, nitrogen, and sulfur; and the oxygen content must be less than 1.0 percent by weight. Fuels and fuel groups in the non-baseline diesel fuel category are derived from sources other than those listed for the baseline category or contain 1.0 percent or more oxygen by weight, or both. Fuels and fuel groups in the atypical diesel fuel category contain one or more elements other than carbon, hydrogen, oxygen, nitrogen, and sulfur.

2. *Federal Diesel Fuel Quality Standards*

a) On-Road Diesel Fuel

The current U.S. EPA diesel fuel standards have been applicable since 1993. The U.S. EPA regulation – 40 CFR §80.29 – prohibits the sale or supply of diesel fuel for use in on-road motor vehicles, unless the diesel fuel has a sulfur content no greater than 500 ppmw. In addition, the regulation requires on-road motor-vehicle diesel fuel to have a cetane index of at least 40 or have an aromatic hydrocarbon content of no greater than 35 percent by volume (vol. %). All on-road motor-vehicle diesel fuel sold or supplied in the United States, except in Alaska, must comply with these requirements. Diesel fuel, not intended for on-road motor-vehicle use, must contain dye solvent red 164.

On January 18, 2001,[25] the U.S. EPA published a final rule which specifies that, beginning June 1, 2006, refiners must begin producing highway diesel fuel that meets a maximum sulfur standard of 15 ppmw. All 2007 and later model year diesel-fueled vehicles must be fueled with this new low sulfur diesel. The requirements are contained in 40 CFR §§80,500 et seq.

The U.S. EPA's regulations contain temporary compliance options and flexibility provisions not offered in the ARB's proposed amendments. The EPA's temporary compliance option including an averaging, banking and trading component, begins in June 2006 and lasts through 2009, with credit given for early compliance before June 2006. Under this temporary compliance option, up to 20 percent of highway diesel fuel may continue to be produced at the existing 500 ppmw sulfur maximum standard. Highway diesel fuel marketed as complying with the 500-ppmw sulfur standard must be segregated from 15-ppmw fuel in the distribution system, and may only be used in pre-2007 model year heavy-duty vehicles.

The U.S. EPA's regulations also provide additional hardship provisions that the EPA believes will minimize the economic burden of the small refiners in complying with the 15-ppmw sulfur standard. These provisions include the following:

500 ppm Option
A small refiner may continue to produce and sell diesel fuel meeting the current 500-ppmw sulfur standard for four additional years, until May 31, 2010, provided that it reasonably ensures the existence of sufficient volumes of 15-ppmw fuel in the marketing area(s) that it serves.

Small Refiner Credit Option
A small refiner that chooses to produce 15 ppmw fuel prior to June 1, 2010 may generate and sell credits under the broader temporary compliance option. Since a small refiner has no requirement to produce 15 ppmw fuel under this option, any fuel it produces at or below 15-ppmw sulfur will qualify for generating credits.

Diesel/Gasoline Compliance Option

For small refiners that are also subject to the Tier 2/Gasoline sulfur program (40 CFR part 80, subpart H), the refiner may choose to extend by three years the duration of its applicable interim gasoline standards, provided that it also produces all its highway diesel fuel at 15-ppmw sulfur beginning June 1, 2006.

Geographic Phase-in Area (GPA) Provisions

The EPA is providing additional flexibility to refiners subject to the Geographic Phase-in Area (GPA) provisions of the Tier 2 gasoline sulfur program. The additional provisions will allow refiners the option of staggering their gasoline and diesel investments.

General Hardship Provisions

Under the general hardship provisions, any refiner may apply on a case-by-case basis under certain conditions. These hardship provisions, coupled with the temporary compliance option, will provide a "safety valve" allowing up to 25 percent of highway diesel fuel produced to remain at 500 ppmw for these transitional years to minimize any potential for highway diesel fuel supply problems.

b) Nonroad Diesel Fuel

On May 23, 2003, the U.S. EPA published a proposed rulemaking for the control of emissions from nonroad diesel engines and fuel.[26] The U.S. EPA is proposing that sulfur levels for nonroad diesel fuel be reduced from current uncontrolled levels ultimately to 15 ppmw, though they are proposing an interim cap of 500 ppmw. Beginning June 1, 2007, refiners would be required to produce nonroad, locomotive, and marine diesel fuel that meets a maximum sulfur level of 500 ppmw. This does not include diesel fuel for stationary sources. Beginning June 1, 2010, the proposed maximum sulfur level would be 15 ppmw for fuel used for nonroad diesel applications (excluding locomotive and marine engines) since all 2011 and later model year nonroad diesel fueled engines are expected to be equipped with aftertreatment systems to meet the new standards and will require this low sulfur fuel. The U.S. EPA is also asking for comments on reducing sulfur levels for locomotive and marine fuel to 15 ppmw in 2010.

C. SCAQMD Fuel Regulation – Rule 431.2

Health and Safety Code Section 40447.6 authorizes the South Coast AQMD to adopt regulations that specify the composition of diesel fuel manufactured for sale in the District, subject to ARB approval.

In September 2000, SCAQMD amended Rule 431.2 to define low sulfur diesel fuel as having a sulfur content no higher than 15 ppmw. This is applicable to fuel for stationary engines on or after June 1, 2004. In addition, on or after January 1, 2005, the amended regulation will prohibit refiners and importers from selling diesel fuel for use in the District that exceeds the new low sulfur diesel standard of 15 ppm by weight. The rule also allows for extension of the effective date to match a later compliance date adopted by the California Air Resources Board, but no later than June 1, 2006, applicable to refiners and importers in the South Coast District. The adopted amendments apply to diesel fuel produced for both stationary and mobile sources, including RECLAIM sources but excluding ships and locomotives.

VII. PM Risk Reduction Activities

This chapter describes state and local activities to reduce the adverse impacts of diesel PM emissions. It includes descriptions of measures that identify the risk associated with diesel fuel use and provide recommendations for control. The chapter also includes descriptions of regulations that will require the use of low sulfur diesel fuel to be effective in reducing diesel PM emissions, exposure, and risk.

A. State Activities

1. Identification of Diesel Exhaust as a Toxic Air Contaminant

In 1998, the ARB identified particulate matter from diesel-fueled engines as a toxic air contaminant.[27] Section 39655 of California's Health and Safety Code defines a toxic air contaminant as an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health. Further, Assembly Bill (AB) 2728 (Tanner, 1992; Health and Safety Code Section 39656) requires all federally listed hazardous air pollutants to be defined by the ARB as toxic air contaminants. The TAC designation was based on research studies which showed that exposures to diesel PM resulted in an increased risk of cancer and an increase in chronic non-cancer health effects including a greater incidence of coughing, labored breathing, chest tightness, wheezing, and bronchitis.

Once the Board approved the identification of diesel PM as a TAC, it directed staff to begin the risk management process. The Board directed staff to form a diesel risk-management working-group to advise staff during its development of a risk management guidance document and a risk reduction plan.

2. ARB's Risk Reduction Plan

In September 2000 the ARB approved a Diesel Risk Reduction Plan developed by its staff following an extensive public process.[28] The staff's proposed plan contained the following three components:

- New regulatory standards for all new on-road, off-road, and stationary diesel-fueled engines and vehicles to reduce diesel PM emissions by about 90 percent overall from current levels;
- New retrofit requirements for existing on-road, off-road, and stationary diesel-fueled engines and vehicles where determined to be technically feasible and cost-effective; and
- New diesel fuel regulations to reduce the sulfur content levels of diesel fuel to no more than 15 ppmw to provide the quality of diesel fuel needed by the advanced diesel PM emission controls.

With the Board's approval of the risk reduction plan, staff can now develop the specific statewide regulations proposed in the plan. The goal of each regulation will be to make diesel engines as clean as possible by establishing state-of-the-art technology.

The diesel Risk Reduction Plan is not in itself a regulatory action, but a blueprint for future action. The proposed measures comprise a comprehensive program to be implemented over the next decade in California to control emissions and reduce risk from exposure to diesel PM over the complete lifetime of diesel-fueled engines. The measures recommended in the risk reduction plan will also reduce the localized risks associated with activities that expose nearby individuals to diesel PM emissions.

ARB staff estimates that full implementation of the recommended measures, including retrofit of locomotives and commercial marine vessels, will result in an overall 85 percent reduction in the diesel PM inventory and the associated potential cancer risk by 2020 compared to today's diesel PM inventory and risk. These reductions will occur through the combined actions of both California and the U.S. EPA to adopt and implement rules that reduce diesel PM.

Many of the proposed measures will also control and reduce emissions of NOx and other criteria and toxic air pollutants from compression-ignition engines. During the actual rulemaking process for each recommended measure the cost-effectiveness and technological feasibility of each recommended measure will be fully assessed. Each recommended measure will be developed, through a public process, with full opportunity for stakeholders to participate before a rule is finalized.

Appendix III of the RRP report also provides expected emission reductions, and expected cost for implementation of the proposed measures. Non-regulatory strategies such as retrofit programs for locomotives and marine vessels are also discussed.

3. Public Transit Fleet

In February of 2000, the ARB approved a Fleet Rule for Urban Transit Bus Operators (13 CCR section 1956.2) that was intended to reduce emissions of both ozone precursors (NOx and NMHC) and toxic air contaminants (diesel PM). Transit agencies and leasing companies must participate in a program to retrofit diesel buses in their fleets, and to operate their diesel buses on very low-sulfur diesel fuel. Beginning July 1, 2002, medium and larger transit agencies and companies that lease buses to these transit agencies must use diesel fuel with a sulfur content no greater than 15 ppmw in all diesel buses.

This program is meant to encourage the use of clean alternative fuels and high-efficiency diesel emission control technologies. It includes requirements for zero-emissions buses, fleet average NO_X levels, and retrofits for PM control, as well as model year 2007 NO_X and PM standards levels of 0.2 and 0.01 g/bhp-hr, respectively (equal to the levels finalized in this rule). It also requires that all diesel fuel used by transit agencies after July 1, 2002 must meet a cap of 15-ppmw sulfur.

4. Portable Engines

Pursuant to State law, the ARB has established the Portable Equipment Registration Program (PERP) which is a voluntary program for the registration and regulation of portable engines and associated equipment. Portable engines registered under ARB's Statewide Portable Equipment

Registration Program are also required to use CARB diesel (13 CCR 2456(e)(2)). Several Districts have implemented similar registration programs. Portable equipment not registered through the ARB or a local district may be subject to District stationary source permit requirements depending on the size of the engine. In addition, the U.S. EPA and ARB have established engine certification standards for new off-road engines of which portable engines are a subset.

The ARB staff is investigating the development of regulations to reduce diesel particulate emissions from portable diesel-fueled equipment. The staff is proposing to develop an air toxic control measure for portable equipment that is subject to local air districts' permitting programs. In addition, staff is proposing to develop amendments to the Portable Equipment Registration Program regulation to include diesel particulate air toxic control measures and to clarify specific provisions in the regulation. The staff expects to present the regulations to the Board at the end of 2003.[29]

5. Airborne Toxic Control Measures (ATCM)

An ATCM restricting school bus idling has already been adopted and should become effective later this year. Several proposed ATCMs for diesel engines are in development.[30] They include the following:

- Proposed ATCM for New and In-Use Stationary Compression Ignition Engines Greater Than 50 Horsepower
- Proposed ATCM for New and In-Use Stationary Compression Ignition Engines Less Than or Equal to 50 Horsepower
- Draft Transport Refrigeration Unit ATCM

Staff is working on several other diesel-PM control-measure proposals to bring before the Board in 2003 and 2004. These activities are directed towards:

- Garbage trucks
- Fuel delivery trucks
- On-road public fleets
- Off-road public fleets
- Truck idling
- M17 Measures to obtain additional emission reductions from on-road heavy-duty vehicles
- Adoption of proposed federal off-road Tier 4 standards for new off-road engines

B. Local Activities

1. Stationary Engines

Stationary engines are not required by state regulations to use fuel that meets CARB diesel formulation requirements, but most use complying fuel because of California's single fuel distribution network. Also, under state law, local air pollution control and air quality management districts (Districts) have the authority to establish formulation requirements for fuels to be used in stationary engines. To date, several districts have established best available control technology requirements for diesel-fueled engines that specify the use of CARB diesel.

Larger new or modified sources located in a nonattainment area must apply the Lowest Achievable Emission Rate control technology to minimize emissions, and they must "offset" the remaining emissions with reductions from other sources when appropriate. A new or modified source located in an attainment or unclassified area must apply the best available control technology and meet additional requirements aimed at maintaining the region's clean air. In addition, "major sources" of air pollution must obtain federal Title V operating permits that govern continuing operation.

Many Districts have also adopted, pursuant to the California Health and Safety Code, Reasonably Available Control Technology/Best Available Retrofit Control Technology requirements that apply to existing sources located in nonattainment, attainment, and unclassified areas. These requirements are also implemented through the district's permit program.

The South Coast Air Quality Management District's Rule 431.2 specifies the sulfur content of diesel and other liquid fuels to be used for any stationary source application in the District. Currently, the sulfur content cannot exceed 500 ppmw. The District has adopted an amendment to the rule, which will change the sulfur limit to 15 ppmw for stationary-engine use, beginning June 1, 2004, and for other applications, no later than June 1, 2006.

2. *South Coast AQMD: Clean On-Road Vehicles for Captive Fleets*

Under California Health & Safety Code section 40447.5 the SCAQMD is given the authority to require public and private fleet operators with 15 or more vehicles to purchase clean-fueled vehicles at the time the operators are purchasing or replacing vehicles in their fleets. Under that authority, the SCAQMD is implementing several rules [Rule 1190 series] to reduce diesel PM in the South Coast Air Basin. These rules are summarized in Appendix III of the ARB's Risk Reduction Plan.[3]

VIII. PROPOSED AMENDMENTS TO SULFUR STANDARD FOR CALIFORNIA DIESEL FUEL

This chapter describes the staff's proposed amendments to Title 13, CCR, section 2281, "Sulfur Content of Diesel Fuel." The proposed amendments to the regulatory standard for sulfur would reduce the sulfur content of commercial motor vehicle fuel.

The text of the proposed amendments is presented in Appendix A.

A. Background

The statewide sulfur limits in Title 13, CCR, section 2281, "Sulfur Content of Diesel Fuel," were approved by the Board in 1988, originally as section 2255, and were implemented in October 1993. Section 2281 limited the sulfur content of motor vehicle fuel for use in California to 500 ppmw. The purpose of the sulfur standard is to reduce sulfur dioxide (SO_2) emissions and directly emitted sulfate which affect ambient concentrations of SO_2 and sulfate and contribute to ambient levels of fine particulate matter.

Almost all motor vehicle diesel fuel sold in California today is produced under the alternative diesel formulation provision to comply with the aromatic hydrocarbon standard (section 2282) of the California diesel fuel regulations. Under this provision, the ARB has certified diesel fuel for use in California that typically has a lower sulfur content than 500 ppmw and a higher maximum aromatics content than 10 percent. The average sulfur content of California diesel is estimated to be about 140 ppmw (see Table III-1).

About 90 percent of the diesel fuel sold or supplied in California meets the "CARB Diesel" requirements for sulfur and aromatic hydrocarbons prescribed by the California diesel fuel regulations. Only stationary sources, marine vessels and locomotives are currently exempt from the CARB diesel requirements.

B. Proposed Amendment to Reduce the Sulfur Limit for California Diesel

Staff is proposing that the specification for the maximum sulfur content of motor vehicle diesel fuel be reduced from 500 ppm by weight to 15 ppm by weight. This fuel sulfur requirement will apply to both on-road and-off-road vehicle use. The 15-ppmw sulfur limit will apply to all diesel supplied from production and import facilities starting June 1, 2006. The limit would apply 45 days later – starting July 15, 2006 – to all downstream facilities except bulk plants, retail outlets, and bulk purchaser-consumer facilities. After another 45 days – starting September 1, 2006 – the 15-ppmw sulfur limit will apply throughout the distribution system. This proposed amendment does not affect the aromatic hydrocarbon standard.

C. Rationale for Proposed Reduction of the Sulfur Limit for California Diesel

The amendment to the sulfur limit for California vehicular diesel fuel is being proposed because it is needed to enable the effective performance of sulfur-sensitive exhaust gas treatment technologies. However, the lower sulfur content can also have a direct effect by decreasing direct sulfate PM and other sulfur derived emissions.

1. *Enabling Diesel Exhaust Aftertreatment Systems*

The proposed 15-ppmw limit for the sulfur content of diesel fuel is needed for two primary reasons: to enable the effective use of the emissions control technology that will be required by heavy-duty diesel vehicles and engines that must meet the new PM and NOx emission standards adopted by the U.S EPA and ARB; and to enable the use of the exhaust gas treatment technologies that will be required by new and retrofitted diesel engines to meet the diesel PM reduction targets proposed in the diesel risk reduction plan. Current sulfur levels in diesel fuel will prevent effective operation of both the NOx and PM control technologies.

<u>Heavy-Duty and Medium-Duty Diesel Emission Standards</u>

In October 2001, the ARB approved amendments to section 1956.8, Title 13, California Code of Regulations and the incorporated "California Exhaust Emission Standards and Test Procedures for 1985 and Subsequent Model Heavy-Duty Diesel Engines and Vehicles" to adopt requirements adopted by the U.S. EPA in their 2007 Rule. The emissions standards will apply to all medium duty diesel engines (MDDE) and heavy-duty diesel engines (HDDE) produced for sale in California in the 2007 and subsequent model years. Specific requirements include more stringent emission standards for NOx emissions at 0.2 grams per brake horsepower-hour, NMHC emissions at 0.14 grams per brake horsepower-hour, and PM emissions at 0.01 grams per brake horsepower-hour. These emission standards represent a 90% reduction of NOx emissions, 72% reduction of NMHC emissions, and 90% reduction of PM emissions compared to the 2004 emission standards.

The EPA and the ARB have identified catalyzed diesel particulate filter (CDPF) and NOx adsorber technologies as the most likely candidates to be used to meet the emissions standards. However, neither of these technologies will be effective enough on diesel engines and vehicles unless low sulfur diesel fuel is available. Both the PM and NOx technologies have the potential to make significant amounts of sulfate PM under operating conditions typical of heavy-duty vehicles. The U.S. EPA's position is that the sulfate PM formed in this manner will result in total PM emissions in excess of the total PM standard unless diesel fuel sulfur levels are at or below 15 ppmw.

<u>Diesel Risk Reduction Plan</u>

In September 2000 the ARB approved a diesel Risk Reduction Plan to reduce public exposure to diesel exhaust PM.[28] The measures recommended in the plan would require high efficiency diesel particulate filters for new stationary engines and retrofitting of on-road and off-road diesel engines with high efficiency diesel particulate filters. Low sulfur diesel is required to enable the effective use of these diesel particulate emission control systems.

<u>Emissions Control Technologies</u>

(a) <u>Catalyzed Diesel Particulate Filters</u>

Advanced CDPFs with precious metal catalysts are able to provide more than 90 percent control of diesel PM, provided they are operated on diesel fuel with sulfur levels at or below 15 ppmw. The CDPF works by mechanical filtration of solid and liquid PM from the exhaust through a ceramic or metallic filter and then oxidation of the stored PM (filter regeneration). The collected

PM, mostly elemental carbon particles, is oxidized to CO_2 which is released to the atmosphere. Catalyzed diesel particulate filters also reduce hydrocarbon emissions.

Current sulfur levels in diesel fuel can limit the effectiveness of the CDPFs in two ways: first, the catalyst is poisoned by the current sulfur levels thereby preventing proper regeneration of the CDPF; second, there is a loss of PM control effectiveness due to the high rate of SO_2 oxidation to SO_3 by the CDPF and the eventual formation of hydrated sulfuric acid or sulfate PM downstream of the filter.

(b) NOx Adsorbers

The U.S. EPA is projecting that NOx adsorbers will be the technology used to meet the NOx emissions standards.[31, 32] NOx adsorbers have been demonstrated to reduce NOx emissions by over 90%,[33] but this control efficiency is directly affected by the sulfur content of the diesel fuel. There still remains some engineering development to be done but the U.S. EPA expects significant development in the years before implementation of the new standards. The NOx adsorber technology has the potential to significantly lower hydrocarbon and carbon monoxide emissions from diesel exhaust. Because a NOx adsorber contains high levels of precious metals, it may also be effective in oxidizing the soluble organic fraction of diesel particulate matter.

The NOx adsorber technology requires the diesel engine to cycle between fuel lean and fuel rich conditions to reduce NOx emissions. The catalyst oxidizes nitric oxide (NO) in the exhaust to NO_2 and then stores it as inorganic nitrate on the surface of the catalyst or adsorber (storage) bed during the fuel lean conditions typical of diesel engine operation. Before the NOx adsorbent becomes fully saturated, engine operating conditions and fueling rates are adjusted to produce a fuel-rich exhaust. Under these rich conditions, the stored nitrate compounds are reduced to nitrogen over precious metal adsorber catalyst sites.

NOx adsorbers are extremely sensitive to to the sulfur content of the diesel fuel. Current sulfur levels in diesel fuel can limit the effectiveness of NOx adsorbers by poisoning the NOx storage bed and by increasing sulfate PM emissions. NOx adsorbers are very effective at oxidizing SO_2 and storing it in the adsorber bed as sulfate. This deactivates the catalyst and makes it less efficient over time for storing NOx. Further, the sulfate compounds are more stable than nitrate compounds on the catalyst, making the sulfate compounds more difficult to remove during regeneration of the catalyst. Improved NOx adsorber desulfurization systems, active catalyst layers that are more sulfur-resistant, and other methods are under development to maintain the NOx adsorber's high efficiency for the useful life of the engine.[34,35]

2. Reduction of Emissions of Sulfur Compounds

Nearly all of the sulfur in diesel fuel reacts with oxygen during combustion to form SO_2 which can react with oxidizing agents and water vapor to form hydrated sulfuric acid (H_2SO_4) or sulfate aerosols. Typically 1 percent to 3 percent of the fuel sulfur is converted to sulfate through the diesel combustion process.[36] Reducing the sulfur content of diesel fuel will reduce emissions of sulfur dioxide and particulate sulfate thus lowering the overall mass of PM emitted from diesel engines.

Once the low sulfur diesel fuel requirements become effective, pre-2007 model year heavy-duty engines will be using low sulfur fuel, as will engines using new PM control technology. Because these pre-2007 engines will have been certified with a higher sulfur fuel, they will achieve reductions in PM beyond their certification levels. A U.S. EPA on-road emission model predicts that reducing the sulfur content of diesel fuel from the current statewide average of 140 ppmw to 15 ppmw would reduce diesel PM emissions by about 4 percent from engines with FTP-cycle specific emissions rates of 0.1 grams per brake horsepower-hour.

D. Alternatives

Staff considered the following alternatives to the proposed amendment:

- Do not amend the current regulation
- Adopt a more stringent standard.

Do not amend the current regulation: The current sulfur standard would not be acceptable. The sulfur content permitted by the current regulation would reduce the efficiency of exhaust after-treatment systems that are essential to meet the PM and NOx emissions standards adopted by the U.S. EPA and ARB for 2007 and subsequent model year heavy-duty diesel engines. Also, the sulfur contents would be too high for the effective performance of the PM control technologies for new and retrofitted engines that will have to meet the PM reduction targets proposed in the risk reduction plan.

If the ARB did not amend the current regulation, the sulfur content of diesel in California would be limited by the requirements of the U.S. EPA's 2007 Final Rule and the SCAQMD's Rule 431.2. The SCAQMD's 15-ppmw sulfur limit applies to diesel used in on-road, off-road, and stationary engines, but the federal 15-ppmw sulfur limit applies only to on-road diesel fuel use. These two regulations could ensure that low sulfur diesel is available for on-road use regardless of California action. However, the SCAQMD rule is not sufficient to ensure the statewide availability of low-sulfur diesel needed for effective implementation of the proposed control measures to reduce diesel PM emissions.

Low sulfur diesel is a critical component of the diesel Risk Reduction Plan which recommends measures for diesel-fueled off-road engines and stationary engines that include retrofitting of older engines with exhaust treatment technologies as well as stringent diesel PM emission standards for new engines that would require exhaust treatment technologies. Without low sulfur diesel available for use in off-road and stationary engines, the exhaust treatment systems could not be effective. Emissions reductions from off-road and stationary engines are also needed to meet the commitment in the State Implementation Plans for ozone and PM_{10} and to make further progress towards attainment of both the State and federal ambient air quality standards.

Adopt a more stringent requirement: A lower sulfur limit is not necessary as the emissions reductions required by the new heavy-duty diesel engines emission standards for PM can be achieved with diesel sulfur levels up to 15 ppmw. The proposed limit for sulfur is also low enough to enable the use of NOx adsorbers – the most advanced emissions control technologies available for reducing NOx emissions. This technology is extremely sensitive to sulfur and there still remains engineering development to be done, but the EPA expects significant development before the implementation of the new NOx standards. We also expect that commercial fuel produced to comply with the proposed limit would have sulfur contents in the range of 5 to 10 ppmw. The additional investments and operating costs for additional processing required to reduce the fuel sulfur content even further cannot be justified at this time in light of the small additional air quality benefit of a lower sulfur fuel. Therefore, staff is not recommending a lower sulfur limit than that adopted by the U.S. EPA and the SCAQMD.

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IX. Proposed Amendments to the Diesel Engine Certification Fuel Regulation

This chapter describes the staff's proposal for amendments to the following sections of CCR Title 13 and incorporated test procedures. These amendments would revise the sulfur specification for diesel engine certification fuel to make it consistent with the proposed amendment to the sulfur specification for commercial diesel fuel.

- Section 1956.8(b) and the incorporated test procedures for determining compliance with the standards as set forth in the "California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines."
- Sections 1961(d) and 1962 and the incorporated test procedures for determining compliance with the standards as set forth in the "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles."

The text of the proposed amendments is presented in Appendix A and the test procedures are given in Appendix B.

A. Background

Certification fuel is used to test motor vehicles to determine whether or not the vehicles comply with emission standards established by the ARB. The current specifications for California diesel engine certification fuel were approved by the ARB in 1994 and adopted in 1995. They represent the average composition expected for commercial diesel fuel if all diesel fuel produced in California met the 10 volume percent aromatic hydrocarbon limit. The current California diesel engine certification fuel specifications were presented earlier in Table VI-2. The regulation sets an allowable range of 100 to 500 ppm by weight for the sulfur content of the certification fuel. Manufacturers may also certify diesel engines using certification fuel meeting the federally established certification fuel specifications. In addition, manufacturers have the option to use an alternative certification test fuel provided they can demonstrate that this test fuel will be the predominant in-use fuel.

B. *Proposed Amendment to the Diesel Engine Certification Fuel Sulfur Specification*

Staff is proposing that the Board adopt a range of 7 to 15 ppm by weight for the allowable sulfur content of the optional California diesel engine certification fuel, for exhaust emissions testing, starting with the 2007 model year. As shown in Table IX-1, staff is proposing an allowable range for sulfur content that is the same as that promulgated by the U.S. EPA in its revised specifications for fuel for diesel engine exhaust emissions testing. The specifications for the remaining fuel properties shown in Table IX-1 would be unchanged from the values for current California diesel certification fuel

C. Rationale for Proposed Amendments to the Certification Fuel Specifications

The proposed change to the allowable sulfur content of certification fuel is necessary for consistency with the proposed amendment to lower the upper limit for the sulfur content of commercial California diesel to 15 ppm by weight starting June 2006. The proposed allowable range of 7 to 15 ppm by weight for sulfur in certification fuel will be more representative of the fuel that will be used in heavy-duty diesel engines to comply with the exhaust emission standards promulgated by the U.S. EPA in January 2001 and adopted by the ARB at a hearing in October 2001. Also, because exhaust emissions are affected by the properties of the fuel used during certification testing, a lower sulfur content in certification fuel is necessary to help manufacturers meet the more stringent exhaust emissions standards that will apply to 2007 and subsequent model-year diesel engines. The lower sulfur level in diesel fuel is needed for effective operation of both the NOx and PM aftertreatment technologies that manufacturers are expected to use to help them meet the standards.

D. Alternatives

A higher maximum sulfur content was not considered an acceptable alternative as this would not be typical of in-use fuels subject to the 15-ppmw sulfur limit that is being proposed in this rulemaking. Also, a higher sulfur limit would not provide manufacturers a low enough sulfur content for effective performance of the aftertreatment technologies that are essential to meet the new PM and NOx emissions standards. Another alternative to the proposed amendment would be a sulfur content range with a lower maximum than the 15-ppmw limit being proposed for certification diesel fuel. A lower sulfur limit is not necessary as the proposed allowable range for the certification fuel includes sulfur contents that would be typical of commercial diesel produced to comply with the 15-ppmw maximum allowed for in-use diesel. The U.S. EPA expects that refineries will typically produce diesel fuel with about 7 ppmw sulfur and that this fuel could have a slightly higher sulfur content after distribution.[37] Based on this, the U.S. EPA expects to use fuel having a sulfur content between 7 and 10 ppmw sulfur for their emission testing. The current range allows them to adjust the target sulfur content upward if in-use fuel is determined to have higher levels than expected.

Table IX-1: Specifications for Diesel Engine Certification Fuel for 2007 and Subsequent Model Year Vehicles

Fuel Property	Units	Federal Specifications		ARB Specifications
		D-1[a]	D-2	
Cetane Number		40-54	40-50	47-55
Cetane Index		40-54	40-50	
Distillation Range				
IBP	°F	330-390	340-400	340-420
10% point	°F	370-430	400-460	400-490
50% point	°F	410-480	470-540	470-560
90% point	°F	460-520	560-630	550-610
EP	°F	500-560	610-690	580-660
API Gravity	-	40-44	32-37	33-39
Total Sulfur	ppmw	7-15	7-15	7-15
Nitrogen Content (maximum)	ppmw	—	—	100-500
Hydrocarbon Composition				
Total Aromatics	% (vol.)	8[b]	27[b]	8-12
Polycyclic Aromatic Hydrocarbons (maximum)	% (wt.)	—	—	1.4
Flash Point (minimum)	°F	120	130	130
Viscocity @ 40°F	centistokes	2.0-4.1		2.0-4.1

[a] Type 1-D grade diesel is allowed only if the engine manufacturer demonstrates that this fuel will be the predominant in-use fuel.
[b] Minimum, the remainder shall be paraffins, naphtnenes, and olefins.

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X. PROPOSED AMENDMENTS TO REGULATORY PROVISIONS ON CERTIFIED ALTERNATIVE DIESEL FUEL FORMULATIONS

This chapter describes proposed amendments to Title 13, CCR, subsection 2282(g), "Certified Diesel Fuel Formulations Resulting in Equivalent Emissions Reductions." The amendments are proposed to maintain consistency with the sulfur content requirements of section 2281, to further ensure that alternative-formulation diesel fuel sold in California results in emissions that are equivalent to the emissions achieved with diesel fuel that complies with the 10-percent aromatic hydrocarbon standard, and to eliminate an unneeded provision for sulfate credit.

A. Background

1. Section 2282

Title 13, CCR, section 2282, "Aromatic Hydrocarbon Content of Diesel Fuel" was approved by the ARB in 1988, originally as section 2256, and was implemented in 1993. Along with the certified alternative formulation option described below, section 2282 requires that the aromatic hydrocarbon content of vehicular diesel fuel sold, offered for sale or supplied in California not exceed 10 percent by volume, 20 percent for small-refiner fuel, or a designated alternative limit (DAL). A DAL blend of greater than 10 percent aromatic hydrocarbons must be offset by the producer or importer with an equal or greater volume of DAL blend less than 10 percent within 90 days before or after the start of transfer. The DAL of the offsetting blend must have sufficiently low aromatic hydrocarbons that the excess aromatics in the high-DAL blend are fully offset. Analogous requirements apply to small-refiner DAL blends, with the substitution of 20 percent for 10 percent. There is an annual limit on the volume of a small refiner's vehicular diesel fuel that is subject to the 20 percent aromatic hydrocarbon standard.

Many studies completed both before and since the adoption of section 2282 have shown the emission benefits of reducing the total aromatic hydrocarbon content of diesel fuel. Reducing the aromatic hydrocarbon content of diesel fuel reduces emissions from diesel engines, including NOx, particulate matter, CO, and hydrocarbons (HCs), as well as toxic compounds in both vapor and condensed phases.

As an alternative means of compliance with 10- or 20-percent aromatic fuel, subsection 2282(g) establishes procedures for certifying alternative emission-equivalent formulations of diesel fuel that have greater than 10- or 20-percent aromatic hydrocarbon content. Formulations that have been certified under 2282(g) as equivalent to 10-percent aromatic fuel generally have aromatic hydrocarbon contents of about 20 percent and cetane numbers above 50.

2. Subsection 2282(g)

Subsection 2282(g) prescribes the procedures for submitting, testing, evaluating, and specifying fuel formulations for ARB certification. "Candidate fuel" formulations are tested in a laboratory engine for emission equivalency against a defined "reference fuel."

a) Candidate Fuel Specifications

Subsection 2282(g)(2) requires candidate fuels to meet the specifications for No. 1 or No. 2 diesel fuel set forth in ASTM D975-81. The sulfur content, total aromatic hydrocarbon content, poly-cyclic aromatic hydrocarbon content, nitrogen content, and cetane number of each candidate fuel must be determined as the average of three tests conducted in accordance with referenced test methods. The sulfur content of a candidate fuel cannot exceed 500 ppmw. In addition, the identity and concentration of each additive must be determined.

b) Reference Fuel Specifications

Reference fuels must be produced from straight-run California diesel fuel by a hydrodearomatization process. General reference fuels have a maximum aromatic hydrocarbon content of 10 percent, and small-refiner reference fuels have a maximum aromatic hydrocarbon content of 20 percent. Other composition and property limitations also apply to reference fuels (see Table X-1).

Table X-1: Reference Fuel Specifications

Property	Unit	ASTM	Limit	General	Small Refiner
Sulfur Content	ppmw	D2622-94	maximum	500	500
Aromatic Hydrocarbon Content	vol. %	D5186-96	maximum	10	20
Poly-cyclic Aromatic Content	wt. %	D5186-96	maximum	1.4	4
Nitrogen Content	ppmw	D4629-96	maximum	10	90
Natural Cetane Number		D613-84	minimum	48	47
API Gravity		D287-82	min – max	33 – 39	33 – 39
Kinematic Viscosity at 40 °C	cSt	D445-83	min – max	2.0 – 4.1	2.0 – 4.1
Flash Point	°F	D93-80	minimum	130	130
Distillation Temperatures		D86-96			
Initial Boiling Point	°F		min – max	340 – 420	340 – 420
10 % Volume Recovered	°F		min – max	400 – 490	400 – 490
50 % Volume Recovered	°F		min – max	470 – 560	470 – 560
90 % Volume Recovered	°F		min – max	550 – 610	550 – 610
End Point	°F		min – max	580 – 660	580 – 660

c) Testing and Evaluation

Candidate fuel formulations must be shown to be equivalent or better than reference fuels for NOx, sulfate-corrected PM, and PM soluble organic fraction (SOF) emissions. Each fuel must be tested at least 20 times according to one of several specified test sequences. A statistical margin of safety and an allowable tolerance are included in the emission-equivalency determinations. The allowable tolerances are 2 percent, 4 percent, and 12 percent of the mean emissions with the reference fuel for NOx, sulfate-corrected PM, and SOF, respectively. The sulfate correction is a reduction, which is applied only to the candidate fuel's PM emissions. It is the lesser of the calculated specific secondary-sulfate emission difference between 500 ppmw and the actual sulfur content of the candidate fuel or the actual measured specific sulfate emissions with the candidate fuel.

d) Specifications for Certified Formulations

Alternative formulations are certified by Executive Orders issued by the Executive Officer of the ARB. The Executive Order must impose at a minimum the five property specifications shown in Table X-2. In addition, the Executive Order must specify the presence and concentration of all additives that were contained in the candidate fuel, except for an additive demonstrated by the applicant to have the sole effect of increasing cetane number.

Table X-2: Specifications for Certified Formulations

Property	Specification
Sulfur Content	Shall not exceed that of the candidate fuel
Total Aromatic Hydrocarbon Content	Shall not exceed that of the candidate fuel
Poly-cyclic Aromatic Hydrocarbon Content	Shall not exceed that of the candidate fuel
Nitrogen Content	Shall not exceed that of the candidate fuel
Cetane Number	Shall not be less than that of the candidate fuel

3. 2282(g)(9)(A) – Modification of Specifications for a Certified Formulation Based on Subsequent Emissions Testing

Based on additional emissions testing following the protocol in the regulations, the Executive Officer may determine that a commercially available diesel fuel blend meets all of the specifications of a certified diesel fuel formulation set forth in an Executive Order, but does not meet the emission criteria for a candidate fuel to be certified. In that case, the Executive Officer must modify the Executive Order as is necessary to assure that diesel fuel blends sold commercially pursuant to the certification will meet the emission criteria set forth in subsection 2282(g)(5). The modifications to the order may include additional specifications or conditions, or a provision making the order inapplicable to diesel fuel produced by the producer of the commercially available diesel fuel blend found not to meet the criteria.

B. Proposed Changes to Subsection 2282(g)

We are proposing four types of changes to subsection 2282(g): 1) for consistency with section 2281; 2) to ensure emission equivalency of fuels sold as a certified formulations to candidate fuels; 3) to ensure emission equivalency of candidate fuels to reference fuels; and, 4) to eliminate a provision for sulfate credit in determining equivalency of the candidate fuel.

1. Consistency With Section 2281

Since we are proposing under section 2281 that all California diesel fuel meet a 15-ppmw sulfur limitation, for consistency and to improve the effectiveness of subsection 2282(g) we are also proposing that all reference and candidate fuels meet the 15-ppmw sulfur limitation. The new limitation would be applied to reference and candidate fuels beginning August 1, 2004 instead of

June 1, 2006, when producers of California diesel fuel must meet the new sulfur limitation. Fuels produced under existing certified formulations will have to meet the 15-ppmw limit beginning June 1, 2006.

2. *Emission Equivalency of In-Use Fuels to Candidate Fuels*

To ensure emission equivalency of certified formulations produced for sale to the candidate fuels that had been tested in the laboratory, we are proposing that the reporting requirements for candidate fuel properties be expanded to include all the properties that must be reported for reference fuels. We are also proposing a requirement that the same property limitations and ranges apply to candidate fuels as currently apply to reference fuels, except for the five properties that are always designated in the Executive Order. Moreover, the API gravity, viscosity, flash point and distillation temperatures of the candidate fuel could not differ from the corresponding values of the reference fuel used in testing by more than half the range of reference fuel properties. For example, if the reference fuel used in testing has an API gravity of 34.1, the candidate fuel could not have an API gravity of less than 33.0, the bottom of the absolute property range, or greater than 37.1, the top of the relative property range. For new formulations when candidate fuel properties are outside applicable ranges, if the applicant agrees, additional specifications for those properties may be identified in the formulation by executive order. Otherwise, the formulation would not be certified. An additional requirement would be that if a candidate fuel property were outside of the reference fuel property range, then the reference fuel property value could not lie beyond the midpoint of the range away from the candidate fuel property. For example, if a candidate fuel were to have an API gravity of 40.1, then the API gravity of the reference fuel would have to be no less than 36.0 – the midpoint of the property range. These new requirements would be applied to all candidate and reference fuels for all formulations certified after July 31, 2004.

3. *Emission Equivalency of Candidate Fuels to Reference Fuels*

For a candidate fuel to qualify as an alternative formulation, the average emissions of NOx, PM, and SOF during testing with the candidate fuel each have to not exceed the average emissions of NOx, PM, and SOF, respectively, during testing with the reference fuel. A statistical margin of safety, based on the pooled standard deviation of the tests with the candidate and reference fuels, is specified for each pollutant. Tolerances are allowed for each pollutant to make sure that a truly emission-equivalent fuel will always pass. Based on the testing of the sixteen fuels that by now have all been qualified in the same laboratory, we have found that the standard deviations and calculated safety margins warrant that the tolerances be lowered. Therefore, we are proposing that the tolerances be lowered from 2, 4, and 12 percent to 1, 2, and 6 percent of the average emissions of NOx, PM, and SOF, respectively, during testing with the reference fuel.

4. *Elimination of Sulfate Credit*

In the interest of updating subsection 2282(g) to be applicable to fuels with the proposed future 15-ppmw sulfur content limitation, we are proposing that the two provisions for sulfate credit under subsection 2282(g)(5)(B) be eliminated. Effectively, the average PM emissions during testing with the candidate could not exceed the average PM emissions during testing with the reference fuel. In the case of a formulation tested under subsection 2282(g)(9)(A), the average

PM emissions during testing with the formulation produced for sale could not exceed the average PM emissions during testing with the reference fuel.

C. Rationale for Proposed Changes to Subsection 2282(g)

1. Consistency With Sulfur Standard in Section 2281

For consistency with the proposed amendments to section 2281, we are proposing that subsection 2282(g) be amended to require that both the candidate fuels and the reference fuels meet a sulfur limitation of 15 ppmw, effective for all fuels certified on or after August 1, 2004. Certification of new formulations based on the higher sulfur content currently allowed for reference fuels could result in higher PM emissions for future alternative formulation fuels. We are also proposing that the required sulfur content test method be changed to ASTM D5453-93 for improved precision. Fuel produced under the existing certified formulations will have to meet the 15-ppmw-sulfur limit when it becomes effective.

2. Ensuring Emission Equivalency of Candidate Fuels to In-Use Fuels

Studies have shown that emissions from diesel engines are affected by fuel properties other than the five properties that always must be covered by the specifications for a certified formulation.[38, 39] Emissions are especially influenced by fuel density (or API gravity), but also are influenced by backend volatility (or distillation temperature at 90 percent volume recovered, T90) and other properties. The effects of these and other properties on emissions do not change the applicability of subsection 2282(g) for certifying emission-equivalent California diesel fuel formulations. Candidate fuels produced by the same process that is, or would be, used to commercially produce the certified formulation for sale should not reduce the effectiveness of the certified formulation. The unspecified properties normally are expected to not vary greatly among fuels which are equivalent in the specified properties and which are produced the same way. However, if there are large differences in properties between a reference fuel and a candidate fuel and between the candidate fuel and the fuel produced under the certification, the emission equivalency of the fuel produced for sale is in doubt. Appendix F provides further discussion of the effect of diesel fuel properties on emissions from diesel engines.

To eliminate doubts about the emission equivalency between candidate fuels and fuels produced commercially for sale, we are proposing that subsection 2282(g)(2) be amended to require that candidate fuels meet the specifications for No. 2 as set forth in ASTM D975. This would prohibit the testing of a No. 1 diesel as the basis for the production of No. 2 diesel. The testing of No. 1 diesel as the basis of emission equivalency must be excluded, since No. 1 diesel has improved emission performance over No. 2 diesel, and certified-formulation diesel fuel is sold in California as No. 2 diesel fuel. We are further proposing, for candidate fuels, determination and reporting of all fuel properties specified in subsection 2282(g)(3) for reference fuels. A candidate fuel would be subject to the same specifications and ranges required of the reference fuel, except for properties (other than sulfur content) specified by executive order for the resultant certified formulation.

We are also proposing a requirement that candidate fuel properties be within half the allowable reference fuel property ranges of the actual reference fuel properties (Table X-3). A candidate fuel outside of an allowable property range or limit could still be allowed as the basis of a certified formulation, if the applicant agrees that the certified formulation include additional specifications based on the candidate fuel properties. This would prevent the applicant from changing other candidate fuel properties that could affect emissions unless the applicant is willing to accept that specifications for those properties be included in the certified formulation. An additional requirement would be that if a candidate fuel property were outside of its required absolute range, then the reference fuel property value could not lie beyond the midpoint of the range away from the candidate fuel property. This additional requirement would help to eliminate the production of reference fuels with properties at the far ends of the ranges and candidate fuels with properties outside of the ranges to qualify formulations that are not truly equivalent.

Table X-3: Proposed Candidate Fuel Requirements

Property	Unit	ASTM	Limit	Absolute	Relative*
Sulfur Content	ppmw	D5453-93	maximum	15	None
API Gravity		D287-82	min – max	33 – 39	R-3.0 – R+3.0
Kinematic Viscosity at 40 °C	cSt	D445-83	min – max	2.0 – 4.1	R-1.0 – R+1.0
Flash Point	°F	D93-80	minimum	130	None
Distillation Temperatures		D86-96			
Initial Boiling Point	°F		min – max	340 – 420	R-40 – R+40
10 % Volume Recovered	°F		min – max	400 – 490	R-45 – R+45
50 % Volume Recovered	°F		min – max	470 – 560	R-45 – R+45
90 % Volume Recovered	°F		min – max	550 – 610	R-30 – R+30
End Point	°F		min – max	580 – 660	R-40 – R+40

*Relative to reference fuel property value (R)

3. *Ensuring Emission Equivalency of Candidate Fuels to Reference Fuels*

To determine whether the average specific emissions $\bar{x}_C$ of NOx, PM, and SOF, during testing with the candidate fuel, do not exceed the average specific emissions $\bar{x}_R$ during testing with the reference fuel, an arithmetic criterion is applied the average emissions of each pollutant. The criterion that must be satisfied for each pollutant is

$$\bar{x}_C < \bar{x}_R + \delta - S_p \sqrt{\frac{2}{n}}\, t$$

where S_p is the pooled standard deviation of the emissions over the total number n of valid tests run for each fuel, and t is the value of the one-sided Student's t distribution for a=0.15 and $2n$-2 degrees of freedom (same as for the two-sided distribution with a=0.30). The total number of valid tests must always be the same for the candidate fuel as the reference fuel, so the pooled standard deviation is just the square root of the mean of the squares of the standard deviations for each fuel separately. The δ is a tolerance which is a percentage of $\bar{x}_R$ specific to each pollutant. The original objectives of the standard deviation and tolerance terms were to provide a margin of safety in determining equivalency, while assuring that a fuel tested against itself would be able to satisfy the equivalency criteria. The tolerances were established by estimating the value of the standard deviation term based on data from previous emission test programs.

To determine whether the tolerances allowed by the existing regulation are still appropriate, we looked at the test programs for sixteen large-refiner certified formulations. The sixteen were chosen because all of the test programs were run in the same laboratory. The total number of valid tests run on candidate fuels and on reference fuels was 335 each. We calculated $\bar{X}_R$ for each pollutant over the 335 tests with the reference fuels, and we calculated the pooled standard deviations of specific emissions for each pollutant from the 670 individual tests. Then, we set $n=20$, since 20 is the minimum number of tests required and requires the greatest margin of safety, and we calculated the standard deviation term as a percentage of $\bar{X}_R$ for each pollutant. Table X-4 shows the results of $\bar{X}_R$, S_p, and the relative safety margins calculated for each pollutant with $t=1.05077$. Table X-5 shows the tolerances allowed now and the proposed new tolerances, as percentages of $\bar{X}_R$. Based on the newly calculated safety margins, we are proposing that the allowable tolerances be reduced by one half to 1, 2, and 6 percent for NOx, PM, and SOF emissions, respectively. By reducing the allowable tolerances, we will preserve almost all of the benefits of the 10-percent aromatic standard, making the regulation more effective. The new tolerances will apply to all future testing of existing certified formulations under subsection 2282(g)(9)(A), and future candidate fuel formulations.

Table X-4: Average Emissions, Pooled Standard Deviations, and Relative Safety Margins

Pollutant	$\bar{X}_R$ (g/hp-hr)	S_p (g/hp-hr)	$S_p(2/n)^{1/2}t$ / $\bar{X}_R$
NOx	4.101	0.0553	0.45 %
PM	0.1749	0.0062	1.2 %
Sulfate-Corrected PM	0.1749*	0.0062	1.2 %
SOF	0.0370	0.0058	5.2 %

*The sulfate correction is not applied to the emissions with the reference fuels.

Table X-5: Current Tolerances and Proposed Tolerances

Pollutant	**Current Tolerance**	**Proposed Tolerance**
NOx	2 %	1 %
PM	Inapplicable	2 %
Sulfate-Corrected PM	4 %	See Section B.4
SOF	12 %	6 %

4. Eliminate Sulfate Credit in Determining Equivalency of the Candidate Fuel.

Title 13, CCR, section 2282(g)(5)(B) currently allows a sulfate credit for the candidate fuel when calculating PM emissions. The sulfate credit was provided to encourage reducing sulfur in diesel fuel, since fuel-originated secondary sulfates in the environment would significantly outweigh the sulfate portion in the primary PM emissions. Because ARB staff did not want to provide unlimited credit, the sulfate credit was capped at the primary sulfate level. A comparable sulfur credit is not given to the reference fuel. What actually happened was the opposite of the intent, and candidate fuels with high sulfur contents received more credit due to their higher actual sulfate emissions. In most cases, it was as easy to pass a high sulfur formulation as a low sulfur formulation.

The staff proposes that the sulfate credit be eliminated, because the proposed sulfur level of 15 ppmw reduces the allowable sulfate credit for future applicants to almost nothing. Almost all past applicants of certified diesel fuel formulations have received the actual candidate fuel sulfate emissions as a reduction to the candidate fuel PM emissions. Most successful formulations have not needed the credit to pass equivalency for PM emissions.

D. Alternatives Considered

1. Consistency With Section 2281

The only practical alternative to amending the certification procedure to be consistent with section 2281 would be to maintain those aspects of section 2282 which are inconsistent with the proposed amendments to 2281. Preserving the 500-ppmw sulfur content limitation for the reference fuel would allow a higher PM-emitting fuel to be used as the reference for equivalency testing. Staff recommends against allowing a higher-emitting fuel to be used as a reference than commercially produced fuel, which would comply with the 15-ppmw sulfur and 10-percent aromatic standards. Furthermore, the best way to assure that certified formulations in use are equivalent to the fuels tested in the laboratory is to require that the candidate fuels be as much as possible like fuel produced for sale. This means that the candidate fuels should be required to meet the 15-ppmw-sulfur limit. There would be no advantage to a fuel producer to test a candidate fuel with a higher sulfur content, since it would be more difficult to qualify the fuel for PM emission equivalency.

2. Emission Equivalency to Candidate Fuels

The alternatives to the proposed amendments to ensure emission equivalency would be to adopt no changes or to require that the values of all fuel properties be specified for certified formulations as equal or better than the candidate fuel property values. We are proposing a middle ground, which we believe will eliminate most of the uncertainty with regard to the emission performance of formulations produced for market.

If no changes are made, then it is possible that a fuel with some properties significantly different than the formulation that would be commercially produced could be tested as the basis of the formulation. Since it is known that other properties such as density can affect emissions, there would be no way to know whether the proposed alternative formulation would be protective of the benefits of the aromatic hydrocarbon content regulation.

We have found that, on average, the properties of California diesel fuel are similar to what was expected when the California diesel fuel regulations were originally adopted. Requiring that many more properties be specified for all certified formulations would significantly reduce producer flexibility and could impact the supply and availability of diesel fuel for California consumers. In cases where not all of the candidate fuel properties are known for existing formulations, either the formulations would have to be decertified or fuel property values would have to be assigned. The staff recommends against retroactive application of these proposed new amendments, since the regulation still provides the option under subsection 2282(g)(9)(A) to make a determination of emission equivalency on a commercially available diesel fuel blend.

3. Emission Equivalency to Reference Fuels

The alternatives to the proposed new tolerances would be to maintain the existing tolerances, lower the tolerances even more than proposed, or eliminate the tolerances and safety margin.

We think that our proposal is a good compromise in that it provides further assurance that the benefits of the 10 percent aromatic fuel will be maintained, while assuring that a truly equivalent would have a high probability of being certified. Since the test-to-test variation is less than what was expected when the regulations were amended in 1990, the tolerances do not need to be as large. Maintaining the existing tolerances could reduce emission benefits by allowing candidate fuels to pass even though they were not as close to being emission-equivalent as practicable.

Reducing the tolerances beyond the proposed levels would make it difficult to certify a truly equivalent fuel, therefore defeating the intention of a procedure for certifying equivalent alternative formulations of California diesel fuel.

Another alternative would be to apply the proposed new tolerances retroactively to previous test programs, which have qualified existing formulations. The staff recommends against the application of the proposed new tolerances retroactively. However, the staff reserves the option of applying the proposed new tolerances to future testing of commercially available diesel fuel blends for the purpose of making a determination under subsection 2282(g)(9)(A).

4. Elimination of Sulfate Credit

The alternatives to eliminating the sulfate credit would be to maintain the provision for sulfate credit or amend the provision to be consistent with section 2281. Since the provision was not needed for successful equivalency determination of most of the existing formulations – and either maintained or amended, it should be even less useful in the future – we think that it would be best to delete the provision. In the future, either alternative will essentially become useless, since we have proposed that all formulations of California diesel fuel meet a 15-ppmw sulfur limit and that all reference and candidate fuels meet the 15-ppmw limit. Whether for testing of formulations produced for sale or for testing of candidate fuels to qualify a formulation, the sulfate credit will diminish to negligibility. Therefore, in the interest of cleaning up the regulation, we recommend that the proposal to eliminate the sulfate credit provision be adopted.

XI. Proposed New Fuel Specifications for Equivalency to the Aromatic Hydrocarbon Limit

This chapter describes proposed alternative equivalent property limits to the 10-percent aromatic hydrocarbon limit of California diesel fuel. We are proposing the alternative equivalent limits to provide additional flexibility for refiners and to make it easier to market diesel fuel in California. A means of compliance other than by 10-percent aromatic content or by certified formulation would be available to fuel producers or importers for marketing diesel fuel in California.

A. Background

1. Section 2282

Title 13, CCR, section 2282, "Aromatic Hydrocarbon Content of Diesel Fuel," requires specifically that the aromatic hydrocarbon content of vehicular diesel fuel sold, offered for sale or supplied in California not exceed 10 percent by volume (20 percent for small-refiner fuel) or a designated alternative limit (DAL). A DAL blend of greater than the aromatic limit must be offset by the producer or importer with an equal or greater volume of DAL blend less than the aromatic limit within 90 days before or after the start of transfer. Small-refiner specification production volumes of California diesel fuel are limited by the regulation or by Executive Orders. The actual small refiner production is less than 5 percent of the statewide California diesel fuel production at this time.

2. Subsection 2282(g)

As an alternative means of compliance with the 10-percent aromatic requirement, subsection 2282(g) provides procedures for certifying alternative emission-equivalent formulations of diesel fuel that have greater than 10-percent aromatic hydrocarbon content. The same procedures with different reference fuel properties are provided for certifying small-refiner fuels that have greater than 20-percent aromatic hydrocarbon content. Formulations certified under 2282(g) as equivalent to 10-percent aromatic fuel generally have aromatic hydrocarbon contents of about 20 percent and cetane numbers above 50.

3. Average Properties of Certified Formulations

Table XI-1 presents the fuel properties of the candidate fuels for five certified formulations along with the averages of properties for the five candidate fuels. The companies that qualified the five formulations shown in the table have allowed their disclosure. Also shown in the table are averages of properties for the candidate fuels of eleven other 10-percent-aromatic equivalent formulations, and for all sixteen candidate fuels together. The other individual formulations cannot be disclosed because the companies that qualified them have requested that the formulations be kept confidential.

Table XI-2 presents average California diesel fuel properties from actual field samples. The Alliance of Automobile Manufacturers (AAM) averages are taken from EPA's "Staff Discussion Document," *Strategies and Issues in Correlating Diesel Fuel Properties with Emissions*[38], and cover years 1995 through 2000 for the Los Angeles area. The British Petroleum (BP) averages are from three Emission Control Diesel (EC-D) test programs conducted by ARCO Products Company (now BP), each of which used three-fuel blends of major oil company fuels from the Los Angeles area between 1998 and 2001. The ARB averages are from enforcement samples taken statewide from July 1999 to March 2002, excluding fuels meeting the 10-percent aromatic standard and high aromatic fuels. Effectively, all of the averages represent blends of large-refiner certified California diesel formulations.

Table XI-1: Properties of Candidate Fuels for Certified Formulations[1]

Executive Order Number	API Gravity	Aromatic HC (% by vol.)	PAH (% by wt.)	Cetane No.	Sulfur (ppmw)	Nitrogen (ppmw)
G-714-001	37.2	18.7	2.2	58	54	484
G-714-003	37.2	18.7	4.7	59	196	466
G-714-006	38.9	15.1	3.6	55	200	340
G-714-007	36.3	21.7	4.6	55.2	33	20
G-714-008	36.4	24.7	4.0	56.2	42	40
Five-Fuel Average	37.2	19.8	3.8	56.7	105	270
Eleven-Fuel Average	36.9	22.0	4.2	52.5	314	630
Sixteen-Fuel Average	37.0	21.3	4.0	53.8	249	520

[1] API gravities are not currently included in executive orders specifying certified formulations. Sulfur contents are shown in the table but would become obsolete when the proposed 15-ppmw sulfur limit under section 2281 becomes effective.

Table XI-2: Average California Diesel Fuel Properties

Property	AAM in LA	BP in LA	ARB Statewide	Averaged
Aromatic Content (% by vol.)	21.9	19.0	19.9	20.3
PAH Content (% by wt.)	Not Measured	3.3	3.2	3.3
API Gravity	37.6	36.1	Not Measured	36.9
Cetane Number	52.3	52.9	Not Measured	52.6
Sulfur Content (ppmw)	130	119	132	128
Nitrogen Content (ppmw)	120*	98**	Not Measured	110

* Data taken directly from AAMA/AAM summary reports, available for summer surveys only
** Measured for only one test fuel blend

B. Proposed Equivalent Limits

We are proposing new equivalent limits that could be used by diesel fuel producers, importers, and marketers as an alternative means of complying with the 10-percent aromatic standard. The new limits would be set forth in a new subsection of 13 CCR 2282. To comply with the proposed limits, a diesel fuel must meet each fuel property standard. The new limits, except for nitrogen content, were derived as averages of the average fuel property values tabulated in

Table XI-1 and Table XI-2 above. The sixteen-fuel average from Table XI-1 was averaged with the available fuel property averages shown in Table XI-2 for aromatic content, PAH content, API gravity, cetane number, and sulfur content. The proposed new limit for sulfur content would become obsolete when the proposed 15-ppmw sulfur limit under section 2281 becomes effective. Data on nitrogen content of California diesel fuel outside of Los Angeles are not readily available. The publicly available formulations have nitrogen limitations less than 500 ppmw, and the average limitation of the sixteen formulations is about 500 ppmw, so we have set the equivalent limit for nitrogen content at 500 ppmw. The 500-ppmw level is adequate to curb significant fuel NOx contribution, while allowing the use of cetane-improving nitrates. Table XI-3 presents the proposed new equivalent limits. The aromatic hydrocarbon limit is expressed as percent by weight (% by wt.) to be consistent with the specified method of determination. The value expressed as percent by volume (% by vol.) would be about a half a percent less.

Table XI-3: Proposed New Equivalent Limits for California Diesel Fuel

Property	Equivalent Limit[1]	Test Method
Aromatic Content (% by wt.)	≤ 21.0	ASTM D5186-96
PAH Content (% by wt.)	≤ 3.5	ASTM D5186-96
API Gravity	≥ 36.9	ASTM D287-82
Cetane Number	≥ 53	ASTM D613-84
Nitrogen Content (ppmw)	≤ 500	ASTM D4629-96
Sulfur (ppmw)[2]	≤ 160	ASTM D2622-94
	≤ 15	ASTM D5453-93

[1] ≤ means "less than or equal to"
≥ means "greater than or equal to"
[2] ≤ 160 ppmw before June 1, 2006
≤ 15 ppmw starting June 1, 2006

C. Rationale for Proposed New Equivalent Limits

The rationale for proposing equivalent limits as an alternative to the 10-percent aromatic standard, or to compliance with a certified formulation, is to provide another compliance option while maintaining the benefits that the existing regulations are achieving. Having another compliance option will help to bring more diesel fuel to the California market. Since different California diesel fuels are blended in the distribution process, basing the proposed new equivalent limits on the average properties of certified formulations would preserve the actual emission benefits of California diesel fuel. We have included API gravity as an equivalent limit property to eliminate the potential for production of nonequivalent higher-emitting fuels. Studies have shown that emissions from diesel engines are affected independently by the API gravity (or specific gravity or density) of the fuel. See Chapter X for more discussion on diesel fuel property specifications and emissions.

The proposed equivalent property limits, if used, would preserve the emission benefits of California's diesel fuel program. The proposed limits are similar to the properties of three candidate fuels that qualified as emission-equivalent formulations to the 10-percent aromatic reference fuels. Overall, the emission performance of an equivalent limit fuel is expected to be a little better than the three similar candidate fuels. This is because at least three of the proposed property limits provide some extra emission benefit compared to the candidate fuel properties.

D. Alternatives Considered to Proposed New Equivalent Limits

One alternative to the new equivalent limits would be to allow only the existing options for complying with section 2282. If the proposed equivalent limits are not adopted, there would be no net economic benefit to the state. If the proposed equivalent limits are adopted, there may be a net economic benefit to the state, since the overall costs of producing and supplying diesel fuel to California could be less. Either way, there should be no difference in emission benefits. Therefore, we recommend that the Board adopt the proposed new equivalent limits for California diesel fuel.

Another alternative would be to develop a mathematical model to relate diesel fuel properties to engine exhaust emissions. Producers of diesel fuel could use such as model to evaluate potential alternative formulations that could provide equivalent emissions as a 10-percent aromatic hydrocarbon reference fuel. Staff is pursuing this option but have not yet developed an acceptable model.

XII. Proposed Regulation Establishing a Diesel Fuel Lubricity Standard

This chapter discusses the staff's proposed new regulation (Title 13, CCR, section 2284) establishing a minimum lubricity standard for commercial motor vehicle diesel fuel.

A. Introduction

Diesel fuel lubricity can be defined as the ability of diesel fuel to provide surface contact lubrication. Adequate levels of fuel lubricity are necessary to protect the internal contact points in fuel pumps and injection systems to maintain reliable performance. Natural lubricity of diesel fuel is provided by trace levels of oxygen- and nitrogen-containing compounds, and certain classes of aromatic and high molecular weight hydrocarbons in diesel fuels. [40, 41]

Fuel lubricity levels are expected to be reduced as a result of the severe hydrotreating refiners are anticipated to use to meet the proposed 15-ppm sulfur limit, as discussed in Chapter XIV. Hydrotreating, a process used to reduce fuel sulfur levels, also depletes the levels of natural fuel lubricity agents. Lubricity additives have and continue to be used to increase the lubricity of fuels that have had their natural lubricity agents depleted. It has been found that fuels that contain more of these natural lubricity agents require less additive to bring the fuel lubricity up to acceptable levels.[40] Consequently, it is expected that increased levels of lubricity additives will be required as the sulfur contents of diesel fuels are lowered.

Diesel fuel lubricity is dependent on the presence of trace components that provide surface-active molecules that adhere to or combine with metallic surfaces to produce a protective film that reduces wear.[42] Rotary or distributor type injection pumps commonly used in light and medium-duty diesel engines, including most agricultural equipment, rely on the fuel for lubrication of the moving parts and are therefore very sensitive to fuel lubricity. This is in contrast to in-line pumps, commonly used in heavy-duty applications, in which some of the components are lubricated by engine oil. New fuel injector systems, including common rail systems, developed to more accurately tailor fuel injection to reduce exhaust emissions, use extremely high pressures and require higher levels of fuel lubricity than older systems. The high injection pressures provide finer fuel atomization that results in improved fuel air mixing, more complete combustion, and lower exhaust emissions.[40, 43]

B. Lubricity Evaluation Tests

Various laboratory scale bench tests have been developed for evaluating the lubricity of diesel fuels.[44, 45] These bench tests have been compared to diesel fuel injection pump tests to evaluate their accuracy in predicting lubricity levels.[46] One advantage of the bench tests is that they can be completed in a few hours whereas pump tests require hundreds of hours. However, pump wear due to low lubricity involves a variety of wear mechanisms of which each bench test can only simulate one or two. In spite of this limitation, good correlation has been shown between some bench tests and pump tests for unadditized fuels.[40, 46] However, these tests appear to be significantly less accurate in discriminating the beneficial effects of lubricity additives in additized fuels.

ASTM has adopted test methods for two of the lubricity evaluation bench tests. These two test methods are the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) test method[47] and the High-Frequency Reciprocating Rig (HFRR) test method.[48] These two test methods have not shown good correlation with each other and show differing degrees of sensitivity to additives depending on both the base fuel and the additive chemistry.

1. SLBOCLE

The SLBOCLE test consists of a cylinder that rotates with its lower portion immersed in 77°F (25°C) temperature fuel and a stationary ball pressed onto the upper portion of the rotating cylinder for a duration of 60 seconds. The friction force between ball and cylinder is measured for different applied loads. The load at which the friction coefficient exceeds a specified value is determined as the scuffing load, reported in total grams. Higher lubricity fuels will result in higher scuffing loads. The wear mechanism measured by the SLBOCLE test is an adhesive wear called scuffing.[44] The complete SLBOCLE test method is contained in ASTM standard D6078-99.[47]

2. HFRR

In the HFRR test, a steel disk is submerged in 140°F (60°C) temperature fuel and a steel ball, loaded with a 200 gram mass, is rubbed on the disk using a 1 mm stroke at a frequency of 50 Hz for 75 minutes. The lubricity of the fuel is determined from the measurement of the resulting wear scar on the ball. The wear mechanism measured by the HFRR test is an oxidation/adhesive wear.[44] While the HFRR test is relatively insensitive to acidic type lubricity additives, it has been shown to be more sensitive to non-acidic additives.[49] The complete HFRR test method is contained in ASTM standard D6079-02.[48]

C. Hardware Lubricity Requirements

The lubricity requirements for different types of hardware vary with the technology employed. The more stringent emissions requirements placed on light duty vehicles have driven manufacturers to more sophisticated fuel injection systems. Heavy-duty vehicles predominately use more conventional systems, however, this may change in the future.

a) Heavy-Duty Engines

Heavy-duty engines primarily use in-line pumps in which critical parts are fuel lubricated.[40] The Engine Manufacturers Association (EMA), which represents manufacturers of heavy-duty engines, supports both a SLBOCLE standard of 3,100 grams, similar to the California voluntary lubricity standard, and an HFRR standard of 460 microns.[50] However, as discussed in sections below, these two standards are not equivalent. Pump wear data for conventional pumps are shown in Appendix G.

b) Light-Duty Engines

High pressure common rail fuel injection systems are being developed to meet the increasingly stringent emissions requirements for light duty diesel vehicles. The extreme high pressures (on the order of 24,000 pounds per square inch, psi) required to achieve the fine atomization and improved fuel/air mixing, result in excessively harsh wear conditions. These harsh conditions, in combination with the demanding life requirement (over 100,000 miles), result in greater fuel lubricity demands. Consequently, the Alliance of Automobile Manufacturers, which represents the light duty vehicle manufacturers, supports a more stringent diesel fuel lubricity requirement of an HFRR WSD of 450 microns. Wear data for high pressure common rail fuel injection systems are shown in Appendix G.

c) Agricultural Equipment

Agricultural equipment primarily use all fuel lubricated rotary pumps to which fuel lubricity is of major importance. These pumps, while heavily dependent on fuel lubricity, operate at more moderate pressures (between 8,000 and 14,000 psi) than the newest light duty technology. Pump manufacturers for these types of equipment recommend the more stringent lubricity requirement of an HFRR WSD of 450 microns.

D. Lubricity Standards

There is currently no government or industry standard controlling diesel fuel lubricity in the United States. However, in California, industry has maintained a voluntary minimum lubricity level consistent with the recommendation of a 1994 Governor's Task Force[51] that was created during the introduction of 500-ppmw sulfur California reformulated diesel. This voluntary level is a SLBOCLE scuffing load of 3,000 grams or higher. The American Society for Testing and Materials (ASTM) has been working since 1993 to develop a lubricity specification for its D-975 specifications for diesel fuel but at this time has failed to come to a consensus. There is significant controversy over which lubricity evaluation test is most representative of the equipment requirements and what level of lubricity is required to adequately protect hardware.

Europe, where 40 percent[52] of new cars are diesel vehicles, has included a lubricity specification in their diesel fuel specification EN 590. Additionally, the World Wide Fuels Charter, a document produced cooperatively by a coalition of vehicle and engine manufacturers throughout the world, also includes a diesel fuel lubricity specification.

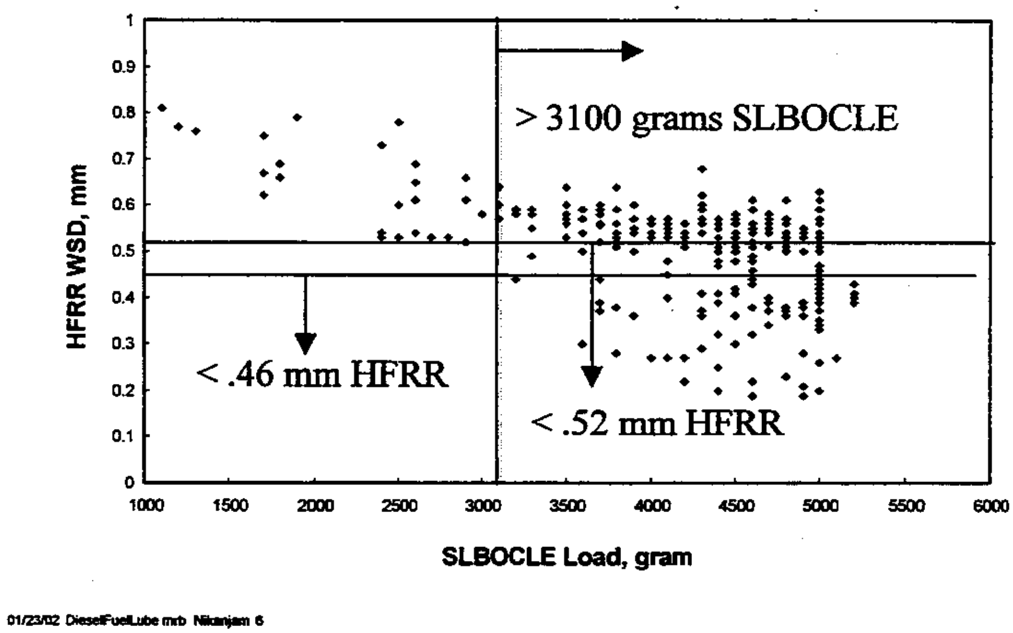
The various specifications and efforts are discussed in the following paragraphs.

1. ASTM Specification Efforts

Fuel system producers, engine and vehicle manufacturers, and the military have been working with ASTM since 1993 to develop protocols and standards for diesel fuel lubricity in its D-975 specifications for diesel fuel. Currently, this ASTM standard includes a section on lubricity (X3. Diesel Fuel Lubricity)[42], that is included as one of the "non-mandatory information" appendices. The ASTM lubricity section gives a range of values for both the SLBOCLE and the HFRR tests. The guideline states that for SLBOCLE lubricity values below 2,000 grams or HFFR with fuels at 60°C with values above 600 microns, the lubricity might not prevent excessive wear. However, fuels with SLBOCLE lubricity values above 3,100 grams or HFFR with fuels at 60°C with values below 450 microns wear scar diameter (WSD) should provide sufficient lubricity in all cases. The guideline cites references as the basis for these values.[49, 53, 46] Additionally, this guideline states that industry-accepted long-term durability pump tests, such as the ones used on a test stand or in a vehicle, can be used to evaluate the lubricity more accurately.

ASTM has balloted two different lubricity standards without success in their effort to replace the non-mandatory appendix with a lubricity standard. These ballots have included both the SLBOCLE minimum 3,100 grams and the HFRR maximum WSD of 460 microns. However, it should be noted that these two standards are not equivalent. The HFRR maximum 460 micron WSD standard provides a higher level of lubricity than the SLBOCLE minimum 3,100 grams. As shown in Figure XII-1 below, all of the fuels that meet the HFRR 460 micron maximum WSD resulted in measured scuffing loads greater than 3,500 grams. The lubricity levels of these fuels exceed the SLBOCLE 3,100 gram standard. Conversely, there are a large number of fuels that meet the minimum 3,100 grams SLBOCLE standard that produced WSDs significantly greater than 460 microns, indicating a lower lubricity level than the HFRR maximum 460 micron WSD standard.

Figure XII-1 Comparison of Lubricity Levels of Diesel Fuels[54]



The latest ASTM ballot currently in progress proposes an HFRR standard of a maximum WSD of 520 microns. As indicated by data in Figure XII-1, this standard is at least as protective as the SLBOCLE 3,100 grams standard, while disallowing fuels that produce WSDs greater than 520 microns.

2. *World Wide Fuels Charter*

The World Wide Fuels Charter is a document produced cooperatively by a coalition of vehicle and engine manufacturers throughout the world that attempts to establish world wide recommendations for quality fuels. The World Wide Fuels Charter recommends a diesel fuel lubricity standard of a HFRR maximum WSD of 400 microns. This standard is significantly more stringent than the SLBOCLE minimum 3,100 gram standard balloted by ASTM.

3. *European Specifications*

The European diesel fuel specification, EN590, issued by CEN - European Committee for Standardization, includes a lubricity specification based on the HFRR test.[45] This standard specifies a maximum WSD of 460 microns and states that the fuel may contain lubricity agent in order to achieve this result.

4. *Canadian Specification*

The Canadian General Standards Board has developed diesel fuel lubricity standards which require that base fuels with cloud point operability temperatures of -20°C or lower be additized for lubricity.[45] Low cloud point diesel fuels, necessary for operation in extreme cold weather, are a lighter distillate with lower viscosity and density, which are known to have poor lubricity. Acceptable additization, based on a representative fuel sample, may be determined based on several optional criteria. These criteria include pump wear in either a vehicle fleet test, with a Bosch pump or with a Stanadyne pump, or meeting the following standards in a bench test: an HFRR maximum WSD of 460 microns or a SLBOCLE scuffing load of greater than 2800 grams.

E. Increasing Fuel Lubricity

1. *Options*

There are three options for increasing the fuel lubricity when it does not meet the recommended lubricity level: 1) modify refinery process operations and crude feed to maximize the trace species that provide natural lubricity properties in diesel fuel, 2) blend in either a biodiesel or refinery stream that is high in lubricity providing species, or 3) treat the diesel fuel with a lubricity additive.[55] When the first two options are not feasible, lubricity additives are used.

Lubricity additives are available in today's market, are effective, and are in widespread use around the world. California refineries report that the additive suppliers have sufficient experience with the effects of the additives to determine how much additive is required to bring the fuel up to the required lubricity without over-additizing. Other examples include Sweden, Canada, and the U.S. military. Since 1991, the use of lubricity additives in Sweden's 10 ppmw sulfur Class I diesel fuel and 50 ppmw sulfur Class II diesel fuel has resulted in acceptable equipment durability.[56] Since 1997, Canadian fuel standards have dictated that diesel fuels with low operability temperature limits be treated with lubricity additives.

2. *Lubricity Additives*

A variety of lubricity additives have been developed. These additives incorporate surface active chemicals that bond to metal surfaces, preventing metal to metal contact and the resulting wear.[57] Additives vary in effectiveness, treat rates, and costs, and can have harm effects depending on the additive type. Some common types of additives are fatty acids, fatty amides, and fatty esters. These additive types can be categorized as either acidic, mono-acid, or non-acidic. Fatty acids can be categorized as either acidic or mono-acidic. Fatty amides and fatty esters are non-acidic.

a) Additive Types

The first lubricity additives to be used were traditional corrosion inhibitors, which are mild fatty acids used in jet fuels at extremely low treat rates. However, it became necessary to increase treat rates by five to 15 times when used in diesel fuel as a lubricity additive. These increased treat rates resulted in engine harm effects, described in the section below. Other types of lubricity additives have since been developed which minimize engine harm effects. These types are mono-acids and non-acids.

The cost and treat rate required for effectiveness vary with additive chemistry. While acidic lubricity additives are the least expensive additives, they have the most significant harm effects. Mono-acidic additives and non-acidic additives do not have the engine harm effects that may be experienced with acidic additives, however they are more expensive than the acidic additives.

Acidic Additives

Acidic lubricity additives are the earliest lubricity additive technology and the least expensive. These additives are fatty acids with multiple replaceable hydrogen atoms. Acidic lubricity additives are primarily divalent acids, or acids with two replaceable hydrogen atoms. These additives generally have a total acid number (TAN) greater 200.[58] The SLBOCLE test tends to show response to acidic additives at lower treat rates than with other types of additives.[59] However, with the HFRR test, the measured lubricity level at times plateaus with acidic additives and lower wear scar diameters may not be achievable. Additionally, at higher treat rates, engine harm effects, as discussed below, are a risk.

Mono-acidic Additives

Mono-acidic lubricity additives are fatty acids with a single replaceable hydrogen. These additives generally have a TAN between 50 and 100.[58] These additives are generally successful in attaining HFRR WSDs down to 460 microns. Mono-acidic lubricity additives are generally more expensive than acidic additives but less expensive than non-acidic.

Non-Acidic Additives

Non-acidic may be either fatty esters or fatty amines. Of the three additive types, non-acidic lubricity additives generate the best response with the HFRR test.[60] However they are also the most expensive additives.

b) Harm Effects

There are lubricity additive harm effects associated with engines and with common carrier pipelines.

Engine

Acidic additives can interact with lubrication oil additives and form salts. These salts can precipitate out of solution in the fuel system, plugging filters, causing plungers to stick, and contaminating surfaces. This interaction results only with specific types of divalent acidic additives.[61] The mono-acidic and non-acidic additives are not known to cause engine harm effects.

Pipeline

Common carrier pipeline harm effects can be a result of surface active species in the lubricity additives that plate out on pipeline walls. Other fuels following diesel fuel treated with lubricity additive through the pipeline can become contaminated with these surface active species. Jet fuel contaminated with these species can have an increased affinity for water. This can result in the jet fuel being out-of-specification for moisture content.

Pipeline contamination of jet fuel can be addressed by pipeline protocol. In Western Canada, jet fuel pipeline contamination is avoided by additizing at the rack or fuel terminal.[62] Another option would be to follow shipments of diesel fuel with gasoline prior to running jet fuel. Since gasoline shipments are approximately three times the amount of diesel shipped, and approximately five times the amount of jet fuel shipped through California pipelines,[58] this protocol could be feasible for California.

F. Regulatory Actions

1. U.S. EPA's Action on Lubricity

The U.S. EPA decided not to establish a lubricity standard in their current action to require 15 ppmw maximum sulfur nationally for on-road motor vehicle diesel fuel. The U.S. EPA's position is that the best approach is to allow the industry and the market to address the lubricity issue in the most economical manner. This approach allows for the continuation of current industry practices for diesel fuel produced to meet the current federal and California 500-ppmw-sulfur diesel fuel specifications, which draws from the considerable experience gained since 1993. This approach offers flexibility to recognize any new specifications and test procedures that might be developed and adopted by the ASTM, regarding lubricity of highway diesel fuel.[56]

2. California's Action on Lubricity

California's implementation of the low-aromatic and statewide 500-ppmw sulfur diesel regulations initiated an evaluation of diesel fuel lubricity in 1993. In 1994, the California Governor's Diesel Fuel Task Force recommended that the lubricity of diesel fuel be maintained at pre-regulation lubricity levels as defined by a SLBOCLE scuffing load of not less than 3,000 grams.[51] The refineries agreed to comply with this recommendation for minimum lubricity and have been maintaining this level as part of their present specification for diesel production.

From October 1993 through the end of 1996, the ARB Monitoring Laboratory Division staff monitored the lubricity of California diesel for five different months.[63] The production weighted mean lubricity SLBOCLE values for November 1993 and August 1994 were 2,700 grams, which is slightly below the recommended SLBOCLE value of 3,000 grams. However, the 95% confidence level for the data for December 1994, June 1995 and December 1996 were at or above the 3,000 grams recommendation. No lubricity-related fuel pump damage had been documented for California vehicles for that time period.[63] It appears that maintaining the Task Force recommendation precludes damage to California's historical hardware due to changes in lubricity. Consequently, lubricity levels with low sulfur (<15 ppmw) diesel should not be an issue for current California equipment as long as the current guideline (a SLBOCLE scuffing load of not less than 3,000 grams) is maintained. However, light duty vehicle and injection hardware manufacturers warn that new advanced technology fuel systems presently being introduced into California require a higher lubricity level than the existing voluntary level.

G. Proposed Action for Instituting a Lubricity Standard

Staff is proposing a two phase strategy to institute a fuel lubricity standard that will apply to all diesel fuel marketed in California.

The proposed initial phase will be to immediately adopt a standard that is at least as protective as the current voluntary standard in place in order to protect existing engines in use today. This proposed standard is a HFRR maximum WSD of 520 microns. The HFRR ASTM test method, D6079-02,[48] would be incorporated by reference. Staff is proposing that this standard be implemented on a phase-in schedule, similar to that proposed for the 15-ppmw maximum sulfur diesel standard. The HFRR maximum WSD of 520 microns standard will apply to all diesel fuel supplied from production and import facilities starting no later than August 1, 2004 unless the Executive Officer has been notified that arrangements have been made to additize the diesel fuel at the terminal. In this case the terminal operator would be required to comply on August 1, 2004. In all other cases, this standard would apply 45 days after applicability at the production and import facilities, starting September 15, 2004, to all downstream facilities except bulk plants, retail outlets, and bulk purchaser-consumer facilities. After another 45 days, starting November 1, 2006, the standard will apply throughout the distribution system.

The proposed second phase would be to determine a 2006 lubricity standard protective of advanced technology fuel systems via a technology assessment. Staff proposes that a place holder be included in the regulation for the 2006 standard and that the Board's resolution direct staff to conduct a technical assessment, to be completed in 2005, to determine an appropriate 2006 standard. The Board's resolution would further direct staff to return to the Board in 2005 with a proposed 2006 lubricity standard if the technology assessment determines that a HFRR maximum WSD of 460 microns at 60 degrees C, or a more appropriate standard, should be implemented on the same schedule as the proposed 15-ppmw sulfur limit for diesel fuel.

Staff proposes that a provision be included in the regulation that would sunset the 2004 lubricity standard if ASTM adopts a lubricity specification to be included in D-975 diesel fuel specifications and the California Department of Food and Agriculture, Division of Measurement Standards (DMS) adopts and enforces it. Staff proposes that this provision also sunset the 2006 lubricity standard if ASTM adopts a lubricity specification that is shown to be protective of advanced technology fuel systems based on the Coordinating Research Council (CRC) Diesel Performance Workgroup lubricity test program.

H. Rationale

The proposed diesel fuel lubricity standard is needed to ensure that California diesel fuel has adequate lubricity to protect fuel systems of existing and future diesel engines. Diesel fuel lubricity is the characteristic of diesel fuel that provides sufficient lubrication to protect each of the many types of contact points within fuel pumps and injection systems for reliable performance.

The levels of natural lubricity agents in diesel fuel are expected to be reduced by the more severe hydrotreating needed to lower the sulfur content of diesel fuel to meet the proposed 15-ppmw sulfur limit. Lubricity additives can be used to increase the lubricity of fuels that have had their natural lubricity agents depleted.

Several types of diesel fuel injection equipment rely on the fuel for lubrication of the moving parts.[40] Historically, a minimum lubricity level of SLBOCLE scuffing load of 3,000 grams has been adequate in California to protect hardware. However, advanced technology fuel injection systems will be required in the future to meet more stringent heavy-duty emissions requirements and to expand the use of diesel technology into the light-duty market. Such systems, including common rail, are currently being introduced in medium-duty vehicles. These systems, which utilize extremely high operating pressures, require a higher level of fuel lubricity. While a minimum lubricity level consistent with current refinery practice may be adequate for the short term, this level is not adequate for enabling and maintaining future low emissions technology. Consequently, staff is proposing a two phase strategy to protect both existing and future hardware.

The first phase of the proposed strategy is to implement an HFRR standard of a maximum WSD of 520 microns. The HFRR standard is the level presently supported by the vast majority of the stakeholders as being appropriate for the preponderance of diesel fuel systems currently in use in California. Data show that an HFRR maximum WSD of 520 microns is at least as protective as the current California voluntary level being practiced by California refiners (minimum SLBOCLE 3,000 grams) and the recommendation of EMA (minimum SLBOCLE 3,100 grams).[49, 64] Additionally, statistical pump data[64] are available to support these levels as being protective of conventional pump technology. Pump wear data are included in Appendix G. The HFRR test was chosen because the HFRR test wear mechanisms better represents the wear mechanisms present in the advanced technology fuel systems, such as common rail.

The second phase of the proposed lubricity standard strategy is to conduct a technology assessment to determine an adequate diesel fuel lubricity level for advanced technology fuel injection systems. Fuels with insufficient lubricity contribute to excessive wear that results in reduced equipment life and performance. Excessive wear in these systems is also expected to increase emissions due to compromised pump performance. In Europe, where the technology was first introduced, the HFRR maximum WSD of 460 microns standard has proven to be protective of advanced technology fuel injection systems. Additionally there are pump wear data to support this level, as shown in Appendix G.[52] However, many in industry believe that there may be a less stringent fuel lubricity level that may be similarly protective of this equipment. Consequently, the CRC Diesel Performance Workgroup has begun planning a test program to determine the correlation between diesel fuel lubricity levels and wear in advanced technology fuel injection systems in the U.S. This test program is scheduled to be initiated by the third quarter of 2003 and will be completed in 2004.

ASTM is currently balloting a lubricity standard of a HFRR maximum WSD of 520 microns at 60 degree C for inclusion in their D-975 diesel fuel specifications. This ballot is a compromise between stakeholders and includes a commitment to form a lubricity panel within the CRC Diesel Performance Group and conduct a research program to determine the level of lubricity required for protection of advanced technology fuel injection systems. The CRC lubricity panel has been formed and the planing of the research test program initiated. ASTM adoption of the lubricity specification in this ballot and the subsequent adoption by DMS would preclude the necessity for the ARB 2004 lubricity specification. Upon completion of the CRC lubricity testing, ASTM may propose to adjust the lubricity specification level based on the research results. A deferral of the ARB 2006 lubricity specification would be warranted by either the determination that the HFRR maximum WSD of 520 microns is adequately protective of advanced technology fuel injection systems or the ASTM adoption of a lubricity standard based on the CRC research results.

The first phase of the proposed strategy would become effective in 2004 in order to protect equipment in the field today, since some advanced technology diesel fuel systems have entered the market as well as some 15-ppmw maximum sulfur fuel. There is currently no industry or government lubricity standard in place and as diesel fuel sulfur levels continue to be reduced, equipment manufacturers and consumers have expressed concern regarding the lack of a lubricity standard. ASTM has been working to develop lubricity standards for its D-975 diesel fuel specifications since the introduction of low sulfur diesel fuel in 1993. Currently, ASTM has not been successful in adopting a lubricity standard.

The technology assessment of the second phase of the proposed strategy would be conducted and completed in 2005. The timing allows for the CRC Diesel Performance Workgroup to initiate and complete testing to generate statistical data for the determination of lubricity levels required for the protection of advanced technology fuel injection systems. A minimum lubricity level consistent with these findings would then be proposed to the Board for implementation in 2006. It is expected that advanced technology fuel injection systems will be introduced on a larger scale at that time.

I. Alternatives

An alternative to the proposed lubricity standard is to continue to rely on the current California refinery voluntary standard based on the 1994 Governor's Diesel Task Force recommendation. However, this voluntary standard does not address imported fuel and is not enforceable by DMS. Additionally, this standard is not adequate for the protection of advanced high pressure fuel injections systems that will become more prevalent within the next few years.

A second alternative to the proposed lubricity standard is to defer to ASTM to adopt a standard. DMS would then be required to adopt and enforce the ASTM lubricity standard. However, ASTM has been sharply divided on this issue, and, until recently, has not shown promise in this effort. The latest ASTM ballot currently in progress involves a compromise between the different factions and may be successful.

J. Future Work

Staff will participate in the CRC Diesel Performance Group lubricity panel and the associated lubricity testing of advanced technology fuel injection systems. Staff will conduct a technology assessment of the lubricity level required by advanced technology fuel injection systems in 2005, considering the CRC research results as well as additional data as it becomes available. If necessary, staff will propose a 2006 lubricity standard of a HFRR maximum WSD of 460 microns, or a more appropriate value as determined by the technology assessment.

XIII. Other Proposed Amendments to the Diesel Fuel Regulations

This chapter describes amendments proposed by staff to clarify requirements of the regulations and to ensure that the regulations work effectively.

A. Amendments to Test Method for Sulfur

Staff is proposing a change to improve the test method for determining the sulfur content of diesel fuel. Currently CCR, Title 13, subsection 2281(c) requires that sulfur in diesel fuel be determined by ASTM D2622-94, which is a x-ray spectrometry method.[65]

Staff is proposing that the Board amend the regulation to replace ASTM D2622-94 with ASTM D5453-93, an ultraviolet fluorescence method, for determining compliance with the 15-ppmw sulfur standard. Staff is proposing that ASTM D5453-93 be incorporated by reference as the specified method for determining the sulfur level in diesel fuel.

The reported detection limit for the current method (ASTM D2622-94) is 10 ppm and the repeatability for sulfur in the range of 10 ppm to 49 ppm is 60 percent of the sulfur level.[66] For a diesel fuel with 15 ppmw sulfur, the repeatability of the method is plus or minus 9 ppm, which provides a range of 6 ppm to 24 ppm for a single measurement. This range is not acceptable for determining sulfur content of diesel fuel that must comply with a permissible maximum sulfur content of 15 ppm. The proposed method will provide a more suitable detection limit and better precision for determining sulfur at the levels expected in diesel fuels produced to comply with the proposed limit of 15 ppm on the sulfur content.

The ARB staff has already determined that the proposed test method, D 5453-93 is equivalent to the current method D2622-94 for diesel fuels. This method has a detection limit of 1 ppm and a precision of plus or minus 2.8 ppm for determination of a sulfur content of 15 ppm. In a study conducted by Nadkarni,[67] the precision of D5453-93 and D2622-94 were compared for analyses of motor gasoline, jet fuel, and reformulated gasoline fuel samples containing between 2.5 and 8.7 ppm sulfur. The precision of D2622-94 ranged from 5.7 ppm to 13.3 ppm, while the precision of D5453-93 ranged from 0.9 ppm to 1.8 ppm. The lower detection limit and better precision of D5453-93 makes this method more suitable than D2622-94 for determining sulfur levels of 15 ppm and less.

B. Definition of "Diesel Fuel"

Staff is proposing a revision of the definition of "diesel fuel" that will clarify the applicability of the diesel fuel regulations and make the definition consistent with the definition for fuel for internal combustion, spark ignition engines. The revised definition will include any liquid fuel that is predominantly a mixture of hydrocarbons that is used or intended for use or represented for use in internal combustion, compression ignition (diesel cycle) engines.

Staff is also proposing a conforming amendment to the definition of diesel fuel in the verification procedure and in-use compliance requirements for in-use strategies to control emissions from diesel engines, in Title 13, CCR, subsection 2701(a). This amendment would assure that the current effect of the requirements for the verification procedure regulation will not be changed by the expansion of the definition of diesel fuel.

Also, staff is proposing that an exemption from the diesel fuel requirements be established for diesel fuel used in qualifying military vehicles, closely paralleling provisions in the U.S. EPA regulations. This would be combined in a new section 2285 of Title 13, CCR.

XIV. Feasibility of Refining Low Sulfur Diesel Fuel

This chapter presents ARB staff's assessment of the feasibility of refining and distributing diesel fuel with a sulfur content of no more than 15 ppmw. The staff's evaluation incorporates the findings of the U.S.EPA's feasibility study and the results of two surveys: one conducted by ARB staff and the other conducted by staff of the South Coast Air Quality Management District.[68] Also presented is a brief discussion of the desulfurization technologies that the staff expects refiners to use. Appendix H contains more information on the desulfurization technologies as well as the other refinery processes affected by the changes in refinery desulfurization operations.

A. Diesel Production in the United States

The diesel fuel produced by a given refinery is composed of one or more blendstocks from the crude oil fractionation and conversion units at the refinery. Refinery configuration and equipment, and the range and relative volumes of products manufactured (the product slate) can significantly affect the sulfur content of diesel fuel.

In their regulatory impact analysis for the new federal diesel fuel regulation adopted in January, 2001, the U.S. EPA reported that most of the highway diesel fuel volume manufactured in the U.S. is produced from the crude fractionation tower (called straight-run diesel).[69] Most of the remainder comes from the fluid catalytic cracker (FCC) conversion unit (called light cycle oil). The remaining small fraction of diesel fuel volume comes from a coker conversion unit (called light coker gas oil), or from the hydrocracker conversion unit (called hydrocrackate). The blendstock streams from these process units are typically further processed to reduce their sulfur content to comply with the current federal 500-ppmw cap for the sulfur content of highway diesel fuel.

A survey conducted by the American Petroleum Institute (API) and National Petroleum Refiners Association (NPRA) in 1996 examined the typical blendstock properties for the U.S. highway diesel pool as a whole.[1] The U.S. EPA summarized the results for the various Petroleum Administrative Districts for Defense (PADD) excluding California. Approximately 80 percent of all blendstocks used to manufacture highway diesel fuel outside of California are hydrotreated to reduce their sulfur content. Hydrocrackate is desulfurized to a substantial extent as a necessary element of the hydrocracking process and is not further processed in a hydrotreater. The EPA's summary also showed that approximately 16 percent of highway diesel fuel comes from nonhydrotreated blendstocks. Production of 15-ppmw sulfur fuel is expected to require severe hydrotreating of all components to be acceptable for blending for on-road uses.[70,71]

B. Diesel Production in California

Diesel fuel is produced in California at 12 large refineries and two small refineries. The blendstocks used to manufacture CARB diesel fuel differ from the rest of the nation. Only hydrotreated or hydrocracked blendstocks are used in the manufacture of CARB diesel fuel. The results of the NPRA/API survey[1] indicated that CARB diesel fuel is made primarily from hydrotreated and hydrocracked distillates in roughly equal proportions (48 and 47 percent, respectively) with small fractions of hydrotreated cracked stock (2 percent) and hydrotreated coker gas oil (3 percent).

Data from the State Board of Equalization indicates that the total volume of diesel fuel sold in California during 2002 was approximately 2.8 billion gallons. The average sulfur content is about 140 ppmw, with about 20 percent of the California production already meeting the proposed 15-ppmw sulfur limit.

C. Technology Options for Low Sulfur Fuel Production

Refineries can, to a limited extent, reduce the sulfur content of their diesel fuel by using more crude oil with lower sulfur concentration. However, this change alone would not satisfy future needs for low sulfur diesel fuel. All surveys indicate that the sulfur requirement will be achieved through chemical removal of sulfur from distillate by reaction with hydrogen.

1. EPA's Conclusions

The U.S. EPA projects that all refiners will be technically capable of meeting the 15-ppmw sulfur cap with extensions of the same conventional diesel desulfurization technologies which they are using to meet the current highway diesel fuel standard of 500 ppmw sulfur.[69] Improvements to current hydrotreaters alone do not appear to be sufficient to provide compliance with the proposed 15-ppmw cap. Past commercial experience suggests that it is possible to incorporate current distillate hydrotreaters into designs that can provide compliance with the proposed 15-ppmw cap. Thus, the equipment added to meet the 500-ppmw standard in the early 1990s will continue to be useful in meeting a more stringent standard.

The U.S. EPA reports that existing commercial hydrotreaters are already producing distillate with average sulfur levels below 10 ppmw, which should be more than sufficient to meet a 15-ppmw cap. These hydrotreaters process distillate with typical breakdowns of straight run light gas oil (SRLGO),light cycle oil (LCO), and light cycle gas oil (LCGO). Therefore, the proposed 15-ppmw cap appears to be feasible with today's distillate processing technology. These commercial demonstrations were designed to reduce aromatics content, or improve cetane, as well as reduce sulfur. Therefore, the hydrogen consumption and its associated cost are higher than that needed for simple sulfur removal. This combination of sulfur and aromatics reduction has been encouraged by fuel tax incentives in Europe. The incentive to reduce sulfur by itself to such low levels has not existed, so refiners have generally had no incentive to produce such a product commercially.

The primary changes to refiners' current distillate hydrotreating systems would be the following:

1. the use of a second reactor to increase residence time, possibly incorporating counter-current flow characteristics, or the addition of a completely new second stage hydrotreater,
2. the use of more active catalysts, including those specially designed to desulfurize sterically hindered sulfur containing material,
3. greater hydrogen purity and less hydrogen sulfide in the recycle gas, and
4. possible use of higher pressure in the reactor.

The U.S.EPA also projects that all refiners will use recently developed high activity catalysts which increase the amount of sulfur that can be removed relative to the catalysts which were available when the current desulfurization units were designed and built. Changing to a more active catalyst can by itself reduce sulfur moderately. This will help to reduce the reactor size needed, but by itself would not appear to be sufficient for most refiners to meet a 15-ppmw limit.

The U.S.EPA also anticipates that some refiners (roughly 20 percent of current production volume) will decide to invest in a completely new two-stage hydrotreater rather than revamp their current unit. This could occur because the current hydrotreater is too old or designed to operate at too low a pressure, or because the refiner desires to expand production of highway diesel fuel.

2. *ARB Survey*

The ARB staff conducted a statewide survey of refineries to obtain information on current and future diesel fuel production. A copy of the survey questionnaire is included in Appendix L. Among other questions, refiners were asked to indicate what new equipment, modifications to existing equipment and changes in refinery operations would be needed to produce diesel fuel to meet the proposed sulfur limit. The responses to the survey did not contradict the EPA's conclusions listed above.

Refiners in California have had about ten years of experience with hydrodesulfurization technology in producing low sulfur diesel fuel. Most refiners will meet the requirements for increased sulfur removal by modifying existing units to increase their hydrodesulfurization capability. Eight refiners expect that modifications will be minimal with process modifications that could include additional reactors in series with existing reactors. Three refiners have reported that new hydrotreating units would likely be needed to comply with the proposed 15-ppmw sulfur limit

One other option for increasing the desulfurization capability is the use of more effective catalysts, such as double density catalysts, in the reactor of the hydrotreater. The double density catalyst increases reactor yield by increasing the amount of metal, in this case nickel, cobalt, and/or molybdenum, on the catalyst pellets.

The increase in desulfurization means an increase in demand for hydrogen and an increase in generation of hydrogen sulfide if refiners are to maintain current CARB diesel production levels for the lower fuel sulfur limit. Some refiners may need to upgrade the hydrogen production and amine scrubbing capacity. Increased demands for hydrogen may be met by modifying existing hydrogen plants or by new construction. Another option is to purchase hydrogen from a producer thereby incurring an operational cost as opposed to a capital investment.

3. *SCAQMD Survey*

The South Coast Air Quality Management District (AQMD) conducted a survey of the eight area refiners that the AQMD considered potential suppliers of low sulfur fuel to the district.[68]

According to the District, the information supplied by the refineries indicated that the proposed reduction in diesel sulfur would require modifications to refinery desulfurization units.

A number of refineries in the SCAQMD currently produce low-sulfur ($\leq$ 15 ppmw) fuel in their hydrocrackers. A portion of this volume is sold, while the remainder is used for blending with higher sulfur hydrotreated blendstock, and this has been adequate to meet current regulatory requirements. With the proposed regulation, the sulfur content of the hydrotreated distillate will have to be reduced significantly. Most refiners will enhance or expand their current distillate hydrotreating capability to meet the sulfur cap. The methods that they will use to achieve this goal include all of the options identified above in the summary of EPA's conclusions and in the results of the ARB survey.

D. Hydrodesulfurization

One method to reduce diesel fuel sulfur is to chemically remove sulfur from the hydrocarbon compounds which comprise diesel fuel. This is usually accomplished through reaction with hydrogen at moderate to high temperature and pressure. Specific examples of this process are hydrotreating and hydrocracking. Hydrogen for these processes is produced by catalytic reformers or hydrogen generation units and is distributed to the hydrotreaters through a refinery-wide network. Hydrotreating for sulfur removal is called hydrodesulfurization.

In the hydrotreating process, liquid distillate from the crude unit is combined with hydrogen and brought to the reaction temperatures and pressures prior to entering the reactor. The reaction occurs in the presence of a solid catalyst. Hydrogen reacts with the sulfur and nitrogen compounds in the distillate, forming hydrogen sulfide and ammonia. The resulting vapor is then separated from the desulfurized distillate, which is usually mixed with other distillate streams in the refinery.

The vapor still contains valuable hydrogen, because the reaction requires a significant amount of excess hydrogen to operate effectively and practically. However, the vapor also contains a significant amount of hydrogen sulfide and ammonia, which inhibit the desulfurization and denitrogenation reactions and which must be removed from the system. To avoid a build-up of hydrogen sulfide and ammonia in the system, the hydrogen sulfide and ammonia are usually chemically scrubbed from the hydrogen recycle. The hydrogen recycle is then usually mixed with fresh hydrogen and recycled to the front of the reactor for reaction with fresh distillate feed.

Hydrocracking is a two-stage process combining catalytic cracking and hydrogenation, wherein heavier feedstocks are cracked in the presence of hydrogen to produce more desirable products. The process employs high pressure, high temperature, a catalyst, and hydrogen. Hydrocracking is used for feedstocks that are difficult to process by either catalytic cracking or reforming, since these feedstocks are characterized usually by high polycyclic aromatic contents or by high concentrations of the two principal catalyst poisons, sulfur and nitrogen compounds, or by both.

E. Effect of Hydrodesulfurization on Fuel Volume

Conventional desulfurization processes employ hydrotreating to remove sulfur. The processes lead to a decrease in fuel density and decrease in fuel energy density as well. To make up the loss in energy density, and to meet fuel demand, refiners' fuel production volumes must increase by approximately the same amount. Since conventional desulfurization is not very efficient, we expect that additional hydrotreating well beyond the theoretical minimum required for desulfurization will occur, resulting in additional fuel production mass. The additional production mass combined with the higher mass-based energy content of the hydrotreated fuel means that, once refiners are equipped to process their feedstocks to produce the low-sulfur diesel fuel, they should be able to produce more than enough fuel to meet demand. Overall, to provide the same amount of work, diesel engines will burn slightly more volume of the low-sulfur diesel fuel, but slightly less mass.

F. Recovery of Sulfur from Hydrotreating

During the hydrotreating process, hydrogen reacts with sulfur-containing compounds in the distillate to form hydrogen sulfide (H_2S). The desulfurized distillate is separated from the mixed stream leaving the reactor to yield a gaseous stream containing the H_2S by-product. The H_2S is removed from this gaseous stream by an amine solution scrubber and the solution is sent to a sulfur recovery unit where the H_2S is separated and then converted to elemental sulfur. State and federal regulations now require recovery of more than 99% of the sulfur in refinery gas. The most widely used recovery system is the Claus process, which uses both thermal and catalytic-conversion reactions. In a typical process, hydrogen sulfide is burned under controlled conditions to produce SO_2, H_2O, and saleable elemental sulfur which may be used by a number of industries including fertilizer production, and the chemical industry.

G. *Other Desulfurization Processes*

There are other low temperature and pressure processes being developed, such as biodesulfurization, and chemical oxidation. Sulfur can be removed by these processes early in the refining process; for example, from crude oil, before being processed into diesel fuel. These processes can also be used to remove sulfur from those refinery streams, which are to be blended directly into diesel fuel. Another process was announced recently which uses a moving bed catalyst to both remove and adsorb the sulfur using hydrogen at moderate temperature and pressure. Finally, another method to reduce diesel fuel sulfur is to shift sulfur-containing hydrocarbon compounds to other fuels produced by the refinery.

In cases where they are cost effective, these other methods may be used by refiners to complement the primary sulfur reduction achieved through hydrotreating. The following is a summary of four alternatives to conventional distillate hydrotreating discussed in the EPA's regulatory impact analysis.[72]

1. Biodesulfurization

Biodesulfurization involves the removal of sulfur-containing hydrocarbon compounds from distillate or naphtha streams using bacteria. Enzymes in the bacteria first oxidize the sulfur atoms and then cleave some of the sulfur-carbon bonds. The sulfur leaves the process in the form of hydroxyphenyl benzene sulfonate, which can be used commercially as a feedstock to produce surfactants. In pilot plant studies biodesulfurization was combined with conventional hydrotreating to produce diesel fuel containing 50 ppmw sulfur.

2. *Chemical Oxidation and Extraction*

Two oxidative desulfurization processes were described in the EPA document. In one process, a water emulsion is first formed with the diesel fuel. The diesel sulfur atom is then oxidized to a sulfone using peroxyacetic acid. With an oxygen atom attached to the sulfur atom, the sulfur-containing hydrocarbon molecule becomes polar and hydrophilic and then moves into the aqueous phase. Like biodesulfurization, some of the sulfones can be converted to surfactants.

The other oxidative desulfurization process differed from the first in the sulfur product of the oxidation reaction. This process does not create a sulfonate. Instead, the oxidized sulfur atom is separated from the hydrocarbon immediately after the oxidation reaction and the resulting sulfate is then easily separable from the petroleum.

3. *Sulfur Adsorption*

In this process, highway diesel fuel (typically with about 350 ppmw sulfur) reacts with hydrogen and a catalyst in a reactor at relatively low pressures and temperatures. The sulfur atom of the sulfur-containing compounds adsorbs onto the catalyst, which then cleaves the sulfur atom from the sulfur-containing hydrocarbon. The catalyst is continually removed from the reactor and regenerated in a separate regeneration vessel. Here the sulfur is burned off before being sent to the sulfur plant. The regenerated catalyst is then recycled back to the reactor for removing more sulfur. This process would likely be used to treat distillate containing 500 ppmw sulfur or less as the sulfur in untreated distillate can overwhelm the catalyst.

4. *FCC Feed Hydrotreating*

The FCC unit primarily produces gasoline, but it also produces a significant quantity of distillate, called light cycle oil (LCO). LCO is high in aromatics and sulfur and contains a relatively high fraction of the sterically hindered sulfur compounds found in diesel fuel. Hydrotreating feed to the FCC unit requires higher temperatures and pressures than hydrotreating distillate streams because FCC feed contains much larger and heavier molecules. Because of this, FCC feed hydrotreating is more expensive than distillate hydrotreating.

The LCO produced at refineries with a FCC feed hydrotreating unit should contain a much lower concentration of sterically hindered compounds than refineries that do not hydrotreat their FCC feed. FCC feed hydrotreating is much more costly than distillate hydrotreating. FCC feed hydrotreating by itself is generally not capable of reducing diesel fuel sulfur to the levels required by the proposed amendment to the regulation. The decision to use FCC feed hydrotreating is based on both environmental and economic benefits. FCC feed hydrotreating decreases the sulfur content of gasoline significantly, as well as reduces sulfur oxide emissions from the FCC unit. Economically, it increases the yield of relatively high value gasoline and LPG from the FCC unit and reduces the formation of coke on the FCC catalyst. For individual refiners, these additional benefits may offset enough of the cost of FCC hydrotreating to make it more economical than distillate hydrotreating.

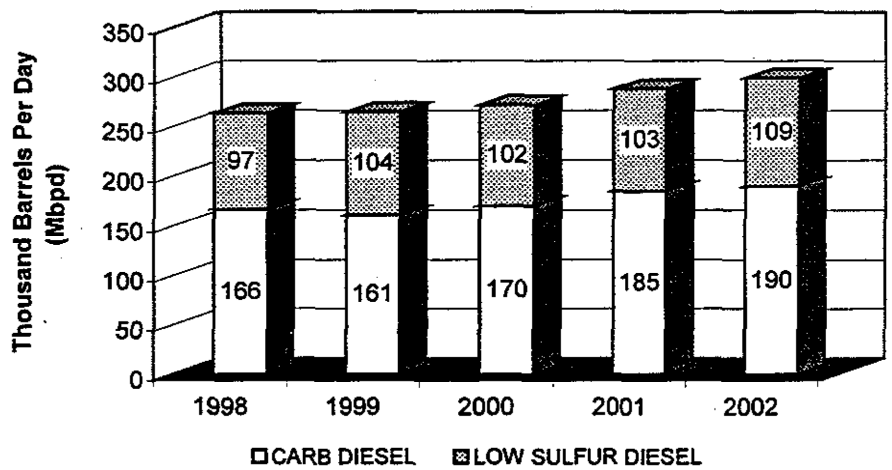
XV. Potential Impacts of the Proposed Specification on the Production of Diesel Fuel by California Refineries

This chapter presents a summary of the potential impacts of the proposed amendments on diesel production by California refineries and diesel production capacity of California refineries.

A. Diesel Production in California Refineries

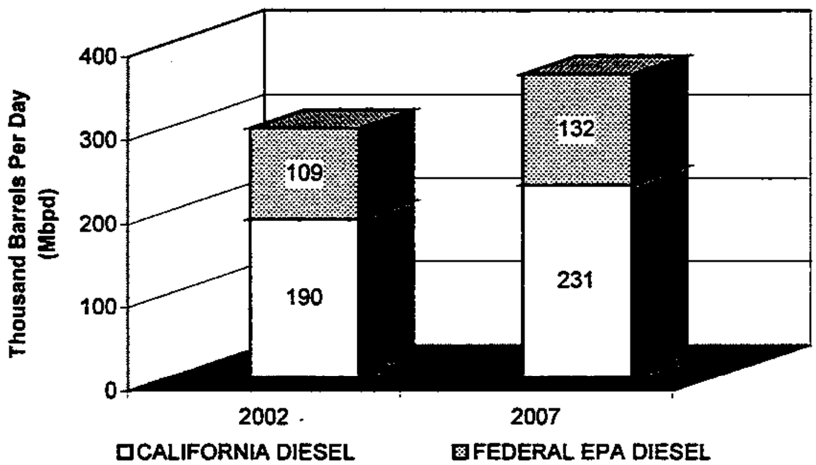
The proposed requirements for California low sulfur diesel fuel are not expected to have any impact on the ability of California to produce and supply adequate volumes of California diesel fuel. In California, on-road diesel fuel (either California or U.S. EPA) is produced at 12 large refineries and two small refineries. Based on information from the CEC, in 2001, these refineries produced 190 Mbpd of California diesel fuel, and nearly 110 Mbpd of U.S. EPA on-road diesel fuel. This is an increase in California diesel fuel production of over 14 percent, and an increase of over 12 percent for U.S. EPA on-road diesel fuel over 1998 levels. Figure XV-1 shows the annual diesel fuel production from California refineries from 1998 through 2002.

Figure XV-1
California Refinery Diesel Production (1998 – 2002)



Based on recent diesel fuel consumption trends showing increases of nearly four percent per year, staff estimates that in 2007, nearly 231 Mbpd of California low sulfur diesel fuel will need to be produced to meet anticipated California demand. Also, over 130 Mbpd of U.S. EPA on-road diesel fuel will be needed to meet diesel demands in neighboring states. These diesel fuel production demand estimates are shown in Figure XV-2.

Figure XV-2
Anticipated 2007 On-Road Diesel Production Compared to 2002 Actual Diesel Production

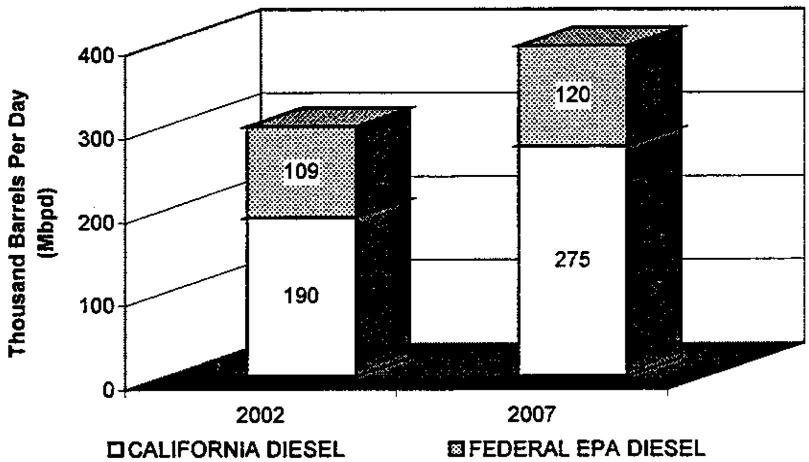


Based on survey responses, California diesel capacity is approximately 275,000 barrels per day. As can be seen, there is still a wide margin between projected estimates for diesel production in 2007 and the estimated diesel capacity, as reported by the refineries.

B. Diesel Capacity of California Refineries

Currently, California refineries have the capacity to produce about 190 Mbpd of California diesel fuel, and about 110 Mbpd of capacity to produce U.S. EPA on-road diesel fuel. Based on information provided by refiners, the requirements to produce low sulfur diesel fuel will not have any impact on the ability of California refiners to produce adequate volumes of low sulfur diesel fuel. Because several refiners indicated that they will expand their ability to produce volumes of California diesel fuel, it is expected that California refining capacity to produce California diesel fuel will increase to 275 Mbpd by 2007. In addition, the capacity of California refiners to produce U.S. EPA on-road diesel fuel will increase to about 120 Mbpd by 2007. This is shown in Figure XV-3.

Figure XV-3
California Refiners' Diesel Fuel Production Capacity
(2002 Versus 2007)



In comparing Figure XV-2 to Figure XV-3, it can be seen that there should be more than adequate refining capacity by California refineries to increase their production of California diesel fuel to meet projected demand estimates. However, it appears the situation may be more constrained for the production of U.S. EPA diesel fuel. Staff does not believe that this should be significant for two reasons. First, the ability of refiners to import U.S. EPA diesel from other parts of the country fuel to supply to neighboring states will be available. Also, since there appears to be excess California diesel fuel production capacity available to California refiners, they have the ability to supply California diesel fuel to neighboring states as demand and market conditions allow.

XVI. OTHER ISSUES

A. Small Refiners

Currently, the California diesel regulations contain provisions for small refineries. A "small refiner" is defined in CCR, Title 13, Section 2260 as a refiner who owns or operates a refinery in California that satisfies the following:

- Has and at all times had since January 1, 1978, a crude oil capacity of not more than 55,000 barrels per stream day;
- Has not been at any time since September 1, 1988, owned or controlled by any refiner that at the same time owned or controlled refineries in California with a total combined crude oil capacity of more than 55,000 barrels per stream day; and
- Has not been at any time since September 1, 1988, owned or controlled by any refiner that has the same time owned or controlled refineries in the United States with a total combined crude oil capacity of more than 137,00 barrels per stream day.

Small refiners are allowed to produce diesel fuel meeting a 20 volume percent aromatic hydrocarbon content limit while large refiners are required to meet a 10 volume, percent aromatic hydrocarbon content standard. Both large and small refiners can certify alternative diesel formulations that are shown to be equivalent to their respective standards. The production of small refiner diesel fuel is limited to a specific volume determined by the capacity and operating characteristic for each refinery. A small refiner may produce an unlimited quantity of large refiner California diesel fuel. At this time the staff is not proposing any specific amendments to the California diesel fuel regulation for small refiners.

Some small refiners have indicated that they will have greater difficulty than large refiners in complying with the proposed 15-ppmw sulfur standard due to such factors as limited operation flexibility, lack of access to blendstocks, poorer economies of scale, or difficulties in raising capital. Staff recognizes that small refiners could experience a "significant and disproportionate financial hardship in reaching the objectives of the diesel fuel sulfur program," as stated in the EPA's final rule. The ARB staff will continue to monitor California's refining industry to evaluate the issues and consider possible actions that could provide some relief to disproportionately affected parties without compromising the benefits of the diesel fuel program.

B. Diesel Engine Lubricating Oils

Diesel engine lubricating oils are a source of sulfur and other compounds that could potentially poison emissions control systems that will likely be used to comply with new heavy-duty diesel emissions standards. Lubricating oils also have the potential to contribute to engine-out sulfur and particulate emissions. The significance of these two effects is not known but current research efforts should establish whether or not these effects should be of concern. Appendix I provides more detailed information.

1. Lubricant Formulation

Diesel engine lubricating oils are comprised of approximately 80 to 85% base oil, with the remainder made up of additives that modify or enhance the properties of the base oil. Base oils may be synthetic oils, which contribute essentially no sulfur to the lubricant, or petroleum-derived base oils. Petroleum-derived base oils can contribute significantly to sulfur content if they are not highly refined and hydrotreated. The EPA[73] reported that the sulfur content of current engine lubricating oils can range from 2,500 ppmw to as high as 8,000 ppmw by weight with the base oil contributing up to half of the sulfur.

Except for the sulfur contribution from high-sulfur base oils, performance additives are the major source of sulfur and ash in lubricating oils. The sulfur containing compounds, in the form of sulfonates, phenol sulfide salts and thiophosphonates, are vital to the performance of the additives that function as anti-wear agents, detergents, corrosion inhibitors, friction modifiers, and anti-oxidants.[74, 75] Anti-wear agents, primarily zinc diakyl dithiophosphates (ZDDP), are the main source of sulfur in the additives. Proven substitutes for all sulfur-containing additives are not available.

The following two sections briefly describe current efforts to determine whether there is a need for sulfur-free low ash substitutes for performance additives.

2. Lubricant Contribution to Sulfur in Exhaust

Under proper operation, only a small percentage of the oil consumed by open-crankcase ventilation heavy-duty diesel engines travels past piston rings and valves and burns in the combustion chamber. In both open-crankcase ventilation systems and closed-crankcase filtration systems, the magnitude of the contribution of engine oil sulfur to the exhaust is unknown. Estimates made for the magnitude of the equivalent fuel sulfur level contributed by engine oil range from nearly zero to seven ppmw. The EPA concluded that, while some sulfur from lubricating oils is almost certainly present in diesel engine exhaust, the amount may not be significant, even for after treatment systems requiring fuel sulfur levels of 15 ppmw or less.[73]

3. Research

There are currently two major research groups working to determine the effects of sulfur and other chemical compounds in diesel engine lubricating oils on diesel engine emissions and the performance of emission control devices.

The two research groups are the lubricants work group of the Advanced Petroleum-Based Fuels Program Diesel Emission Control - Sulfur Effects (APBF-DEC) program and a Southwest Research Institute (SwRI) private consortium called Diesel Aftertreatment Sensitivity to Lubricant/Non-Thermal Catalyst Deactivation (DASL/N-TCD).

The APBF-DEC lubricants workgroup has completed its first phase of testing. The first phase investigated the effect of lubricant formulations on engine out emissions. The second phase will explore the effect of oil formulations on after treatment performance.

The DASL/N-TCD consortium plans to conduct both parametric and research studies, including both gasoline and diesel engines, complementing the APBF-DEC lubricants work.

The results from these research efforts are expected to give engine and emission control system manufacturers insight into the magnitude of the potential problems and to help oil additive/component makers in formulating future additive packages.[76]

4. *ASTM Proposed Engine Oil Category*

An ASTM Heavy-Duty Engine Oil Classification Panel has been formed to develop a new engine oil classification, called Proposed Category 10, for use with advanced after treatment technology. This effort will be exploring the performance of oil formulations with reduced sulfur, phosphorous and sulfated ash. Oil licensing for this new classification is scheduled for mid 2006.

5. *Ash Content of Lubricating Oils*

The ability of the lubricating oil to control acidification (the total base number (TBN) of the oil) is a function of the lubricating oil ash content. Lubricating oil acidification is primarily due to the sulfur content of the fuel and the sulfuric acid that it forms. The proposed lowering of sulfur in diesel fuel will decrease the need for TBN control, requiring less ash content in the lubricating oils.[56] A decrease in ash content will result in a reduced particulate load on the particulate matter filter.

C. Alternative Diesel Fuels

Reformulated and alternative diesel fuels have shown promise for achieving significant reductions in PM and NO_x emissions. In addition to very low sulfur contents, all of these fuels have relatively low density, with low aromatic and PAH contents. The ARB's Interim Procedure for Verification of Emission Reductions for Alternative Diesel Fuels may be used to demonstrate emissions reductions with alternative diesel fuels.

Alternative diesel fuels generally contain more than trace amounts of oxygenated fuel constituents or are emulsified with water. Synthetic diesel fuel, with nearly zero sulfur and aromatic contents, is the cleanest burning of the reformulated diesel fuels. The fuel is produced by the gas-to-liquid chemical conversion process known as Fischer Tropsch (FT). Laboratory engine and truck chassis dynamometer emission testing have demonstrated average emission reductions of 26% and 24% for PM, 4% and 12% for NO_x, 20% and 40% for HC, and 36% and 18% for CO, respectively, for FT diesel over ARB Diesel.[2]

Microemulsions of water or ethanol in diesel fuel have been shown to reduce both PM and NO_x emissions through rapid vaporization of the emulsified droplets. These microexplosions break fuel droplets into smaller droplets, resulting in more complete vaporization and turbulent mixing and consequently more complete combustion of the fuel. The vaporization of the emulsified droplets also lowers peak combustion temperatures, thereby reducing NO_x formation. Enhanced fuel atomization also reduces soot formation. Appendix IV of the Risk Reduction Plan reports the results of testing of a water microemulsion where emission reductions of 62.9% for PM and

14% for NO_x were verified relative to the performance of a 10% aromatic ARB Diesel reference fuel.[2]

Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from vegetable oil or animal fats. It contains 11% oxygen by weight and nearly zero sulfur and no aromatic compounds. Otherwise, it has properties similar to petroleum-based diesel fuel and can be blended into conventional diesel fuel at any ratio. Neat biodiesel (B100) has been classified as an alternative fuel by the U.S. Department of Energy and the U.S. Department of Transportation. Biodiesel is most commonly blended into petroleum-based diesel fuel at 20 percent by volume – a mixture commonly referred to as "B20."

The use of B100 may reduce heavy-duty diesel engine emissions of PM by 47%, HC by 67%, and CO by 48% over conventional diesel fuel; however, its use tends to increase NOx emissions by 10%.[77] Compared to conventional diesel fuel, B20 can reduce emissions of PM by 10%, HC by 20%, and CO by 10%, but it can increase NOx emissions by 2%.[77]

Biodiesel reduces the health risks associated with conventional diesel fuel: emissions of PAH and nitro-PAHs are significantly reduced. The toxic emissions differences are likely to be smaller when compared to CARB diesel fuel but data comparing the two fuels are not available. Testing has been conducted to satisfy Tier2 requirements for the registration of biodiesel as a fuel and fuel additive. In an inhalation study in which rats were exposed to dilute biodiesel exhaust, no significant emissions exposure effects were observed.[78]

D. Actions in Other States

Other states with difficult air pollution problems have emulated California's strategy to achieve clean air benefits through clean diesel fuel. On December 6, 2000, the Texas Natural Resource Conservative Commission approved a low sulfur diesel fuel program patterned after the diesel fuel regulations adopted by California in 1988. Beginning May 1, 2002, diesel fuel produced for sale must not exceed 500 ppmw sulfur, must contain less than 10% by volume of aromatic hydrocarbons, and must have a cetane number of 48 or greater. The regulation also contains provisions for alternative formulations similar to the provisions in the California regulation. Low Emission Diesel Fuel will be required for all on-road motor vehicle use and for off-road use in several areas that are required to distribute federal reformulated gasoline and Texas' low Reid vapor pressure gasoline. These include the eight counties in the Houston/Galveston ozone nonattainment area, the four counties of the Dallas/Fort Worth ozone nonattainment area, the three counties of the Beaumont/Port Arthur ozone nonattainment area; and 95 additional central and eastern Texas counties. Beginning June 1, 2006, the Low Diesel Fuel rules will require the sulfur content in the diesel fuel supplied to the Houston/Galveston area, the Dallas/Fort Worth ozone area, and 95 additional counties covering central and eastern Texas, be reduced to 15 ppmw sulfur.

E. Actions in Other Countries

Diesel fuel is widely used in other countries. In fact, about 40 percent of new cars sold in Europe are powered by a diesel engine.[52] As a result of this large market share enjoyed by diesel passenger cars and the effect of their considerable emissions on air quality, diesel fuel quality programs are assuming a more important role in environmental policies. By 2005, the sulfur content of diesel fuel throughout the European Union (EU) will contain no more than 50 ppm by weight sulfur and perhaps as little as 10 ppm.

The United Kingdom made a rapid conversion to 50 ppmw maximum sulfur diesel fuel in 1999 by offering tax incentives to offset higher production costs. Some refinery production in that country is at levels well below 50 ppmw. Germany is moving forward with plans to introduce a 10 ppmw sulfur cap for diesel fuel by 2003, also with tax incentives, and is trying to get the 50 ppmw specification that was adopted by the European Commission revised downward to the 10 ppmw

Sweden has had extensive experience with low sulfur diesel fuel. With the help of a large tax incentive, Sweden introduced 10 ppmw sulfur fuel (Class I Swedish Diesel) into city areas in 1991. By 1999, over 90% of the highway diesel fuel sold in Sweden met the 10 ppmw sulfur maximum and other specifications (including a 5% by volume aromatics maximum) of the Class I Swedish Diesel.

Canada has harmonized its fuel regulations with the new U.S. 15 ppmw sulfur specification for 2006.[79] This would accommodate the operation of new-technology vehicles that cross the U.S-Canada border. The government is also looking to establish lower off-road sulfur standards. Japan, which currently has a 500 ppmw standard, is scheduled to implement 50-ppmw sulfur diesel by 2005 and has proposed 10-ppmw sulfur diesel for 2008.[80] Western Australia adopted 500-ppmw sulfur fuel for 2000, with a 50-ppmw standard to follow in 2006. In the meantime, the government has granted diesel tax breaks starting in 2003 for early introduction of the 50-ppmw sulfur fuel. will shortly introduce a tax incentive to reduce sulfur in diesel from the national average of 1300 ppmw.

Table XVI-1[81] is a summary of programs in various countries that will reduce the sulfur content of diesel fuel,

F. World Wide Fuel Charter

The international community of vehicle and engine manufacturers has established the World-Wide Fuel Charter "to promote greater understanding of the fuel quality needs of motor vehicle technologies and to harmonize fuel quality world-wide in accordance with vehicle needs." Four different categories of fuel quality have been established by the World-Wide Fuel Charter. They are described in Table 2. Category 4 fuel quality standards are proposed for markets with requirements for advanced PM and NO_x emissions control technologies and would therefore apply to the USA. The Category 4 standards include a minimum cetane number of 55, maximum sulfur content of 5 to 10 ppmw, and maximum total aromatics and polyaromatics contents of 15% and 2% respectively. Fuels meeting these specifications should provide emissions benefits equal to or greater than current ARB diesel requirements.

Table XVI-1: Summary of Diesel Fuel Regulations and Incentive Programs for Selected Countries

Country	Regulation or Incentive	Max S limit	Conventional Fuel limit (and typical content)	Introduced
EU	EURO2 98/70/EC EURO3 98/70/EC EURO4		500 ppm (450) 350 ppm 50 ppm	1 Jan 1997 1 Jan. 2000 1 Jan 2005
Belgium	National incentive	50 ppm	350 ppm	1 Oct. 2001
Denmark[1]	National incentive	50 ppm	500 ppm	June 1999
Finland[2]	National incentive Neste/Fortum Initiative	50 ppm 10 ppm	350 ppm	2002
Germany[3]	National incentive	50 ppm 10 ppm	350 ppm	1 Nov 2001 Jan 2003
Netherlands	National incentive	50 ppm	350 ppm	Jan 2001
Sweden	National incentive[4] National incentive[5]	10 ppm 10 ppm 50 ppm	2000 ppm 350 ppm 350 ppm	1991 2001 2001
Switzerland	National incentive Agrola initiative BP initiative	50/10 ppm[6] 10 ppm[7] 10 ppm[8]	350 ppm 350 ppm 350 ppm	2003 2000 2000
UK	National incentive National incentive	50 ppm 50 ppm	500 ppm 350 ppm	March 1999 7 Mar 2001
Australia	National regulation BP initiative[9]	50 ppm 50 ppm	1300 ppm 500 ppm	Jan 2006 End 2000
Hong Kong[10]	"Ultra low sulphur" national incentive	50 ppm	500 ppm	July 2000
Japan[11]	National regulatory proposal	50 ppm	500 ppm	Before 2005

Selected from Report to Committee of Deputies, European Conference of Ministers of Transport. March 2001

1 100 % penetration by July 1999
2 100 % penetration
3 From 2003, the incentive will shift from 50 ppm fuels to 10 ppm fuels
4 City diesel
5 Current incentive, last adjusted 1 Jan. 2001.
6 Proposal before parliament
7 Small market share
8 Supply to public transport and army
9 Capacity to supply 12% of national market
10 Replaced regular diesel at all filling stations but high sulfur fuel still used by bus fleets as tax free
11 Japan Air Quality Committee has recommended further reduction in the future

Table XVI-2: World-Wide Fuel Charter Fuel Quality Categories[82]

Categories	Basis of Fuel Quality Recommendations
1	Markets with no or first level of emission control; based primarily on fundamental vehicle/engine performance and protection of emission control systems.
2	Markets with stringent requirements for emission control or other market demands. *For example, U.S. Tier 0 or Tier 1, EURO 1 and 2, or equivalent emission standards.*
3	Markets with advanced requirements for emission control or other market demands. *For example, markets requiring US California LEV, ULEV and EURO 3 and 4, or equivalent emission standards.*
4	Markets with further advanced requirements for emission control, to enable sophisticated NO_X and particulate matter after treatment technologies. *For example, markets requiring US California LEV-II, US EPA Tier 2, EURO 4 in conjunction with increased fuel efficiency constraints or equivalent emission standards.*

Table XVI-3: Proposed Diesel Fuel Specifications[83]

Specification	EY Year 2000	Fuel Charter
Cetane Number	≥ 51	≥ 55
Cetane Index	NA	≥ 52
Density @ 15°C, (kg/m^3)	< 845	< 840
Distillation 90% Boiling Point, °C	NA	< 320
95% Boiling Point, °C	< 360	< 340
Final Boiling point, °C	NA	< 350
Polyaromatic Hydrocarbons, wt%	< 11	< 2.0
Total Aromatics Content, wt%	NA	< 15
Sulfur Content, ppmw	< 350*	Zero**

* From Year 2005, the European Union has adopted a sulfur content of 50 ppmw.
** Zero has yet to be defined as either <5 ppmw or <10 ppmw.

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XVII. ENVIRONMENTAL EFFECTS OF THE PROPOSED AMENDMENTS TO THE DIESEL FUEL REGULATIONS

This chapter discusses the environmental impacts of the proposed amendments to the California diesel fuel regulations. The proposed amendments would reduce the limit on sulfur in California diesel from 500 ppmw to 15 ppmw; revise the allowable range for the sulfur content of diesel engine certification fuel to be consistent with the proposed limit on commercial fuel; revise the certification requirements for alternative diesel formulations; adopt new standards for lubricity of diesel fuel, and adopt a new airborne toxic control measure which would extend the applicability of the diesel fuel regulations to nonvehicular diesel engines.

A. Legal Requirements Applicable to Analysis

The California Environmental Quality Act (CEQA) and ARB policy require an analysis to determine the potential adverse environmental impacts of the proposed standards. Because the ARB's program involving the adoption of regulations has been approved by the Secretary of Resources (see Public Resources Code, section 21080.5), the CEQA environmental analysis requirements are to be included in the ARB's Staff Report in lieu of preparing an environmental impact report or negative declaration. In addition, the ARB will respond in writing to all significant environmental issues raise by the public during the public review period or the public Board hearing. These responses are to be contained in the Final Statement of Reasons for the proposed amendments.

Public Resources Code section 21159 requires that the environmental impact analysis conducted by the ARB include the following:

- An analysis of the reasonably foreseeable environmental impacts of the methods of compliance;
- An analysis of reasonably foreseeable mitigation measures; and
- An analysis of reasonably foreseeable alternative means of compliance with the standard.

Compliance with the proposed amendments is expected to directly affect air quality and indirectly affect other environmental media as a consequence of the air quality impact. Our analysis of the reasonable forseeable environmental impacts of the methods of compliance is presented in sections C to H below. Regarding mitigation measures, CEQA requires the lead agency to identify and adopt any feasible mitigation measures that would minimize any significant adverse environmental impacts described in the environmental analysis.

The proposed diesel fuel regulation is needed to ensure compliance with the 2007 exhaust emission standards for new heavy-duty diesel engines and vehicles and to reduce the risk from diesel PM emissions as required by the 2000 California Risk Reduction Plan (RRP). Alternatives to the proposed amendments have been discussed in earlier chapters (VIII to XIII) of this report. ARB staff has concluded that at this time, there is no alternative means of complying with the 2007 emission standards. Other alternatives have been evaluated in the RRP.

B. California Environmental Policy Council

Health and Safety Code section 43830.8, enacted in 1999 (Stats. 1999, ch. 813; S.B. 529, Bowen) generally prohibits the ARB from adopting a regulation establishing a specification for motor vehicle fuel unless the regulation is subject to a multimedia evaluation by the California Environmental Policy Council (CEPC). The CEPC is a seven-member body comprised of the Secretary for Environmental Protection, the Chairpersons of the ARB, State Water Resources Control Board, and Integrated Waste Management Board, and the Directors of the Office of Environmental Health Hazard Assessment, the Department of Toxic Substances Control, and the Department of Pesticide Regulation. Key components of the evaluation process are the identification and evaluation of significant adverse impacts on public health or the environment and the use of best available scientific data.

Multimedia evaluation means the identification and evaluation of any significant adverse impact on public health or the environment, including air, water, or soil, that may result from the production, use, or disposal of the motor vehicle fuel that may be used to meet the state board's motor vehicle fuel specifications.

The statute provides that the ARB may adopt a regulation that establishes a specification for motor vehicle fuel without the proposed regulation being subject to a multimedia evaluation if the CEPC, following an initial evaluation of the proposed regulation, conclusively determines that the regulation will not have any significant adverse impact on public health or the environment.

It is the staff's intention that the proposed regulatory amendments will be reviewed by the CEPC prior to final adoption. The proposed changes include new vehicular diesel fuel specifications of a 15-ppmw limit for sulfur content and a lubricity standard.

C. Effects on Air Quality

Sulfur in diesel fuel contributes to ambient levels of fine particulate matter through the formation of sulfates both in the exhaust stream of the diesel engine and later in the atmosphere. Therefore, reducing the sulfur limit of California diesel to 15 ppmw will have a positive air quality impact by reducing ambient levels of particulate matter. Significant additional air quality benefits will be achieved from reductions of emissions of ozone precursors (NOx and NMHC) and toxic air contaminants (diesel PM) through the use of low sulfur diesel in diesel engines and vehicles equipped with advanced aftertreatment devices.

Implementation of the proposed amendment to the diesel fuel sulfur standard will require changes in processing that could affect emissions from the refinery. The impact of these process changes on air quality will be limited by the requirements of the California Environmental Quality Act (CEQA) and permit requirements of the air pollution control districts. These impacts are discussed in Section K of this chapter.

1. Emissions from Stationary Engines and Portable Engines

Stationary engines are not required to use fuel that meets California Air Resources Board diesel (CARB diesel) formulation requirements but virtually all use complying fuel because of California's single fuel distribution network. Also, several districts have established best available control technology requirements for diesel-fueled stationary engines that specify the use of CARB diesel. Portable engines registered under ARB's Statewide Portable Equipment Registration program are required to use CARB diesel. Therefore, the proposal to reduce the sulfur content of CARB diesel will result in lower sulfur dioxide and particulate sulfate emissions from stationary engines and off-road portable engines.

Low-sulfur diesel will also help provide added emissions benefits by enabling the implementation of measures recommended in the Diesel Risk Reduction Plan to reduce diesel PM emissions from new and existing stationary and off-road portable diesel-fueled engines. The recommended measures will benefit California's environment and reduce the public's exposure to air pollutants, particularly the toxic air contaminant diesel PM. Reductions of diesel PM emission from new stationary diesel-fueled engines would be accomplished through specific technology requirements, such as stringent diesel PM engine certification levels, use of low-sulfur diesel fuel, and application of catalyst-based DPFs, or an equally stringent performance standard.

The proposed amendment will enable the retrofitting of existing off-road portable and stationary diesel engines with sulfur sensitive catalytic after-treatment control technologies to control diesel PM emissions.

2. Emissions from Mobile Sources

The proposed amendment to lower the sulfur content limit of California diesel will provide modest reductions in emissions of sulfate particulate matter from diesel vehicles already in the fleet. A U.S. EPA on-road emission model predicts that reducing the sulfur content of California diesel from the current average of 141 ppmw to 15 ppmw would reduce sulfur oxide emissions (as SO_2) by 0.11 grams per pound (g/lb) of fuel, and sulfate PM emissions (as $H_2SO_4 : 7H_2O$) by 0.0080 g/lb of fuel. The sulfur oxide emission reductions would reduce atmospheric sulfate formation (as half NH_2SO_4 and half NH_4HSO_4) by 0.026 g/lb of fuel. Diesel PM emissions would be reduced by about 4 percent from engines with FTP cycle-specific emission rates of 0.1 grams per brake horsepower-hour.[2]

The proposed diesel sulfur limit of 15 ppmw will help generate significant air quality benefits by enabling the effective performance of advanced diesel exhaust emissions control technologies that reduce emissions of ozone precursors (NOx and NMHC) and diesel PM. These control technologies are needed to achieve the emissions reductions required for compliance with the stringent diesel engine emission standards adopted by the ARB in October 2001 for 2007 and subsequent model year medium-duty and heavy-duty diesel engines. The new emission standards represent a 90% reduction of NOx emissions, 72% reduction of NMHC, and 90% reduction of PM emissions compared to the 2004 emission standards. These standards will significantly reduce emissions of NOx, NMHC, SO_2 and PM, which will in turn result in reductions of ozone levels and ambient PM levels. Reductions in emissions of diesel PM mean reduced ambient levels of the toxic air contaminants (TAC) found in diesel exhaust and reduced public exposure to those TACs.

The proposed lubricity standard for the low sulfur diesel fuel will provide an emissions benefit. Fuels of inadequate lubricity do not provide sufficient fuel system lubrication and will contribute to excessive wear resulting in reduced equipment life and performance. New fuel injector systems, called common rail systems, use extremely high pressures and require higher levels of fuel lubricity than conventional systems. These high pressure injection systems have been developed to more accurately tailor fuel injection, provide finer fuel atomization, and improve fuel/air mixing to reduce exhaust emissions. Excessive wear in these high pressure fuel injection systems is expected to increase emissions due to compromised pump performance. These systems are vital to the success of vehicle manufacturers' efforts to produce diesel engines that meet the California light duty vehicle emissions standards.

D. Effects on Greenhouse Gas Emissions

Greenhouse gases (GHG) are predominantly comprised of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The gases differ in their atmospheric warming potential and as a result, the contribution of each gas is determined as equivalent CO_2 emissions using conversion factors approved by the Intergovernmental Panel on Climate Change; for example, methane has 21 times the warming potential of carbon dioxide.

Transportation is a large source of greenhouse gas emissions around the world. Table XVII-1 reports greenhouse gas emissions as million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) for diesel and gasoline consumption in the transportation sector in California. The CO_2 emissions estimates for diesel consumption include non-highway vehicles, ships, and trains which together are a small proportion of the total emissions. The estimates of CH_4 and N_2O emissions are only for highway vehicles.

Table XVII-1: Greenhouse Gas Emissions from Diesel and Gasoline Consumption in the Transportation Sector in 1999

Greenhouse Gas	Global Warming Potential	GHG Emissions (MMTCO$_2$ Eq.)	
		Diesel	Gasoline
CO_2	1	27.0	126.8
CH_4	21	+	0.4
N_2O	310	0.2	5.6

Source: California Energy Commission[84]
+ Does not exceed 0.05

Implementation of the proposed amendments could have a small net effect on global warming. The production of low sulfur diesel is expected to increase emissions of greenhouse gases, but the greenhouse effect from diesel production is expected to be substantially offset by the effect of a reduction in CO_2 emissions from use of the low sulfur fuel in diesel engines.

Emissions of CO_2 from refineries will increase due to the increased demand for energy for additional hydrogen production and additional processing to produce low sulfur diesel. Methane emissions are expected to increase due to natural gas production and distribution losses but these methane losses will be small compared to the additional carbon dioxide emissions. A smaller amount of methane and nitrous oxide will be emitted in the natural gas combustion process. Some of the extra hydrogen and the energy it represents will be in the fuel, increasing the hydrogen to carbon ratio and reducing CO_2 exhaust emissions. Appendix J provides a detailed discussion of the staff's evaluation of the greenhouse effects.

E. Impact on the State Implementation Plan

The 1994 SIP for ozone is California's master plan for achieving the federal ozone standard in six areas of the state by the federally required date. For the South Coast Air Basin, the 1994 SIP requires that the federal ozone standard be met by 2010. The SIP includes state measures to control emissions from motor vehicles and fuels, consumer products and pesticide usage, local measures for stationary and area sources, and federal measures for sources under exclusive or practical federal control. U.S. EPA approved the 1994 SIP in September 1996. The South Coast Air Quality Management District revised its part of the Ozone SIP in 1997 and again in 1999. U.S. EPA approved the South Coast's 1999 Ozone SIP revision in 2000.

Once the U.S. EPA approved the 1994 SIP and the 1999 update for the South Coast, the emissions inventories and assumptions used in the SIP are frozen. Evaluations of the impacts on the SIP of new measures or modifications to existing measures must use the same emissions inventories and assumptions used in developing the SIP.

As ARB has implemented the SIP over the last eight years, some measures have delivered more reductions than anticipated, while other measures have delivered fewer reductions due to technical or economic concerns. In some cases, measures not originally envisioned in the 1994 SIP are providing benefits that help meet the SIP emission reduction obligations. The 2007 heavy-duty diesel vehicle emission standards is one of the measures not originally included in the 1994 SIP that will provide emission reductions needed to help the state meet its SIP obligations. In the Initial Statement of Reasons[85] for the amendments to the diesel truck standards, the ARB staff quantified the benefits of these emission reductions for the South Coast which is currently the only area with a post-2007 attainment date.

The proposed diesel fuel sulfur standard is central to the success of the diesel truck standards in achieving the emissions reductions estimated for the SIP. The lower fuel sulfur content is needed to ensure the effectiveness and durability of advanced emission control technology. Without the low sulfur fuel, the control devices could not perform effectively enough to meet the new diesel truck standards.

F. Diesel Particulate Matter Emissions, Exposure, and Risk

The proposed amendment to the diesel sulfur specification is critical to the attainment of the emission and risk reduction targets in the Diesel Risk Reduction Plan. The plan would reduce public exposure to toxic air contaminants associated with diesel exhaust PM through various measures. The measures would require the retrofitting of older off-road and stationary engines with CDPFs and would establish stringent diesel PM emissions standards for new engines that would require exhaust treatment with CDPFs. Low sulfur diesel will be needed for the effective performance of these filters.

ARB staff estimated that full implementation of the recommended measures, including retrofit of locomotives and commercial marine vessels would result in an overall 85 percent reduction by 2020 of the diesel PM inventory and the associated potential cancer risk compared to baseline levels in 2000.[86] These reductions would require the combined actions of both California and the U.S. EPA to adopt and implement rules that reduce diesel PM.

The measures recommended in the Diesel Risk Reduction Plan address on-road vehicles, off-road equipment and vehicles, and stationary and portable engines. These measures include the emissions standards adopted by the U.S. EPA and the ARB for 2007 and subsequent model year new heavy-duty diesel engines and vehicles and the proposed low sulfur limit for California diesel fuel.

G. Additional Benefits of the Proposed Amendments

Full implementation of the measures in the Diesel Risk Reduction plan will result in significant reductions in diesel PM emissions and the associated risk. There are additional benefits associated with reducing diesel PM emissions. These include:

- Improved visibility with reduction of both primary and secondary particles;
- Less soiling and material damage as a result of decreased deposition of airborne diesel PM; and
- Decreased noncancer health effects associated with diesel PM.

H. Effects on Water Quality

The proposed amendment to lower the sulfur content limit of California diesel fuel to 15 ppmw should have no significant adverse impacts on water quality. One direct benefit of lowering the sulfur content limit is a reduction of emitted sulfur oxides, and particulate sulfate and consequently a reduction of atmospheric deposition of sulfuric acid and sulfates in water bodies. The low sulfur diesel will enable the use of high-efficiency aftertreatment devices to reduce NOx and diesel PM emissions from 2007 and subsequent model year vehicles and from retrofitted engines. As a result, there should be a decrease in atmospheric deposition of nitrogen and airborne diesel particles as well as the associated heavy metals, PAHs, dioxins, and other toxic compounds typically found in diesel exhaust.

The release of diesel fuel to surface water and groundwater can occur during production, storage, distribution or use. The potential sources of such releases, which include underground storage tanks, above-ground storage tanks, refineries, pipelines, and service stations, will be the same as with the current diesel fuel. Also, the mechanisms by which the diesel fuel enters surface water or migrates in the subsurface at a site will be unchanged. The factors that control the behavior of diesel in soil and water are not expected to be significantly different with the low sulfur fuel. As discussed in Appendix K, the refining process to reduce the sulfur content of diesel fuel to 15 ppmw is not expected to result in a significant change in the chemical composition of the fuel.

Also, the expected increase in additives to meet the proposed lubricity standard should not significantly change the chemical composition of the diesel fuel. Therefore, there should be no significant change in the physical or chemical properties that affect the activity of the fuel in soil and water, and any release of low sulfur diesel fuel to the environment should have no additional impact on water quality compared to the current diesel fuel.

The other proposed amendments to the diesel regulation should not have any significant adverse impacts on water quality.

I. California Environmental Quality Act Review of Refinery Modifications

Every project which is not exempt from CEQA must be analyzed by a lead agency to determine the potential environmental impacts. The lead agency is the single agency responsible for determining the type of environmental analysis CEQA requires. In addition, the lead agency must prepare the environmental review document required by CEQA. Once the lead agency is identified, all other involved agencies, whether state or local, become responsible or trustee agencies. In the case of refiners in the South Coast Air Basin and San Joaquin Valley, historically the air districts have assumed lead agency responsibility for refiner's fuels projects. In the case of the Bay Area, this responsibility has been assumed by local government agencies (city and county).

The lead agency prepares an initial study to determine whether proposed projects may have a significant adverse impact on the environment. If a project is found to have no significant impact, the lead agency prepares a negative declaration document. A mitigated negative declaration is prepared for a project with potential significant effects that can be avoided or rendered insignificant with modifications of the project.

If the initial study shows that the project may have one or more significant effects, the lead agency must circulate a notice of preparation (NOP) in anticipation of preparing an Environmental Impact Report (EIR) and must consult with responsible and trustee agencies as to the content of the environmental analysis. The lead agency first prepares a draft EIR that must include detailed information on the potentially significant environmental effects which the proposed project is likely to have, list ways which the significant environmental effects may be minimized, and indicate alternatives to the project.

A Final EIR is prepared and certified by the lead agency. If the lead agency approves the project, it must find that each significant impact will be mitigated below the level of significance where feasible, and that overriding social or economic concerns merit the approval of the project in the face of unavoidable effects. For example, in the case of refinery modifications for California Phase 2 Reformulated Gasoline, lead agencies approved these projects with a statement of overriding consideration because the regional air toxic and air quality benefits from CaRFG2 far exceeded the local air quality impacts.

J. Air District Permit Requirements

California's programs for permitting new construction or modification of stationary sources which may emit pollutants are referred to as New Source Review (NSR) programs. Each District has its own NSR program and issues its own permits to construct and operate, but the district program must incorporate California and federal requirements for NSR. The California Clean Air Act (CCAA) mandates that there must be no increase in emissions from the permitting of new and modified sources. If potential emissions increases are above specified levels, the district requires the source to install Best Available Control Technology (BACT) to control those emissions. In addition, depending on the type and quantity of pollutants emitted, new or modified sources in California may be required to mitigate or offset any emission increases remaining after BACT has been applied.

The Federal Clean Air Act Amendments of 1990 provides state and local agencies in extreme ozone non-attainment area with the authority to exempt projects from offset requirements for emissions increases resulting from compliance with federal, state, and local air quality mandates. Under this authority, the SCAQMD in a federal extreme ozone non-attainment area chose to exempt CaRFG3 modifications from their offset requirements. The BAAQMD did not allow offset exemptions. As a result, except for CO, refineries in the BAAQMD offset all of the criteria pollutant emissions associated with their CaRFG3 projects.

K. Environmental Justice and Neighborhood Impacts

The primary environmental justice and neighborhood impacts of the proposed action would be potential additional emissions from changes in refinery operation. Refineries are expected to modify their operation to varying extents to comply with the proposed amendment to lower the limit on the sulfur content of diesel fuel. Several of the refiners responding to the staff's survey indicated that process adjustments would be minimal while others could not provide any detail until after the planning process has started. Until then, it will not be possible to determine the impact of refinery modifications on communities near refineries.

The proposed amendment to the diesel sulfur standard would be a benefit to communities as the low sulfur diesel enables the use of control systems on diesel powered vehicles to greatly reduce the exposure to diesel particulate matter and the associated cancer risks.

1. Refinery Modifications

Refinery modifications will be subject to the requirements of CEQA and air pollution control district permit requirements. CEQA requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts, where feasible.

The results of an ARB staff survey suggest that refiners will most likely meet the proposed sulfur limit by increasing their hydrotreating capability. The additional energy needs for this additional processing could mean increases in combustion derived emissions such as NOx, PM, CO, and SO_2 from sources such as heaters and boilers that must increase their operation to meet the additional energy demands.

Increased energy demands could be met by adding new process heaters or by operating existing heaters at higher rates. Demands on power plants are also expected to increase. The increased fuel consumption will result in increased emissions of NOx, CO, and SO_2. The efficiency of new process units and improvements to existing units will also determine whether or not pollutant emissions increase. Also, the impact of additional hydrotreating could be reduced with the use of more selective hydrotreating catalysts that require less hydrogen. Any increases in emissions would be limited under new source review or BACT requirements of the air quality management districts.

Equipment leaks are the main source of VOC emissions from refinery equipment. Leaks typically occur at valves, pumps, compressors, flanges and connectors, pressure relief devices, open-end lines, and sampling connections. The addition of new process units and modification of existing units increase the potential for new equipment leaks. VOC emissions from a new process unit depend on the number and type of components in the unit. However, emissions from new equipment subject to BACT requirements could be lower than emissions from older equipment.

The removal of additional sulfur from diesel fuel will result in higher levels of sulfur in the sour gas stream from the hydrotreater. There is the potential for increases in SO_2 emissions from the combustion of the refinery fuel gas and the discharge of the sulfur recovery tail gas to the atmosphere.

2. SCAQMD's Environmental Assessment

The South Coast AQMD has completed a final Program Environmental Assessment (PEA) to address the potential adverse environmental impacts of the implementation of their fleet vehicle rules and the amendments to Rule 431.2 to reduce the maximum permissible sulfur content of diesel to 15 ppmw.[87] The PEA included an analysis of the impacts of refinery modifications to produce low sulfur fuel.

A "worst case" analysis was conducted because there was insufficient detailed information on the type and extent of refinery process changes required to produce 15-ppmw diesel fuel. It was assumed that all refineries would modify their processes at the same time and to the same extent and that refinery modifications would take up to two years to complete.

The conclusion from this analysis was that there would be significant adverse short-term construction-related air quality impacts from refinery modifications to implement the amendments to Rule 431.2. This would occur despite implementing all feasible mitigation measures. The SCAQMD analysis identified three main sources of emissions from refinery construction activities: 1) grading, 2) off-road mobile source equipment, and 3) on-road motor vehicles for construction worker trips. Once construction is complete, construction air quality impacts would cease while the permanent long-term TAC benefits and criteria pollutant reductions associated with the use of the low sulfur fuel would remain.

Existing sources that could be affected by the implementation of the proposed regulation have already had their permitted maximum potential to emit set by district regulations or programs such as RECLAIM. Incremental emissions from existing sources would not be considered a significant air quality impact if the emissions increases do not exceed maximum permitted levels.

New permitted sources are subject to the district's NSR regulations which require that new, modified, and relocated stationary sources install BACT. If emissions from the stationary sources in the SCAQMD's jurisdiction are greater than one pound, the source must conduct ambient air modeling and provide emission offsets. If a new source complies will all applicable SCAQMD rules or regulations, the district presumes that no significant adverse air quality impacts will result from the project.

3. Diesel Use by On-road, Off-road and Stationary Sources

Since its implementation in 1993, CARB diesel has provided significant reductions in emissions of SOx, NOx, and PM from diesel engines. Communities that are affected by emissions from diesel engines would benefit even further from the proposed amendment to reduce the sulfur content limit of CARB diesel to 15 ppmw. The proposed amendment, which would become effective in 2006, would ensure the availability of the low sulfur diesel fuel required for the effective performance of control devices needed to comply with stringent new exhaust emissions standards that will provide further emissions reductions and air quality benefits. The new emission standards represent a 90% reduction of NOx emissions, 72% reduction of NMHC emissions, and 90% reduction of PM emissions compared to the 2004 emission standards. They will apply to all medium-duty and heavy-duty diesel engines produced for sale in California in the 2007 and subsequent model years. Additional benefits will accrue through early availability of low sulfur diesel for vehicle fleets and stationary engines that are required through state or local rules to install catalytic add-on controls prior to 2006.

The proposed amendment would also enable the retrofitting of existing diesel engines with control devices that reduce PM emissions. ARB staff estimates the full implementation of the measures recommended by the RRP, including retrofit of locomotives and commercial marine vessels, will result in an overall 85 percent reduction in the diesel PM inventory and the associated potential cancer risk for 2020, when compared to today's diesel PM inventory and risk. These reductions will occur through the combined actions of both California and the U.S. EPA to adopt and implement rules that reduce diesel PM.

XVIII. Costs to Produce Low Sulfur Diesel Fuel

This chapter presents a summary of the analysis of the costs to produce low sulfur diesel fuel and of the other proposed amendments.

A. Background

The new requirements for low sulfur diesel fuel will necessitate changes in the way diesel fuel is produced. Refiners will need to perform modifications to their facilities that will ensure that they are capable of producing sufficient and consistent quantities of California diesel fuel below 15 ppmw sulfur. To accomplish this, refiners must increase their flexibility to reduce the concentration of sulfur in various diesel blendstocks. In addition, pipeline operators face new challenges in resequencing the shipping of low sulfur petroleum products (both gasoline and diesel fuel) with jet fuel, which is a high sulfur product.

In developing the cost estimates to produce low sulfur diesel fuel, staff utilized two methodologies. One method was to take a conservative approach and allocate the full economic effect of these various programs to the proposed amendments as though the proposed amendments are the only requirements to produce low sulfur diesel fuel in California. However, since both the U.S. EPA and the SCAQMD have adopted requirements for the use of this fuel, which means that virtually all of the diesel fuel produced by California refineries (both for consumption in and out of California) will have to meet the new low sulfur requirement regardless of new ARB requirements. Staff's alternative method considers this.

In addition to the use of low sulfur diesel fuel in California, staff's proposal also consists of requirements for minimum lubricity standards for California diesel fuel, modifications to the procedures for certifying diesel alternative formulations, and modifications to the ARB's new diesel engine and diesel vehicle certification fuel. The costs for these amendments are also discussed.

In developing the cost estimates for this chapter, staff relied on information provided by California refiners and the major California common carrier pipeline operator, documents prepared by the U.S. EPA, U.S. DOE, and the SCAQMD, specialty fuel suppliers, and conversations with the CEC staff.

B. Effect of U.S. EPA and SCAQMD Low Sulfur Diesel Fuel Regulations in California

As discussed in previous chapters, both the SCAQMD and the U.S.EPA have adopted regulations requiring the use of low sulfur diesel fuel. In California, these two regulations will effectively apply to about 75 percent of the diesel fuel used in the State. As a result, the proposed amendments will extend the requirements for the use of low sulfur diesel fuel to the remaining approximately 25 percent of the diesel fuel market.

While the two pre-existing regulations will apply to 75 percent of the California diesel fuel market, as a practical matter these existing regulations will shift a much greater portion of the California diesel market to low sulfur diesel fuel. This is because many of the modifications required to comply with the SCAQMD and the U.S. EPA low sulfur diesel regulations will, as a side benefit, also reduce the sulfur content of much of the remaining 25 percent of the California diesel fuel production. Because of this, for the low sulfur diesel fuel cost estimates provided later in this chapter, staff estimates that as much as 90 percent of these costs to produce low sulfur diesel can be attributed to the requirements of the U.S. EPA and SCAQMD regulations, and accordingly are not directly a result of the proposed amendments. However, while the majority of the costs associated with the production of low sulfur diesel fuel are not a result of the proposed amendments, staff believes it is appropriate to estimate the overall costs of all of the requirements for low sulfur diesel fuel (U.S. EPA, SCAQMD and the proposed amendments) to California.

C. Costs to Produce Low Sulfur Diesel in California

The development of cost estimates has been divided into two sections, one which describes the cost impacts of producing low sulfur diesel fuel, and a second section which describes the cost impacts of staff's remaining amendments.

In determining the overall cost estimate to produce low sulfur diesel fuel, staff has estimated that first year costs will be 2 to 5 cents per gallon. These costs are summarized in Table XVIII-1. Costs during the second year and beyond are expected to be about 2 to 4 cents per gallon, due to stability and optimization in production, with the most likely cost to be closer to 2 or 3 cents per gallon. The costs of staff's other proposed amendments are not expected to be significant.

Table XVIII-1: Overall Costs of Low Sulfur Diesel Fuel

Expenditure	1st Year (¢/gallon)	Subsequent Years (¢/gallon)
Capital Investment (including O&M)	2.2 – 2.7	2.2 – 2.7
Distribution System	0.0 – 0.2	0.0 – 0.2
Lubricity Additives	0.2 – 0.4	0.2 – 0.4
Fuel Economy Penalty	0.0 – 0.5	0.0 – 0.5
Price Sensitivity	0.0 – 1.0	--
Overall Costs	2 – 5	2 – 4

To develop the cost estimates for the proposed amendments, staff sent out two surveys to California refineries producing California diesel fuel. The first survey was sent in April of 2001 and a second survey was sent out in March of 2003. The purpose of the second survey was to allow refineries to update any changes to the status of their low sulfur diesel production plans since the submission of their original survey. Copies of the two survey forms are provided in Appendix L.

1. Methodology Used to Estimate Annualized Capital Costs

Currently, the California on- and off-road motor vehicle diesel pool has an average sulfur content of about 140 ppmw. It is expected that with the proposed limit of 15 ppmw, the average sulfur content in the California diesel pool will be reduced to about 10 ppmw. This will necessitate changes in the production and distribution of diesel fuel in California. The compliance costs calculated for this section are based on projected increases in capital expenditures and operating and maintenance (O&M) costs for California refineries and the petroleum pipeline distribution system.

Staff analyzed the responses submitted by refiners and compiled two separate capital cost estimates. One estimate is for the cost to produce California low sulfur diesel for both on- and off-road motor vehicle and stationary source applications within California. This takes a conservative approach which presumes that the proposed amendments are the only requirements to produce low sulfur diesel, and that refiners can only recover their production costs over their California production volume.

However, as previously described, since there are already existing federal requirements to produce low sulfur diesel, California refiners have the ability to recover their production costs not just over their California production but over their federal on-road diesel production as well. As such, the second cost estimate consists of the production of both California low sulfur diesel and U.S. EPA low sulfur diesel (for out-of-state consumption) by California refiners. This recognizes the larger diesel pool over which refiners will actually be able to recover their increased capital and production costs.

It is important to recognize that any changes in production costs will not necessarily be reflected in retail prices. Retail prices reflect not only production costs, but also other market conditions (supply/demand, crude oil prices, competitive market considerations, etc.) not associated with the proposed amendments, all of which will influence the final price. However, it is reasonable to assume that over time, refiners will recover the increased costs of production in the marketplace.

2. *Refinery Capital Costs to Produce California Diesel Fuel*

The capital costs associated with staff's proposed amendments are based on the refinery modifications proposed by refiners, as described in Chapter XIV. It is anticipated that these modifications will occur on existing equipment, which generally results in a lower net increase in costs as opposed to the installation of new process equipment.

To determine the costs associated with the production of California and also U.S. EPA low sulfur diesel fuel, staff analyzed survey responses and information supplied by California refiners, as well as documents from the U.S. EPA and the SCAQMD. Most refiners provided their cost estimates in ranges. Therefore, staff's cost analysis provides a range of cost estimates. The cumulative capital costs include estimates from the refiners surveyed, and eight of the 12 large refineries reported that capital expenditures to produce low sulfur diesel fuel should be minimal. Three refineries reported significant costs involving the installation of new hydro-desulfurization units. The refinery cost estimates were given as total capital investment for the purchase, installation, associated engineering, permitting, and start-up costs for necessary equipment.

3. *Annualized Capital Costs to Produce California Diesel Fuel*

Based on survey responses, refiners will incur capital expenditures of approximately $170 to about $250 million to comply with the proposed amendments and produce California low sulfur diesel. These capital expenditures are considered one-time costs that will most likely be recovered over a period of time which staff has assumed at 10 years, and at an interest rate of seven percent per year. Thus, the associated annualized capital recovery cost of the proposed amendments can be determined according to the following equation:

Capital Recovery Cost = (*Capital Cost*) x (*Capital Recovery Factor*)

Where:

Capital Cost - $170 million to $250 million
Capital Recovery Factor – 14.2% (7% per year over 10 years)

This value, calculated to range from $24 to $36 million, represents the annualized capital cost to refiners to upgrade refineries to comply with the proposed amendments.

4. *Annual Operating Costs to Produce California Diesel Fuel*

Along with the initial capital investment, annual O&M costs must also be considered. Most of the survey responses included annual O&M costs. Usually, these are costs associated with labor, material (such as catalysts, etc.), sulfur disposal, maintenance, insurance, and repairs associated with the new or modified equipment. When O&M costs were provided by the refiner, these numbers was used in staff's preparation of the cost estimates. However, when information for O&M costs were not included, staff conservatively estimated, based on available data from the U.S. EPA and the SCAQMD, that annual O&M costs would range from 10% to 20% of the capital expenditure.[88, 68] The O&M costs are estimated to range from $50 to $60 million per year for all California refineries.

Total annualized statewide refinery costs can be determined according to the following equation:

Annualized Statewide Refinery Cost = (*Capital Recovery Cost*) + (*Annual O&M Cost*)

Using this equation, the annualized statewide refinery costs of the proposed amendments are estimated to range from about $74 to $96 million.

5. *Total Annualized Costs to Produce California Diesel Fuel*

To determine the per gallon annualized statewide refinery costs, staff used the 2002 California on-and-off-road diesel fuel production[89] of approximately 2.9 billion gallons and an annual growth factor of 4 percent to grow California diesel production to a 2007 level of about 3.5 billion gallons (about 230 mbpd). Based on refiners' total annualized costs spread over 2007 diesel production, staff estimates that the annualized statewide refinery costs will be about 2.2 to 2.7 cents per gallon. These costs are shown in Table XVIII-2.

Table XVIII-2: Annualized Statewide Refinery Production Costs
(Based on California Diesel Fuel Production Only) [a,b]

Scenario	Capital Recovery Cost (cents/gallon)	O&M Cost (cents/gallon)	Total Cost (cents/gallon)
Low-Range	0.7	1.5	**2.2**
Mid-Range	0.9	1.7	**2.5**
High-Range	1.0	1.7	**2.7**

[a] Numbers may not be additive due to rounding.
[b] Based on California in-state production of 230 mbpd in 2007.

While the 2.2 to 2.7 cents per gallon is the average statewide refinery capital cost increase, individual costs to refiners will vary depending on the level of capital investment needed. A separate analysis of each refinery suggests that individual refiners may experience capital cost increases ranging from 0 to 11 cents per gallon to produce low sulfur diesel.

6. Production Costs to Produce Both California & Federal Low Sulfur Diesel Fuel

In considering the potential capital and O&M costs on a per gallon basis, it is relevant to note that while California refineries will incur costs to comply with the proposed amendments, a significant amount of these costs will be incurred even without the proposed amendments. This is because California refiners, like refiners across the country, will have to produce on-road diesel fuel and meet a 15-ppmw sulfur limit.[88] Since California refiners have to change the on-road diesel fuel production that they export (predominately to nearby states such as Nevada and Arizona), these increased capital costs will in reality be recovered over this volume of exported fuel as well as the California production. As such, it is also appropriate to estimate California annualized refinery costs estimates using this volume as well.

Staff estimates that capital expenditures to comply with both the California and federal low sulfur diesel standards are expected to be about $215 to $300 million ($45 to $50 million more than California-only capital costs). Again, using the capital recovery factor of approximately 14 percent, the annualized capital costs to refiners to produce both U.S. EPA on-road and California low sulfur diesel fuel is estimated to be between $31 to $43 million. The annual O&M costs are expected to be in the range of $60 to $70 million. Summing these costs yields annualized refinery capital costs of $90 to $115 to produce both U.S. EPA and California low sulfur diesel. Using similar methodologies to grow diesel production, an annual growth factor of 4 percent was applied to the 2002 California and U.S. EPA diesel production of approximately 4.6 billion gallons (approximately 300 thousand barrels per day or 300 mbpd). Staff estimated total diesel production in 2007 of about 5.6 billion gallons (370 mbpd). Based on these numbers, it is estimated that annualized refinery capital costs will be between 1.7 to 1.9 cents per gallon. These costs are summarized below in Table XVIII-3.

Table XVIII-3: Annualized Statewide Refinery Production Costs
(Based on California and U.S. EPA On-Road Diesel Fuel Production) [a,b]

Scenario	Capital Recovery Cost (cents/gallon)	O&M Cost (cents/gallon)	Total Cost (cents/gallon)
Low-Range	0.5	1.1	**1.7**
Mid-Range	0.6	1.2	**1.8**
High-Range	0.8	1.2	**1.9**

[a] Numbers may not be additive due to rounding.
[b] Based on California in-state production of 370 mbpd in 2007.

On an individual basis, the estimated cost increase to large refiners ranges from zero to 6 cents per gallon. As can be seen, because of the larger volume of fuel produced, and with only minor increases in the capital costs involved, the per gallon cost, both average and overall diesel production as well as refinery specific, is less than the analysis based on California diesel fuel only.

7. California Distribution System Cost Estimates

Common carrier pipelines ship over 60% of the diesel fuel distributed in California. In addition to shipping diesel fuel (both California and U.S. EPA grades), pipeline operators also ship other petroleum products such as gasoline and jet fuel. Because the pipeline must be full of petroleum products at all times, these various products are shipped next to each other, resulting in a mixing of the interfaces of the two products which creates "transmix." Transmix generally cannot be blended back into either of its products of origin, and must be either downgraded into another product, or reprocessed into another product. Much of the transmix generated (both in California and the rest of the nation) can be downgraded into U.S. EPA off-road diesel fuel.

To minimize the amount of transmix generated during the shipping of petroleum products, pipeline operators attempt to carefully select the order in which they sequence the fuels in the pipeline, based on various fuel quality specifications and fuel properties of the products. While the shipping order of fuels is often left to the customer based on shipping needs, pipeline operators usually attempt to ship products with similar sulfur contents sequentially. This serves to minimize the amount of downgrading or reprocessing of transmix.

Based on industry estimates, no capital expenditures will be needed on pipeline distribution systems in California as a result of low sulfur diesel fuel. However, based on figures generated by the U.S. EPA, current practices by pipeline operators' result in approximately 2.2% of highway diesel fuel shipments to become transmix,[88] which is usually downgraded to lower grade products (such as U.S. EPA off-road diesel). As a result of their on-road low sulfur rulemaking, U.S. EPA estimates that the amount of transmix generated from on-road diesel fuel shipments and downgraded into lower grade off-road diesel will increase to 4.4% of highway diesel fuel shipments. Staff believes that in California, because both on- and off-road diesel fuels must meet the same diesel fuel standards, this value is conservative and that the percentage of transmix will most likely be lower. This is because the amount of low sulfur diesel fuel that will be shipped as a percentage of total diesel fuel shipped within the State represents a much larger percentage in California (approaching 100%). For comparison, this number is about 40 to

50 percent outside of California. However, staff has used U.S. EPA's figure to calculate the anticipated cost increase that could be expected from the increase in transmix generated and downgraded into U.S. EPA off-road diesel fuel. Based on about 160 million gallons of transmix assumed to be generated in 2007, this cost is estimated to be about $8 million annually and represents a cost of about 0.2 cents per gallon. Again, this is a worst case estimate.

8. Lubricity Additive Impacts

As discussed in Chapter XII, California refiners voluntarily additize their current on- and off-road diesel fuel to meet suggested requirements for proper lubrication. Currently, most refiners have been using the Scuffing Load Ball On Cylinder Lubricity Evaluator (SLBOCLE) test to determine if lubricity levels are adequate. As mentioned, since there are currently no government or industry standards, the costs associated with lubricity additives can vary. Based on survey responses, refiners indicated that the current costs to additize to suggested levels of lubricity ranged from 0.1 to 0.2 cents per gallon.

With the proposed amendments of a higher lubricity standard of 520 HFRR, refiners indicated that the cost for lubricity could double because of the need for increased additive use. Staff has conservatively estimated that lubricity costs could range up to 0.2 to 0.4 cents per gallon based on this information.

9. Fuel Economy Impacts

While hydro-desulfurization of diesel fuel tends to reduce the energy content of the fuel, existing vehicle test programs comparing California produced low sulfur diesel fuel to current "typical" California on-road diesel fuel demonstrated no loss in energy density or an associated vehicle fuel economy penalty. The "typical" fuel evaluated was a blend of commercially available California diesel fuels purchased from retail suppliers in volumes that approximated their particular market-share in the State. However, because fuel economy is directly proportional to energy density, more diesel fuel may be consumed on a per mile basis with low sulfur diesel fuel as compared to current diesel formulations. Staff estimates, based on figures developed by the U.S. EIA, that the fuel economy penalty of low sulfur diesel fuel could be as high as 0.5%, resulting in an energy penalty cost of up to 0.5 cents per gallon.[90]

10. Price Sensitivity

Based on past experience, and in consultation with CEC staff, staff has estimated that certain non-recurring costs may occur in the short-term (likely the first year of implementation). These costs could result from temporary limitations on supply and production. Staff estimates that these factors could result in potential first year costs of up to 1 cent per gallon.

11. Overall Cost Estimate

As shown previously in Table XVIII-1, in determining the overall cost estimate of the staff's proposal, the staff has estimated that first year costs of the proposed amendments will be 2 to 5 cents per gallon. However, after the first year, stability in the production of low sulfur diesel fuel, as well as optimization of the new and modified equipment installed by refiners, should result in lower costs. Based on this information, costs during the second year and beyond are expected to be about 2 to 4 cents per gallon, with the most likely cost to be closer to 2 to 3 cents per gallon (based on inclusion of federal on-road diesel fuel in staff's analysis). These costs are also summarized in Table XVIII-1.

D. Impacts of the Proposed Amendments on Small Refiners

To comply with regulatory changes that require the investment of capital at refineries, small refiners are typically impacted differently than large refiners. This is because small refiners have a much smaller economy of scale due to smaller volumes of finished product over which to amortize their installed capital costs and increased O&M costs. Also, the cost to borrow capital may be higher for small refiners as compared to large refiners. This is due to the smaller refiners' generally higher operating costs, lower rates of return, smaller company diversity, and the size of total assets.

Based on information provided by small refiners currently producing California on- and off-road diesel fuel, the anticipated capital costs for California small refiners to produce low sulfur diesel fuel are estimated to be about $40 million. In addition, these refineries could incur an increase in annual O&M costs of approximately $10 million. Assuming the other non-capital costs identified previously also apply equally to small refiners, the per gallon cost to produce low sulfur diesel fuel for small refiners is estimated to be about 11 cents per gallon. This is at the high end of the range of the anticipated costs for large refiners, estimated to be from 0 to 11 cents per gallon.

E. Other Studies on the Costs to Produce Low Sulfur Diesel Fuel

In developing the production cost estimates contained in this chapter, staff also evaluated several other existing studies on the cost impacts of producing low sulfur diesel fuel. These studies included evaluations by: Mathpro, the U.S. EPA, the SCAQMD, the National Petroleum Council (NPC), Charles River and Associates and Baker and O'Brien (CRA/BOB), EnSys Energy & Systems, Inc. (EnSys), and recently, by the Energy Information Administration (EIA), an agency within the US Department of Energy. A summary of these studies is presented in Table XVIII-4.

Table XVIII-4: Summary Of Existing Studies Evaluating Production Costs Of Low Sulfur Diesel

Study	Projected Cost (¢/gallon)	Date Released	Includes California?
Mathpro[91]	4.2 – 6.1	10/99 & 08/00	No
U.S. EPA[88]	4.3 – 5.1	12/00	Yes (PADD V [a])
SCAQMD[68]	1.3 – 3.5 [b]	09/00	Yes
NPC [92]	5.8	06/00	No
CRA/BOB[70]	6.2	08/00	Yes (results are national average)
EnSys[93]	4.2 – 4.4	08/00	No
EIA[90]	5.4 – 6.8	05/01	No
Mathpro[94]	5 – 8	02/02	No

[a] Petroleum Administrative District for Defense 5, which includes California.
[b] Capital costs recalculated using methodology described in Section C.1.

With the exception of the SCAQMD study, the other studies do not directly apply to California refineries for several reasons. These include the assumptions used for current on-road sulfur levels which are higher than in California, differences in existing refinery configurations (and the necessary refinery modifications to produce low sulfur diesel fuel) between California refiners and refiners in the rest of the country, and differences in the diesel volumes over which to amortize the necessary capital costs. The U.S. EPA study does include an analysis of Petroleum Administrative District for Defense (PADD) V, which includes California. The estimated costs for PADD V to produce on-road low sulfur diesel fuel ranged from 4.3 – 5.1 cents per gallon, which is slightly higher than staff's estimate. However, this is likely a result of the other PADD V refiners requiring additional desulfurization capacity, having higher average on-road sulfur levels, and also due to a lesser volume of fuel (which includes off-road and stationary engine uses) over which to amortize capital costs as compared to California. Also, while the CRA/BOB study included California refiners, the analysis of the impacts of low sulfur diesel fuel is on the impacts on the U.S. refining industry as a whole, and is not necessarily applicable to California refiners for the reasons just discussed.

The most applicable analysis of the potential impacts of low sulfur diesel fuel to California refiners has been developed by the SCAQMD in association with the development of their amendments to Rule 431.2. In their analysis, the SCAQMD estimated capital cost numbers of $70 to $315 million, and identified a projected volume of about 1.9 billion gallons of diesel fuel sold within the SCAQMD in 2006. However, in evaluating the cost numbers provided in the SCAQMD's analysis, it is necessary to recalculate the annual costs based on the methodology used in section C.1 of this chapter. When these costs are amortized according the ARB's methodology, and using the O&M costs developed by the SCAQMD, the costs to produce low sulfur diesel fuel in the SCAQMD are 1.3 – 3.5 cents per gallon, which is consistent with the anticipated capital costs identified in this report.

F. Effects of the Staff Proposal on Fuel Prices

With respect to retail diesel prices, it is very difficult to predict what will occur in the marketplace. Supply/demand, crude oil prices, competitive market considerations, etc. predominately influence diesel prices. However, it is reasonable to assume that over time, refiners will recover the increased costs of production in the marketplace. With this assumption, and the staff's estimate that the long-term increased production cost of low sulfur diesel fuel will be from two to three cents per gallon, it is reasonable to assume that this increase in production cost will, on average, be reflected in retail diesel prices. This assumption does not attempt to predict changes in fuel taxes and refinery product markup. In reality, since both the U.S. EPA and the SCAQMD have adopted requirements for the use of this fuel, most of the costs identified in this chapter will be incurred by refiners regardless of staff's proposal. However, this chapter assumes a conservative approach and has allocated the full economic effect of these various programs to the proposed amendments. Refiners will recover cost through increased diesel fuel markup if competitive conditions allow it. However, predictions of 2006 and beyond petroleum product markup and pricing are beyond the scope of this document.

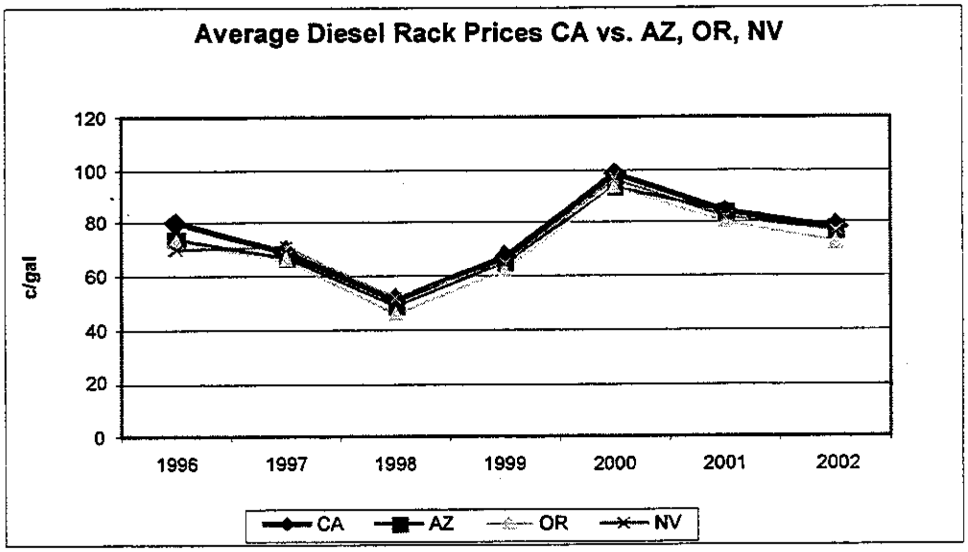
It is very difficult to predict the market for diesel pricing and volatility. However, the proposed amendments should not impact the ability of California refiners to supply sufficient quantities of diesel fuel to the California market. The ARB recent refinery survey suggests that sufficient diesel refinery capacity already exists. In addition, the implementation of the federal on-road low sulfur diesel regulations, adoption of the California diesel fuel regulations by the state of Texas, and the ability of out-of-state refiners to produce diesel fuel meeting California standards should provide even greater diesel fuel availability to the State. As a result, the overall diesel production system - consisting of California refineries and imports - should be no more subject to supply disruptions than today. In fact 2006 market conditions may be better able to readily adjust to any California diesel production requirements that occur in the future.

1. Evaluation of Fuel Prices Between California and Other States

a) Wholesale & Spot Prices

In comparing diesel fuel prices between states or regions, the best indicator of price is the wholesale diesel price. The wholesale price is the price of fuel before taxes and transportation charges have been applied. As can be seen in Figure XVIII-1, California wholesale diesel prices in California and surrounding states (Arizona, Nevada and Oregon,) have generally closely tracked one another.[95] In general, there is very little difference in wholesale diesel prices between California and surrounding states. This would suggest that there is very little difference in the market between California diesel fuel and U.S. EPA on-road diesel fuel between California and the surrounding states.

Figure XVIII-1
Diesel Wholesale Prices Between California and Surrounding States
(1996 through 2002)



Source – Oil Price Information Service (OPIS)

As shown in Table XVIII-5, over this same period, the average California wholesale diesel price was about 69 cents per gallon. This compares with an average wholesale diesel price of 67 cents per gallon in Arizona and Nevada, and an average wholesale diesel price of 65 cents per gallon in Oregon over this same period.

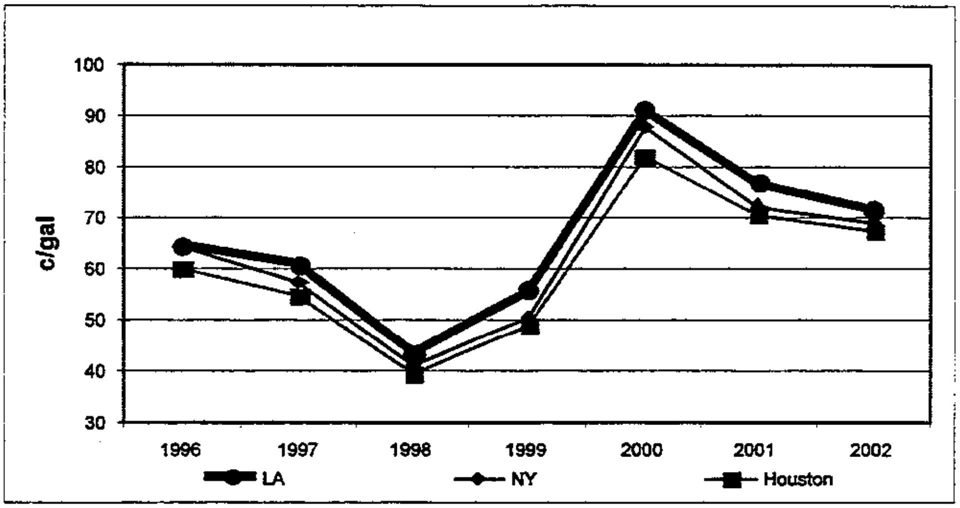
Table XVIII-5: Average Diesel Wholesale Price in California and Surrounding States (1996 through 2002)

Year	Average Wholesale Price (cents/gallon)			
	CA – Avg.	AZ – Phoenix	NV – Reno	OR – Portland
1996	77.75	72.19	70.26	71.33
1997	67.51	65.63	69.58	64.65
1998	49.35	47.22	50.03	44.13
1999	65.57	62.75	63.33	60.12
2000	96.43	92.06	94.90	91.64
2001	81.94	82.38	80.46	78.32
2002	76.57	75.73	75.35	70.81
1996 - 2002	68.75	66.80	67.49	64.78

Source – Oil Price Information Service (OPIS)

In evaluating prices between California and the rest of the nation, this same trend also applies. As can be seen in Figure XVIII-2, diesel spot prices in California have been comparable when compared to those around the nation (based on prices in New York Harbor and the Gulf Coast), and these prices have tracked consistently nationwide over this period.[96] Spot prices are similar to wholesale prices, where the spot price is usually the commodity price paid on any given day for "a one-time open market transaction" of fuel.

Figure XVIII-2
Diesel Spot Prices LA vs. NY and Houston (1996-2002)



Sources: EIA - DOE

As shown in Table XVIII-6, the differences in spot prices between Los Angeles and New York, for the period 1996 to 2002, was about 3 cents per gallon. Differences in diesel spot prices between Los Angeles and Houston (Gulf Area) for this same period were about 6 cents per gallon. Similar to the comparison between California and surrounding states, this would suggest that there is very little difference in the market between California diesel fuel and U.S. EPA on-road diesel fuel between California and the rest of the nation.

Table XVIII-6: Average Diesel Spot Price in California, New York, and Gulf Coast (1996 through 2002)

Year	Average Diesel Spot Price (cents/gallon)					
	LA	NY	Difference	LA	Gulf	Difference
1996	64.7	64.6	0.1	64.7	60.2	4.4
1997	61.1	57.5	3.6	61.1	54.9	6.2
1998	43.6	41.4	2.1	43.6	39.4	4.1
1999	56.1	50.6	5.5	56.1	48.9	7.2
2000	91.4	87.9	3.4	91.4	82.1	9.3
2001	77.2	72.5	4.7	77.2	70.9	6.4
2002	71.7	69.3	2.4	71.7	67.5	4.2
Average 1996-2002	66.5	63.4	3.1	66.5	60.6	6.0

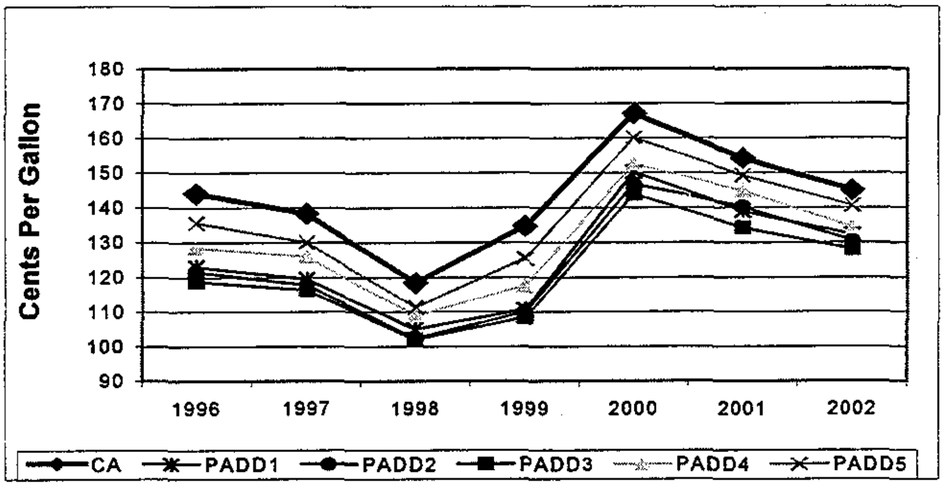
Sources: EIA - DOE

As can be seen by the above graphs, historically, diesel prices (excluding taxes and transportation charges) have remained relatively similar across the nation. As low sulfur diesel is implemented nationwide, staff believes that the price differentials discussed above may be mitigated as low sulfur diesel production costs in the rest of the country increase more significantly than in California (U.S. EPA estimated production costs estimates of 4 to 5 cents per gallon).[88] As a result, California wholesale prices in comparison with other States should remain consistent or even perhaps lower than they have been historically.

b) Retail Prices

Unlike diesel wholesale prices, retail prices also include both federal and state excise taxes, transportation costs, and the retailer's operating costs which likely include a percentage for profit. Aside from state and other government taxes, which are fixed, the transportation costs and retailer's operating costs, along with supply and demand and other competitive market considerations, create a market environment that has a large influence on the retail price. As shown in Figure XVIII-3 and Table XVIII-7, retail diesel prices vary significantly between Petroleum Administration Defense Districts (PADD).[96] In general, PADD 3 (representing the Gulf Coast region) diesel retail prices were the lowest while California, a part of PADD 5 (representing the Western United States), had consistently higher prices compared to the other regions.

Figure XVIII-3
Average Diesel Retail Prices in PADD I - V and California (1996-2002)



Source – Energy Information Administration

As shown in the bottom of Table XVIII-7, the average retail price from 1996 to 2002 for PADD 3 was about $1.21 cents per gallon while in PADD 5 the average retail price was about $1.36 cents per gallon, a 15 cent difference. During this same period, the average retail price in California was $1.43 cent per gallon, a 7 cent difference between California and the rest of PADD 5.

Table XVIII-7: Average Diesel Retail Prices in PADD's I Through V (1996 through 2002)

Date	PADD1	PADD2	PADD3	PADD4	PADD5	CA
1996	123.1	121.6	118.9	128.5	135.7	144.1
1997	119.5	117.9	116.3	125.9	130.0	138.3
1998	105.1	102.3	102.1	109.0	111.4	118.4
1999	110.7	110.1	108.4	117.6	125.5	134.8
2000	150.3	146.8	144.0	152.7	160.3	167.2
2001	139.0	140.2	134.2	144.9	149.3	154.3
2002	132.2	130.5	128.0	134.3	140.7	145.0
Avg. 1996 - 2002	125.7	124.2	121.7	130.4	136.1	143.2

Source – Energy Information Administration

c) Cost Benefits of the Proposed Low Sulfur Diesel Requirements

Staff has identified several cost benefits to the proposed amendments that have not been quantified in the above production cost estimates. These benefits will be felt both initially, and over the course of the life of the program.

Initially, diesel fuel users are expected to see a decrease in engine wear as a result of low sulfur diesel fuel. This is because fuel sulfur tends to produce acidic compounds that increases the corrosion wear of engine components. In addition, lower sulfur fuels should increase the life of diesel engine lubrication oil, as fuel sulfur tends to increase the acidification of engine lubricating oils resulting in loss of pH control. By reducing the diesel fuel sulfur content, it is expected that the interval between oil changes can be extended, leading to a cost saving to diesel engine operators. While it is difficult to quantify these benefits, we expect these benefits to be realized immediately upon implementation of the proposed amendments.

In addition, with the implementation of both new diesel engine certification standards as well as the retrofit of existing diesel engines, the use of emission control equipment will become much more commonplace in diesel powered vehicles and equipment than is the case today. The effects of low sulfur diesel fuel should improve not only the efficiency of this equipment, but also its durability. This should result in longer useful equipment life and decreased maintenance and replacement costs. These benefits are also difficult to quantify, and likely will not be realized until the new standards and retrofit requirements become applicable.

G. Cost of the Other Proposed Amendments

In addition to the use of low sulfur diesel fuel in California, staff's proposal also consists of requirements for minimum lubricity standards for current California diesel fuel, modifications to the procedures for certifying alternative diesel formulations, and modifications to the ARB's new diesel engine and diesel vehicle certification fuel.

1. Proposed Lubricity Standards for Current California Diesel Fuel

As discussed previously, California refiners voluntarily additize their current on- and off-road diesel fuel production to meet industry standards (meeting a minimum lubricity standard of about

3000 SLBOCLE). Based on information provided to the ARB by refiners, this cost is typically about 0.1 to 0.2 cents per gallon. This is consistent with the U.S. EPA's estimate of about 0.2 cents per gallon to additize on-road low sulfur diesel fuel nationwide.

Staff's proposed amendments would require that all California diesel fuel be additized to this level. While the proposed amendment would result in an additional regulatory requirement on the production of California diesel fuel, in practice there should be no additional costs associated with the proposed amendment since refiners are currently additizing to this level on a voluntary basis, and the proposed amendment will not impose any additional requirements above this level on refiners.

2. Proposed Modifications to the Procedures for Certifying Alternative Diesel Formulations

Staff expects that the costs associated with the changes to the procedures for certifying alternative formulations will be minimal. This is because the proposed amendments simply require that the reference fuel be better defined in terms of the properties of the commercial fuels that the refinery produces. This amendment should not require the refiner to perform any additional testing or formulating on the reference fuels during the certification process, nor does it establish any new criteria for certifying alternative formulations.

3. Proposed Modifications to the Certification Fuel for Diesel Engines and Vehicles

Staff also expects that the costs associated with the proposed amendments to the diesel engine and diesel vehicle certification fuel will also be minimal. This is because certification fuels are almost exclusively produced from specialty fuel providers, who blend fuels from a variety of petroleum blendstocks with precisely known properties. The change to the sulfur content range in the certification fuel should not hinder the ability of these specialty fuel providers to continue to produce certification fuels for costs that are similar to the costs already associated with these fuels. They will simply have to use blendstocks with lower sulfur contents. In conversations with specialty fuel providers, they have indicated that they do not expect the costs to produce diesel certification fuels will change significantly with the proposed amendments, as the U.S. EPA has also changed their diesel engine and vehicle certification fuel to require a lower sulfur content. However, even if there were slight increases in the cost to produce and supply diesel certification fuels, fuel costs as a percentage of total new engine or vehicle certification costs are minor.

H. Costs of Other Alternative Proposals Considered

In developing the proposed amendments, staff considered two alternative proposals. One would have not changed the existing California diesel fuel standard, and the other would have proposed a lower fuel sulfur content limit than is contained in staff's present proposal.

The first alternative, not changing the existing California diesel fuel standard, would not provide any significant cost savings to refiners, but would come at the expense of significant environmental benefits that the existing proposal provides. This is because, as stated previously, both the U.S. EPA and the SCAQMD have established rules for the sulfur content of diesel fuel. The U.S. EPA rule applies to all on-road diesel fuel sold in California, and the SCAQMD rule further applies to off-road and stationary source fuel sold in the South Coast Air Basin. These two rules apply to about 75% of the diesel fuel sold in California, and have the same costs associated with them as described in section C.1 of this Chapter. Since most refiners have indicated that they would convert all of their production over to low sulfur to comply with these regulations, the actual incremental cost of staff's proposal is very small. However, nearly 2 tpd of SOx and PM emission benefits from off-road and stationary sources, as well as the potential to retrofit these sources for additional PM and NOx control, would not be realized.

The second alternative considered would have further reduced the fuel sulfur limit below staff's current proposal. Staff's evaluation of this proposal concluded that reductions in fuel sulfur levels below 15 ppmw would result in a significant cost increase with little or no increase in benefits. The increased cost is associated with the difficulty in removing and maintaining sulfur levels as the concentration of sulfur approaches zero. Reductions in diesel sulfur levels below 15 ppmw would require the installation of duplicate refinery desulfurization capacity with no increase in diesel fuel capacity over which to amortize the additional costs. This would mean that the capital costs to comply with a lower sulfur level would likely be in excess of $600 million, and would likely increase diesel fuel production costs by about 8 cents per gallon. This is consistent with a Mathpro analysis that concluded that the cost to produce 2 ppmw sulfur diesel fuel would be 9 cents per gallon[91]. The reason that staff would expect the production costs to be near the upper bound is that refiners would not be able use additional desulfurization capacity on a regular basis. In addition, this additional desulfurization capacity would not translate into increased refinery capacity, and would likely require additional hydrogen production to supplement any new desulfurization capacity. Altogether, with these additional refinery costs incurred, the diesel particulate reduction efficiency of Diesel Particulate Filters (DPFs) would not appreciably increase.

I. Cost-Effectiveness

Most of staff's proposed amendments and associated costs occur in order to enable the application of diesel exhaust after-treatment technology to existing diesel powered engines and vehicles to provide significant future reductions in PM and NOx emissions. As such, it is not feasible to estimate the cost-effectiveness of staff's proposed amendments of these expenditures by using traditional methods commonly used in assessing air quality regulations.

XIX. Economic Impacts of the Proposed Amendments to the Diesel Fuel Regulations

This section describes the economic impacts of the production and use of low sulfur diesel fuel on the economy of the State, petroleum, agricultural, and transportation sectors, and operators of stationary diesel engines. In evaluating the economic impacts, staff used, where possible, both an estimate of the direct costs on a typical business, as well as the combined effects on the entire economic sector.

A. Potential Impacts on the California Economy

As discussed in the previous chapter, the proposed statewide requirements for the use of low sulfur diesel fuel are expected to have a minimal impact on the production costs of diesel fuel in California. This is due to existing requirements of the U.S. EPA and the SCAQMD, which apply to approximately 75 percent of the diesel fuel consumed in the state. Based on staff's analysis, the cumulative impact of these regulations could be expected to increase fuel costs to diesel end users in California by up to about $110 million per year in 2007. This is not expected to have a significant impact on the overall California economy.

The economy-wide impacts of the production of low sulfur diesel fuel were estimated using a computable general equilibrium (CGE) model of the California economy. This model is a modified version of the California Department of Finance's Dynamic Revenue Analysis Model (DRAM) developed by researchers at the University of California, Berkeley. The ARB model called E-DRAM describes the economic relationships between California producers, consumers, government, and rest of the world. The model uses the capital requirements of $70 to $250 million, and a worst case diesel fuel production cost increase of 4 cents per gallon to estimate economic impacts.

1. Potential Impacts on Petroleum Sector

As discussed in Chapter XVIII, diesel refiners are expected to recover their compliance expenditures in the long run. These expenditures include capital investments of $170 to $250 million dollars for equipment and hardware modifications, and annual O&M costs of $54 to $60 million per year.

Staff conducted an overall economic impact of the production of low sulfur diesel fuel on the California petroleum industry assuming that the industry is unable to pass on the compliance costs initially using E-DRAM. The model projects a minor contractionary impact on the industry. The industry output would fall by about $52 million or 0.2 percent and employment by about 61 jobs, or 0.3 percent.

2. Potential Impacts on Agricultural Sector

Diesel fuel is used in agriculture to power a variety of equipment, including irrigation pumps, tractors and combines, light-duty trucks, electrical generators, and refrigeration equipment. As such, diesel fuel is an integral part of the operation of a modern farm.

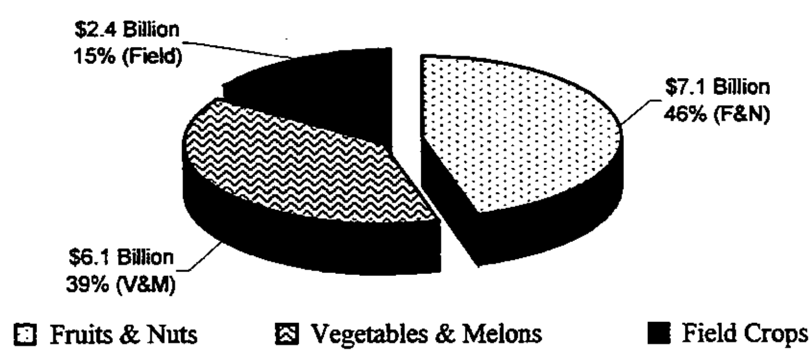
It is estimated that the total impact of the requirement to use low sulfur diesel fuel on the agricultural sector will increase diesel fuel costs by about $23 million annually. This represents a decline of about 0.05 percent in the value of the California agricultural production, and a 0.08 percent increase in agricultural operating costs.

In estimating the potential economic impacts of low sulfur diesel fuel on the agricultural sector, staff first identified the principal harvested commodities of the State, based on both the numbers of harvested acres as well as total commodity values. For the purposes of this analysis, harvested commodities are considered crops that are grown and either picked or harvested by hand or machine. Staff also identified principal livestock commodities, based on their commodity values, to estimate the potential economic impacts of low sulfur diesel to this category within the agricultural sector.

a) Harvested Commodities

Based on data from the California Department of Food and Agriculture (CDFA) California's total production value from agricultural commodities was $27.6 billion in 2001.[97] Of that, $15.7 billion, or approximately 60 percent, was attributable to harvested commodities. As shown in Figure XIX-1, harvested commodities can be broken down into three categories. Figure XIX-1 shows the gross product income from each category in 2001. Harvested commodities include fruits & nuts, such as almonds, strawberries, and grapes; vegetables & melons, including cantaloupe, tomatoes, and lettuce; and field crops, such as cotton, wheat, and hay. These designations are based on a categorization scheme used by the University of California, Davis (UCD) Cooperative Extension. While these commodities are grown all over the state, they are predominately grown in the Central Valley.

Figure XIX-1 California 2001 Gross Harvested Agricultural Income



Source: CDFA 2002 Resource Directory

As part of staff's analysis, ARB staff obtained and evaluated information from studies developed by the UCD Cooperative Extension Department. These studies contained information on typical fuel costs for each of the studied commodities on a per acre basis and total operational costs to produce each of the commodities.[98] With this data, the percentage of costs attributable to both diesel and gasoline, as a portion of the total operating costs, for each commodity was determined.

Because many of the commodities had specific data from several different years, data was normalized and adjusted for inflation to year 2001 dollars based on inflationary factors from the Consumer Price Index (CPI).[99] In developing the potential impacts of the use of California low sulfur diesel on farmers, staff estimated that a 3 cent increase would be felt. Please refer to Appendix M for a more detailed explanation and complete breakdown of the commodities studied.

As can be seen in Table XIX-1, the three evaluated harvested commodity categories have a value of greater than 80% ($12.6 billion) of the total 2001 agricultural harvested commodities total of $15.7 billion. For each commodity category, the average diesel use, diesel fuel costs, total operational costs on a per acre basis, and impact of a 3 cent increase in diesel fuel cost are shown.

As shown in Table XIX-1, staff estimates that a 3 cent increase in diesel fuel will result in an overall average increase in total operating costs for harvested commodities of 0.05 percent. Specific agricultural impacts for each harvested commodity category are also shown in this table.

Table XIX-1: Impacts of a Four Cent Increase in Diesel Fuel Prices on Various Agricultural Commodities (2001 Values)

Crop Type	Value of Crop Sector Analyzed (Billions)	Average Diesel Use (gal/acre)	Average Diesel Fuel Costs[2] (per acre)	Average Total Operating Cost (per acre)	Average Diesel Cost Increase[3] (per acre)	Average Increase in Operating Costs (per acre)
Field	$ 1.7	23.2	$ 19.3	$ 511	$ 0.70	0.15%
Fruits/Nuts	$ 6.2	30.2	$ 25.1	$ 5,578	$ 0.91	0.02%
Vegs/Melons	$ 4.7	41.9	$ 34.8	$ 4,518	$ 1.26	0.04%
Total[1]	$ 12.6	33.1	$ 27.5	$ 4,176	$ 0.99	0.05%

[1] Total 2001 agricultural harvested commodity value of $15.7 billion dollars.
[2] Assumes 2001 average diesel wholesale costs of $0.83 per gallon.
[3] Assumes average diesel wholesale cost increase of 3 cents per gallon.

Because of differences in the manner and processes in which various types of crops are grown, diesel use ranges considerably from about 11 gallons per acre for prunes to about 81 gallons per acre for strawberries. Farmers growing commodities that use a higher amount of diesel per acre will have correspondingly higher diesel fuel costs on a per acre basis. Similarly, diesel costs as a percentage of total operating costs also varied widely from 0.3 percent (strawberries) to almost 7 percent for wheat. As can be seen from the example of strawberries, while diesel use on a per acre basis can be substantial for a particular crop, an increase in diesel fuel costs does not necessarily translate into a significant cost increase as a function of total operating costs. For strawberries, a 3 cent increase in diesel fuel costs represents only a 0.01 percent increase in total operating costs for strawberry growers. Similar results for other high diesel use crops such as nectarines and tomatoes used for processing were also observed.

In terms of each of the harvested commodity categories, fruit and nut growers have the highest product value of the three categories, valued at $7.14 billion. As can be seen in Table XIX-1, staff was able to capture 87 percent of that value, or $6.2 billion. When compared to the other categories, fruits and nuts had the highest average operating cost, on a per acre basis. At approximately $5,600 per acre, staff's analysis shows that operating costs can vary significantly between commodities, from $9,737 to $24,729, for nectarines and strawberries on a per acre basis. Staff estimates that a 3 cent increase in diesel fuel costs will result in a 0.02 percent increase in total production costs.

As can be seen in Table XIX-1, staff was able to capture 77 percent, or $4.7 billion of the vegetable and melon category total of $6.1 billion. Compared to fruit and nut growers, vegetable and melon growers have a slightly lower average operating cost of approximately $4,500 per acre. On a per acre basis, the cost impacts of diesel will be greater for vegetable and melon producers because of a higher volume of diesel usage (almost 42 gallons per acre). On average, staff estimates that a 3 cent increase in diesel fuel will effect average total operating costs by 0.04 percent for the vegetable and melon category.

Within the field crop category, staff was able to capture $1.7 billion of $2.4 billion, or 70 percent of the category total. Among the three harvested commodities categories, field crops generally will feel the largest economic impact and percentage increase in total due to a 3 cent increase in diesel fuel prices. Because of tillage practices, soil types, and irrigation practices common with field crops, fuel costs as a percentage of total operating costs are significantly higher for field crops than for either fruits and nuts or vegetables and melons, even though the amount of diesel fuel used is only about 23 gallons per acre. Staff estimates total average operational cost increases of 0.15 percent for field crops.

b) Livestock Commodities

In California, livestock commodities total $7.3 billion of the total $27.6 billion state agricultural value. Of the livestock products and commodities, staff evaluated dairy milk and cow/calf beef production which accounts for approximately $6 billion of the livestock commodity total of $7.3 billion. This represents over 82 percent of the livestock sector. Data for milk production was obtained from the California branch of the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS).[100] However, no information was available from the California Agricultural Statistics Service (CASS) for the costs of cow/calf beef production in the state. As such, staff utilized source studies on beef production from the Oregon State University Extension Agricultural and Resource Economics Department in their analysis.[101]

ARB staff evaluated information from studies developed by CASS on typical fuel costs for the production of dairy milk. Studies developed by the Oregon State University Extension were used to analyze the typical fuel costs of cow/calf beef production. Staff has assumed that the costs of production of beef are similar in both California and Oregon. From these studies, staff was able to obtain the total operational costs to produce each of the commodities. From the operational cost, the percentage of costs attributable to diesel fuel use as a portion of the total operating costs for each commodity was derived. It should be noted that none of the source studies for dairy milk and cattle production neither defined nor categorized fuel costs (i.e. gasoline and diesel). Therefore, staff conservatively assumed that all fuel, lube, tractor, and truck costs were directly attributable to diesel fuel use.

Because most of the studies on cow/calf beef production had specific data from several different years, data was normalized and adjusted to reflect inflation to year 2001 dollars based on inflationary factors from the CPI.[99] Dairy milk data obtained from CASS already represented information for 2001. In further developing the potential impacts of the use of California low sulfur diesel on dairy milk and cattle producers, staff conservatively estimated a 3 cent increase would be experienced. Appendix M provides a more detailed explanation and complete breakdown of the commodities studied.

Based on available data, the average total operating cost for dairy farmers is $49 per cow per month, or $584 per cow per year. The cost impacts of diesel fuel use on dairy production as a percentage of total operating costs ranged from about two to almost eight percent with an average of nearly 6 percent. These impacts on dairy operations are similar to some commodities in the field crop sector such, as wheat. Assuming a 3 cent increase in diesel costs, the average percentage increase associated to total operating costs is less than 0.2 percent.

For beef producers, data analyzed from the Oregon University Extension studies also showed minimal production cost increases associated with a 3 cent increase in diesel fuel costs. The average impact on total operating costs was 0.14 percent. It should be noted that the method of reporting for cow/calf beef producers showed that operators with smaller numbers of cows (i.e. 50 cows) had relatively higher average costs when compared to operators that had much larger operations (i.e. 500 cows). While the average impact on total operating costs was about 0.14 percent, the costs for cow/calf beef operations ranged from about 0.04 percent for larger operations to 0.37 percent for smaller operators. Appendix M provides additional information about staff's analysis of these commodities.

c) Statewide Agricultural Sector Impact

The overall economic impacts of the production of low sulfur diesel fuel on the California agricultural sector were also estimated using E-DRAM. Since the agricultural sector uses significant quantities of diesel fuel in its operations, the increased costs associated with the use of low sulfur diesel fuel are expected to have a contractionary impact on the sector. The E-DRAM model projects that the use of low sulfur diesel fuel could reduce output in the California agricultural sector by an average of about $27 million and employment by 170 jobs. This represents a decline of about 0.05 percent in the value of the California agricultural production and a decline of 0.04% in employment.

3. Potential Impacts on Transportation Sector

Staff also estimated the costs of the use of low sulfur diesel fuel on a heavy-duty truck operator. This analysis was based on information in the ARB's EMFAC 2002 emissions model data.[102] These costs were based on an average daily fuel use of about 32 gallons per day for a heavy-duty diesel truck used in ARB's emission model EMFAC2002, operating 7 days per week and traveling about 70,000 miles annually. Using this data, staff estimates that a 3 cent per gallon price increase in diesel fuel could result in additional annual cost to the operators of heavy-duty trucks of about $350 per truck. It should be noted that as discussed earlier, this cost for on-road diesel fuel would be incurred even without any action by the Board because of the existing federal requirement for low sulfur on-road diesel fuel.

In addition, while the numbers derived using the data in EMFAC 2002, staff also estimated the costs to a heavy-duty truck owner/operator who drives longer distances than those used in the previous example. For this analysis, it is estimated an owner/operator drives 400 miles per day, at 4.6 miles per gallon, and operates their vehicle 5 days a week, 52 weeks per year. Under this scenario, annual costs of a 3 cent increase in diesel fuel prices would result in additional fuel costs of about $680 per year. Based on information from the American Trucking Association (ATA), fuel, equipment, and other costs, account for nearly 63% of total operating costs based on a typical heavy-duty 18 wheel tractor-trailer traveling 100,000 miles per year and earning $110,000 per year for a typical trucking company.[103] Using these figures for operating cost estimates, staff estimates that the use of low sulfur diesel fuel could impact total operating costs for a typical truck driver by 0.6 percent, based on a 3 cent increase in diesel prices.

It is important to note that while the requirements for low sulfur diesel fuel may result in likely diesel fuel production cost increases of 2 to 3 cents per gallon, these are not necessarily the cost increases that will be reflected in retail diesel prices. As described earlier, retail prices are a function of many different factors, and the impacts on retail prices is difficult to predict. However, as a result of the U.S. EPA's development of nationwide low sulfur diesel fuel standards, staff believe that the nationwide costs of producing on-road diesel fuel will increase more significantly outside of California, thereby "leveling the playing field" for California trucking and transportation companies as their fuel costs are compared to the rest of the nation. In addition, staff also believes that the ability of refiners and distributors to import diesel fuel during times of tight supply will be increased both with the nationwide availability of low sulfur diesel fuel and the other flexibility provisions contained in staff's proposal.

A macroeconomic impact analysis of the use of low sulfur diesel fuel on the California transportation sector was also conducted using E-DRAM. The model projects that the use of low sulfur diesel fuel would reduce output in the California transportation sector by approximately $26 million and employment by 258 jobs. This translates into a decline of less than 0.06 percent in the output value of the California transportation sector and its employment.

4. *Stationary Engines Retrofitted with Diesel Particulate Traps*

Because the Board has identified stationary diesel engines as a category of engines to be retrofitted with diesel particulate traps as part of the DRRP, staff has estimated the impacts of the use of low sulfur diesel fuel on the operators of these engines.

While there are some stationary diesel engines permitted to use high sulfur (greater than 500 ppmw sulfur) U.S. EPA off-road diesel fuel, in reality most stationary diesel engines in the state are currently using fuel meeting the California on-road diesel fuel standards. This is because very limited quantities of U.S. EPA off-road diesel fuel are distributed and available for use within California. For stationary diesel engine operators who are currently using California on-road diesel fuel, the cost impact from the use of low sulfur diesel fuel is expected be 2 to 3 cents per gallon.

5. *Taxable Diesel Fuel Sales*

The requirements for the use of ultra low sulfur diesel fuel in California are also not expected to have any impact on taxable diesel fuel sales in California, nor are they expected to shift future taxable sales of diesel fuel to neighboring states.

As discussed in Appendix N, while there are incentives due to different excise tax rates between states for diesel fuel users to purchase out of state fuel, this does not appear to have had much impact on taxable diesel fuel sales in California. As can be seen in Figure XIX-2 and shown in Table XIX-2, taxable sales in California steadily increased over the period 1995 through 2001[104] from a daily average of 138 Mbpd in 1995 to an average of 173 Mbpd in 2001, an increase of 35 Mbpd or an annual increase of 3.9 percent. Similarly, Arizona, Nevada and Oregon also saw increases in taxable diesel sales during this same period, with Arizona's average taxable diesel sales increasing by 12 Mbpd (6.6 percent annually), Nevada's by 6 Mbpd (7.5 percent annually), and Oregon's by 4 Mbpd (2.7 percent annually).

Figure XIX-2
Taxable Diesel Fuel Sales from 1995 - 2001

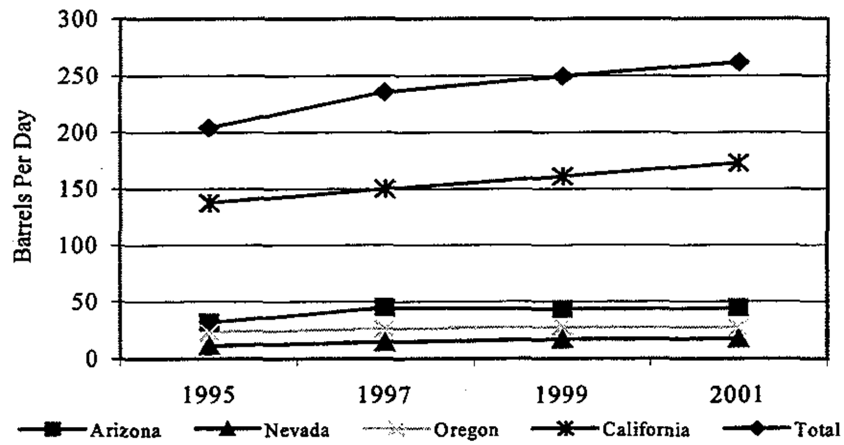


Table XIX-2: Taxable Diesel Fuel Sales in California and Nearby States from 1995 – 2001
(Thousands of Barrels)

State	1995		1997		1999		2001	
	MBPD	% of total	MBPD	% of total	MBPD	% of total	MBPD	% of total
Arizona	32	15.5%	45	19.1%	43	17.4%	44	16.9%
Nevada	12	5.7%	15	6.2%	17	6.9%	18	6.7%
Oregon	23	11.4%	26	11.1%	28	11.3%	27	10.4%
California	138	67.5%	150	63.6%	161	64.5%	173	66.0%
Total	204	100.0%	236	100.0%	250	100.0%	262	100.0%

* Numbers may not be additive due to rounding.

However, while as an annual percentage, the increase in taxable diesel sales were greater in Arizona and Nevada than in California, their relative proportions of the total taxable diesel sales in the four states as shown in Table XIX-2 changed less significantly. This indicates that no large shift in diesel sales is occurring from California to other states.

In considering these numbers, it is important to recognize several factors that could lead to the higher rate of increased taxable sales in Nevada and Arizona compared to California. Based on data provided by the US Census Bureau[105] for the periods 1990 to 2000, and shown in Table XIX-3, population increases in Nevada and Arizona have been significantly higher than California. Over this period, Nevada exhibited the largest increase in population at 6.6 percent, and Arizona saw an increase of 4 percent in its population. By comparison, California only saw a 1.4 percent increase in its population over this same period. This increase in population corresponds very closely with the increased taxable diesel fuel sales observed, as the larger populations living in Arizona and Nevada increase the demand for goods, commodities and services resulting in an increased use of diesel trucks to meet this demand.

Table XIX-3: Average Annual Percent Change in Taxable Diesel Fuel Sales versus Population in California and Nearby States

State	Average Annual % Change In:	
	Taxable Diesel Sales*	Population**
Arizona	6.6%	4.0%
Nevada	7.5%	6.6%
Oregon	2.7%	2.0%
California	3.9%	1.4%

* 1995 - 2001, US DOT - Federal Highway Administration
** 1990 - 2000, US Census Bureau

B. Economic Effects on Small Businesses

Government Code sections 11342 et. Seq. requires the ARB to consider any adverse effects on small businesses that would have to comply with a proposed regulation. In defining small business, Government Code section 11342 explicitly excludes refiners from the definition of "small business." Also, the definition includes only businesses that are independently owned and, if in retail trade, gross less than $2,000,000 per year. Thus, our analysis of the economic effects on small business is limited to the costs to diesel retailers and jobbers, farmers, and transportation companies. A jobber is an individual or business that purchases wholesale diesel and delivers and sells it to another party, usually a retailer or other end-user.

1. Jobbers and Retailers

If the wholesale price of diesel rose as a result of additional costs to refiners to comply with the production of low sulfur diesel fuel, retailers and jobbers would pay more for every gallon of diesel that they resell in the State. Any adverse impacts on retailers and jobbers would occur only if their profits decreased as a result of the higher wholesale prices. The decrease in profits would likely only occur if retail prices did not increase by the corresponding increase in wholesale prices, or if the demand for diesel declined as a result of higher retail prices. Historically, small changes in wholesale fuel prices have not had substantial impacts on diesel purchases. Also, over time, changes in wholesale prices have been passed on to consumers through changes in retail prices.

While the magnitude of any potential reduction in profits is difficult to estimate reliably for any particular wholesale price increase, large swings in price commonly occur in the current wholesale and retail diesel markets and are part of the current business situation faced by jobbers and retailers. While there may be a short-term delay in passing these costs on to consumers, even large swings in wholesale prices are reflected in retail prices in a fairly rapid timeframe.

2. Diesel Fuel End-Users

The potential economic effects of low sulfur diesel fuel requirements are not limited to jobbers and diesel retailers. End users, such as transportation companies and farmers, could be impacted. This is because these two economic sectors are large consumers of diesel fuel, and would likely be impacted by any increase in the costs to produce low sulfur diesel fuel.

As previously discussed, staff considered a likely scenario of a 3 cent increase in diesel fuel prices in the analysis of the potential economic impacts from staff's proposal and analyzed the impact on the agricultural and transportation sectors, and other diesel fuel end-users. Staff reviewed and analyzed a majority of the representative crops in the agricultural sector based on their economic worth. Staff estimated the economic impact on total operating costs to the agricultural sector to range from 0.02 percent to 0.15 percent, with the average impact to the sector of 0.05 percent. For the transportation sector, staff estimated the economic impact on operating costs for a typical truck operator could be about 0.6 percent, based on a 3 cent increase in diesel prices.

XX. NEED FOR NONVEHICULAR DIESEL-ENGINE FUEL REGULATION

This chapter addresses the need for regulating nonvehicular diesel-engine fuel to accommodate high-efficiency after-treatment of stationary, portable, and transportation refrigeration unit (TRU) diesel engines. We are proposing that the Board adopt an Airborne Toxicant Control Measure (ATCM) requiring the use of low-sulfur and otherwise complying CARB diesel in all nonvehicular diesel engines subject to ATCM's implemented as part of California's Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles, other than engines used to power locomotives and marine vessels.

A. Introduction and Background

In 1998, diesel PM was identified by the Board as a TAC in accordance with Division 26, Part 2, Chapter 3.5, Article 3 (section 39660 et seq.) of the California Health and Safety Code (H&SC). Board Resolution 98-35 identifies an estimated range of lifetime excess lung-cancer risk associated with diesel PM inhalation of 1.3×10^{-4} to 2.4×10^{-3} per microgram diesel PM per cubic meter of air exposure (1.3 to $24 \times 10^{-4}\ \mu g^{-1}\text{-}m^{3}$). Resolution 98-35 also directed ARB staff to begin the risk management process for diesel PM and other potentially harmful pollutants from diesel engines.

In the South Coast Air Basin about 70 percent of the lifetime cancer risk due to TAC exposure is attributable to diesel PM. Statewide diesel PM exposure has the potential to cause more than 500 cancer cases per million persons.

In September of 2000 the ARB approved California's Risk Reduction Plan (RRP) to reduce diesel PM emissions 75 percent by 2010 and 85 percent by 2020. A necessary element of the plan is the adoption of a diesel fuel sulfur limitation of 15 parts per million by weight (ppmw) to enable the use of sulfur-sensitive, after-treatment, emission-control devices on all diesel engines operating in California.

H&SC section 39665 directs the Executive Officer of the ARB to prepare a report on the need and appropriate degree of regulation for each substance determined to be a TAC. This chapter addresses the need for and appropriate degree of regulation of nonvehicular diesel-engine fuel for the control of diesel PM.

All diesel fuel sold or supplied in California for motor-vehicle use must have a sulfur content of 500 ppmw or less (13 CCR §2281). The actual sulfur content of California diesel fuel averages about 120 to 140 ppmw. In addition, the average aromatic hydrocarbon content of CARB diesel, except that produced by California small refiners, must not exceed 10 percent by volume, unless the fuel is produced as an ARB-certified alternative formulation (13 CCR §2282). Most California diesel fuel is produced as alternative formulation, averaging about 21 percent in aromatic content.

Some stationary engines are required by district rule or by permit to use California vehicular diesel fuel. Portable equipment registered under the state's portable equipment registration program (PERP) is also required to use California vehicular diesel fuel. In practice, TRU diesel engines, fueled in California, are normally fueled with California vehicular diesel fuel, but existing law does not require the use of the California fuel in TRUs. Locomotive and most marine diesel engines are examples of other applications that are not required to use California vehicular diesel fuel. Locomotive diesel engines fueled in California primarily burn diesel fuel complying with the U.S. EPA's sulfur content regulation (≤ 500 ppmw) for diesel fuel used in on-road engines. Passenger-fleet, marine diesel engines are required by statute to use California vehicular diesel fuel. It is believed that high-sulfur (≤ 5000 ppmw) diesel fuel is burned in most of the rest of the marine diesel engines fueled in California.

Reducing the sulfur level of California diesel fuel from an average of about 140 ppmw to 15 ppmw, in the absence of exhaust after-treatment, would have an expected impact on diesel PM emissions equal to a FTP-cycle specific emission reduction of about 0.004 g/bhp-hr. For nonvehicular diesel engines burning high-sulfur fuel, direct PM emission reductions before after-treatment would be about 0.1 g/bhp-hr. More importantly, improved after-treatment control efficiency (to over 90 percent control of diesel PM emissions) has been consistently demonstrated with low-sulfur (≤ 15 ppmw) diesel fuel. Low-sulfur fuel would allow after-treatment manufacturers to use more highly active catalysts, which operate effectively at lower temperatures and have a broader range of engine applications.

The U.S. EPA has published regulations which require that all diesel fuel sold for use in on-road vehicles have a sulfur content no greater than 15 ppmw, beginning June 1, 2006. U.S. EPA estimates that the overall cost, associated with lowering the sulfur cap from the current level of 500 ppmw to the proposed level of 15 ppmw, will be approximately $0.03 to $0.04 per gallon. U.S. EPA has proposed that diesel fuel for non-road engines meet the 15-ppmw-sulfur standard by 2010. The incremental cost for producing the low-sulfur fuel instead of high-sulfur (≤ 5000 ppmw) fuel was estimated to be about $0.05 per gallon.

The SCAQMD has amended its Rule 431.2, "Sulfur Content of Liquid Fuels," to require that all stationary source applications use low-sulfur (15 ppmw) diesel fuel, beginning June 1, 2004. All other diesel-engine applications must comply with the low-sulfur requirement by January 1, 2005, unless the ARB adopts the low-sulfur diesel fuel requirement, in which case the effective date becomes the same as that adopted by the ARB, but no later than June 1, 2006. Diesel fuel used in marine vessels and locomotives is exempted.

B. Proposed New ATCM for Nonvehicular Diesel-Engine Fuel

The ARB staff recommends that the Board adopt, as new section 93114 of title 17 of the California Code of Regulations, an ATCM for nonvehicular diesel fuel standards. The new regulation would provide that California nonvehicular diesel fuel is subject to all of the requirements of the ARB regulations governing the sulfur content, aromatic hydrocarbon content, and lubricity of motor vehicle diesel fuel, as if it were vehicular diesel fuel. There would be an exception for diesel fuel offered, sold, or supplied solely for use in locomotives or marine vessels. In accordance with H&SC section 39666(d), the regulation would provide that, no later than 120 days after its approval by the California Office of Administrative Law, each air quality district and air quality management district would be required either to implement and enforce the requirements of the proposed ATCM or propose its own qualifying ATCM to reduce particulate emissions from diesel-fueled vehicles. As described in the ARB's RRP for diesel

PM, when implemented, the new fuel standards would complement and enable the use of high-efficiency, PM emission-control devices for nonvehicular diesel engines.

C. Rationale for ATCM for Nonvehicular Diesel-Engine Fuel

The rationale for adopting regulations for nonvehicular diesel-engine fuel is that it is a necessary element for implementing the RRP. The RRP represents the staff's proposal for a comprehensive plan to significantly reduce diesel PM emissions. The basic premise behind the staff proposal is simple: to require all new diesel-fueled vehicles and engines to use state-of-the-art catalyzed diesel particulate filters (DPFs) and very low-sulfur diesel fuel. Further, all existing vehicles and engines should be evaluated, and wherever technically feasible and cost-effective, retrofitted with DPFs. As with new engines, very low-sulfur diesel fuel should be used by retrofitted vehicles and engines. In short, RRP contains the following three components:

1. New regulatory standards for all new on-road, off-road, and stationary diesel-fueled engines and vehicles to reduce diesel PM emissions by about 90 percent overall from current levels;

2. New retrofit requirements for existing on-road, off-road, and stationary diesel-fueled engines and vehicles where determined to be technically feasible and cost-effective; and

3. New Phase 2 diesel fuel regulations to reduce the sulfur content levels of diesel fuel to no more than 15 ppmw to provide the quality of diesel fuel needed by the advanced diesel PM emission controls.

For convenience, we briefly review the statewide diesel PM emission inventories. As presented in Table XX-1, PM emissions from nonvehicular diesel engines represent an increasingly significant portion of the total statewide diesel PM emissions. By 2010 diesel PM emissions from nonvehicular sources could compose about 40 percent of the total diesel PM emissions.

Table XX-1: Estimated Statewide Diesel PM Emission Inventories[106, a]

Year 2000		
Diesel Engine Category	Emissions (tons/year)	Percent of Total
Vehicular	19400	69
Nonvehicular[b]	8600	31
Total	28000	100
Year 2010		
Diesel Engine Category	Emissions (tons/year)	Percent of Total
Vehicular	13900	61
Nonvehicular[b]	8800	39
Total	22700	100
Year 2020		
Diesel Engine Category	Emissions (tons/year)	Percent of Total
Vehicular	10000	53
Nonvehicular[b]	8900	47
Total	18900	100

D. Alternatives to ATCM for Nonvehicular Diesel-Engine Fuel

There are two basic alternatives to the proposed amendment, leave the standard as is, or lower proposed standard.

Leaving the standard as is would seriously limit the implementation of the DRRP. As can be seen from table above, the emissions from nonvehicular sources is significant and is increasing as a proportion of diesel particulate matter emissions. Without low-sulfur diesel fuel, many of the control measure likely to be developed to implement the DRRP would not be technically feasible.

Adopting a lower standard is unnecessary, the DRRP clearly states that going beyond a 15-ppmw limit for the sulfur content of diesel fuel would not be cost effective. Going to a lower level would also, create a standard that is different that that which was adopted by the U.S. EPA for on-road diesel fuel.

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[a] Inventories do not include impacts of control measured adopted since October 2000.

[b] Stationary, portable, transportation-refrigeration-unit, locomotive, and marine diesel PM emissions

APPENDIX C

Diesel Fuel Aromatic Content and Exhaust Emissions of
Polycyclic Aromatic Hydrocarbons

I INTRODUCTION

This appendix discusses how changes in aromatic levels of diesel fuel affect the emissions of polycyclic aromatic hydrocarbons (PAH) in diesel exhaust (DE). Specifically, this appendix focuses on how reductions in diesel fuel aromatic content can reduce PAH and its derivatives. PAH belongs to a group of chemicals called polycyclic organic materials (POM).

A. PAH Chemistry

PAH consists of carbon and hydrogen and can be conceived as consisting of fused rings of benzene. These chemicals belong to the group of compounds commonly referred to as POM. POM includes zaarenes, oxaarenes, thiaarenes (and their derivatives), and transformation products of PAH, e.g. nitro derivatives and quinones. Azaarenes, thiaarenes and oxaarenes can be conceived as a PAH, where a carbon atom in the ring system is replaced by a nitrogen, sulfur or an oxygen atom, respectively. For the purposes of this discussion the term PAH will include all the above mentioned compounds. The chemical state, i.e. solid, liquid, or gas phase, of POM is directly associated with its molecular weight and ring structure. In diesel exhaust large molecular weight PAH (5 - 7 rings) are associated with particle matter (PM) and low molecular weight PAH (3 - 4 rings) are usually found in diesel exhaust vapor or gas phase. The major part of the mutagens in ambient air has been shown to be particle-associated (Fenger et al., 1990). Particulate matter in diesel exhaust is mainly caused by un-combusted fuel, while lubricant and other mechanisms provide a minor contribution to diesel PM.[1, 2]

PAH compounds have attracted considerable attention because of their known mutagenic and, in some cases, carcinogenic character (National Research Council, 1982[3]). POM is a class of compounds and derivatives is listed as a California Toxic Air Contaminant by the Office of Environmental Health Hazard Assessment (OEHHA), California EPA. Recently OEHHA staff reviewed PAH toxicity to identify hazards to which infants and children might be especially sensitive. This activity supported the Children's Environmental Health Protection Act (California SB25). OEHHA concluded "Apparently, children may be both more heavily exposed and also more sensitive to the toxic effects of POM[4]." One may conclude that children and infants are also more sensitive to PAHs and their derivatives.

B. Importance of Diesel Exhaust and PAH

Most industrialized countries limit emissions of four components of diesel exhaust: CO, HC, PM, and NOx. The first three are the result of incomplete combustion and NOx, is a byproduct of combustion. However, diesel exhaust (DE) is a complex mixture of thousands of gases and fine particles emitted by diesel-fueled internal combustion engines. The composition will vary depending on engine type, operating conditions, fuel composition, lubricating oil, and whether an emission control system is present. Gaseous components of DE include carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds, and numerous

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[1] Internal Combustion Engine Fundamentals, Heywood, 1988, ISBN 0-07-028637, McGraw Hill, NY, NY

[2] Transient Emissions Comparisons of Alternative Compression Ignition Fuels, SAE 1999-01-1117, Clark, et. al.

[3] National Research Council. (1982) Diesel cars: benefits, risks and public policy. Final report of the Diesel Impacts Study Committee. Washington, DC: National Academy Press.

[4] See OEHHA web page: http://www.oehha.org/public_info/public/kids/pdf/PAHs%20on%20Children%27s%20Health.pdf

low-molecular-weight hydrocarbons. Recent studies have focused on the toxicity of diesel exhaust and diesel particulate matter (DPM)[5].

Available data for on-road engines indicate that toxicologically relevant organic components of DE (e.g., PAHs, nitro-PAHs) emitted from older vehicle engines are still present in emissions from newer engines, though relative amounts have decreased[6]. Diesel engines, however, emit more PM per mile driven compared with gasoline engines of a similar weight. Over the past decade, modifications engines have substantially reduced particle emissions from both diesel and gasoline engines[7, 8]. However, PM emitted from newer diesel engines is still about 20 times greater than from comparable gasoline engines, on an equivalent fuel energy basis. Over 90 percent of the mass of these particles are less than 2.5 microns in diameter. Because of their small size, these particles are easily inhaled into the bronchial and alveolar regions of the lung. Many of these particles have been found to contain potent mutagens and carcinogens (see Chapter III, section E of "Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant" prepared by the staff of ARB and OEHHA[9]).

Available evidence indicates that there are human health hazards associated with exposure to diesel exhaust. The hazards include acute exposure-related symptoms; chronic exposure related non-cancer respiratory effects, and lung cancer. As new and cleaner diesel engines, together with different diesel fuels, replace a substantial number of existing diesel engines, the expected health hazards associated with diesel exhaust general should be reduced. New engine and fuel technology expected to produce significantly cleaner engine exhaust by 2007 (e.g., in response to new federal heavy duty engine regulations), significant reductions in public health hazards are expected for those engine uses affected by the regulations.

Reducing CO emissions to proposed regulatory levels is not a significant problem in diesel engine design. Reducing hydrocarbon emissions can be solved using proven methods used to improve fuel efficiency and reduce PM emissions. However, current federal and ARB regulations require simultaneous emission reductions in DPM and NOx emissions by 2006. This is major technical problem that requires a comprehensive approach to DPM control. Part of this control strategy includes changes in diesel fuel regulatory specifications.

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[5] Health Assessment Document for Diesel Engine Exhaust. USEPA EPA/600/8-90/057F. 01 May 2002. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC.
[6] Ibid. footnote #3
[7] Hammerle, RH; Schuetzle, D; Adams, W. (1994) A perspective on the potential development of environmentally acceptable light-duty diesel engines. Environ Health Perspect (Suppl.) 102:25-30.
[8] Sawyer, RF; Johnson. JH. (1995) Diesel emissions and control technology. In: Diesel exhaust: a critical analysis of emissions, exposure, and health effects. Cambridge, MA: Health Effects Institute, pp. 65-81.
[9] Rulemaking documents on identifying particulate emissions from diesel-fueled engines as a toxic air contaminant, http://www.arb.ca.gov/regact/diesltac/diesltac.htm.

C. Historical Trends in Diesel Fuel [10, 11]

Use of diesel fuel increased steadily in the second half of the 20th century. According to statistics from the Federal Highway Administration (1995, 1997), in 1949 diesel fuel was approximately 1% of the total motor fuel used, and in 1995 it was about 18%. Over the same time, diesel fuel consumption in the United States increased from about 400 million gallons to 26 billion gallons per year, an increase by a factor of more than 60. The chemistry and properties of diesel fuel have a direct effect on emissions of regulated pollutants from diesel engines.

The chemical makeup of diesel fuel has changed over time, in part because of new regulations and in part because of technological developments in refinery processes. EPA currently regulates on-road diesel fuel and requires the cetane index (a surrogate for actual measurements of cetane number) to be greater than or equal to 40, or the maximum aromatic content to be 35% or less (CFR 40:80.29). EPA recently finalized a regulation that will limit the sulfur content of on-road diesel fuel to 15 PPM starting in 2006 (U.S. EPA, 2000b). California has placed additional restrictions on the aromatic content of diesel fuel (California Code of Regulations, Title 13, Sections 2281-2282) and requires a minimum cetane number of 50 and an aromatics cap of 10% by volume, with some exceptions for small refiners and alternative formulations as long as equivalent emissions are demonstrated. Diesel fuel from larger refiners is limited to 10% aromatic content, and for three small refiners (a small fraction of diesel sales) to 20% aromatic content. The refiners can also certify a fuel with higher aromatic content as being emissions-equivalent to the 10% (or 20%) aromatic content fuels by performing a 7-day engine dynamometer emissions test. This method is chosen by most, if not all, California refiners, and so a typical California diesel fuel has an aromatic content above 20%. Emissions equivalence has been obtained through use of cetane enhancers, oxygenates, and other proprietary additives. Nonroad diesel fuel is not regulated, and consequently, cetane index, aromatic content, and sulfur content vary widely with nominal values for cetane number around 43, 31% aromatics, and sulfur approximately 3,000 PPM.

Studies measuring the emissions impact of changes in cetane number and aromatic content for roughly 1990 model year engine technology find that increasing the aromatic content from 20% to 30%, with an accompanying decrease in the cetane number from 50 to 44, results in a 2% to 5% increase in NOx and a 5% to 10% increase in total DPM (McCarthy et al., 1992; Ullman et al., 1990; Sienicki et al., 1990; Graboski and McCormick, 1996). These ranges may be reasonable upper bounds for the effect of changes in fuel quality on NOx and DPM emissions during the years 1960–1990. Railroad-grade diesel fuel is currently unregulated.

Fuel chemistry is also important for emission of particle-associated PAHs. In studies performed over more than a decade, Williams and Andrews of the University of Leeds have shown that the solvent-extractable PAHs from diesel particulate originate almost entirely in the fuel (Williams et al., 1987; Andrews et al., 1998; Hsiao-Hsuan et al., 2000). The PAH molecules are relatively

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[10] Comparitive Toxicity of Gasoline and Diesel Engine Emissions, SAE 2000-001-2214, Seagrave, et. al.

[11] U.S. Environmental Protection Agency (EPA). (2002) Health assessment document for diesel engine exhaust. Prepared by the National Center for Environmental Assessment, Washington, DC, for the Office of Transportation and Air Quality; EPA/600/8-90/057F. Available from: National Technical Information Service, Springfield, VA; PB2002-107661, and <http://www.epa.gov/ncea>.

refractory, so a significant fraction survive the combustion process and condense onto the DPM. These studies have been confirmed by other research groups (Crebelli et al., 1995; Tancell et al., 1995). There is a consensus among these researchers that pyrosynthesis of PAHs occurs only at the highest temperature operating conditions in a diesel engine. Under these conditions, most of the DPM and other pyrolysis products are ultimately burned before exiting the cylinder. These results indicate that emissions of PAHs are more a function of the PAH content of the fuel than of engine technology. For a given refinery and crude oil, diesel fuel PAH correlates with total aromatic content and T90.

Representative data on aromatic content for diesel fuels in the United States do not appear to be available before the mid-1980s. However, the decreasing trend in cetane number, increasing trend in T90, and the increasing use of light cycle oil from catalytic cracking beginning in the late 1950s suggest that diesel PAH content has increased over the past 40 years. Changes in PAH content of diesel fuel over time, as well as differences between diesel fuels used in different applications (on-road, nonroad, locomotive), may influence the hazards observed in exposed populations from different occupations.

D. Regulatory Context

United States, Europe, and Japan have regulated diesel and gasoline engines emissions separately due to differences in technology and combustion between each engine type. Diesels were initially regulated much less heavily than gasoline engines. As a result, diesel emissions control standards and technology lagged gasoline engine control standards and technology. As emissions from gasoline engines declined due to regulatory control measures, the relative share of diesel engine emissions has increased. This increase prompted the California Air Resources Board (ARB) and U.S. Environmental Protection Agency (EPA) to issue regulations for diesel fuel 1993. The "California" diesel fuel requirements are designed to reduce NOx emissions by 7% and DPM emissions by 25%. Current "federal" diesel fuel regulations do not reduce NOx emissions and only reduce PM emissions by 5 percent. Recently the State of Texas adopted diesel fuel regulations with diesel fuel requirements similar to California regulations. Today even greater regulatory control is being proposed for diesel exhaust. This emphasis in regulatory control is supported by numerous studies including an exhaustive 10-year scientific assessment process where ARB identified particulate matter from diesel-fueled engines as a toxic air contaminant (TAC) in 1988.

The ARB, EPA, other state and local agencies, engine and vehicle manufacturers, emission control manufacturers, and refiners have been working for the past decade to substantially reduce emissions from diesel engines. A significant area of research in this effort is determining the relationship between diesel fuel properties with diesel emissions. The chemistry and properties of diesel fuel have a direct effect on emissions of regulated pollutants from diesel engines.[12,13] Researchers have studied the NOx and DPM effect of sulfur content, total aromatic content, polyaromatic content, fuel density, oxygenate content, cetane number, and T90 on emissions of regulated pollutants, (T90 is the 90% distillation point temperature).

[12] Strategies and Issues in Correlating Diesel Fuel Properties with Emissions, EPA420-P-01-001, July 2001.This appendix extensively cites this report.
[13] Ibid. footnote 2.

In late 1999, EPA issued its "Tier 2" motor vehicle emission standards, i.e., Control of Air Pollution From New Motor Vehicles, Tier 2 Motor vehicle Emissions Standards and Gasoline Sulfur Control Requirements, 64 Fed. Reg. 6698 (2000). The regulations focus on reductions in emissions most responsible for ozone and particulate matter pollution. Most importantly the regulations also set more stringent controls for PM, NOx, and HC emissions from diesel engines.

This staff discussion document describes technical issues related to an assessment of the effect of changes in diesel fuel parameters on the emissions of particulate matter (PM). This discussion is intended as a review of the current understanding of the relationship between diesel fuel aromatic content and emission of PAH in diesel exhaust.

1. National Regulation of Diesel Fuel Parameters

Various European and international authorities have established standards or limit values for air pollution components. With respect to the occurrence of carcinogenic PAH and other mutagens in air the regulators are faced with an extremely difficult situation as these compounds are present in complex mixtures with widely varying compositions and carcinogenic potencies depending on different sources and locations. Most often benzo(a)pyrene is used as a marker substance for the total carcinogenic potency present in ambient air in European regulations.

The Netherlands

In the Netherlands a draft (annual average) tolerable level of 5 ng/m^3 and an acceptable level of 0.5 ng/m^3 for the benzo(a)pyrene content in the outdoor air has been given in the Environmental Programme 1988-1991 (Montizaan et al., 1989).

Germany

In Germany The Umwelt Bundes Amt has stated that "Since dose-effect relationships for man do not exist, the recommended value is based on technical and economic feasibility". In view of the concentrations occurring in Western European cities an annual average of 10 ng/m^3 benzo(a)pyrene is used as an "orientating value". This value should be feasible, considering the values in other countries (Montizaan et al., 1989).

US-EPA

The US-EPA in 1984 has proposed to regulate PAH in the outdoor air by means of emission limits instead of determining a recommended value for PAH in the outdoor air.

World Health Organization (WHO)

The WHO (1987) states that because of the carcinogenic properties of PAH a safe level cannot be recommended. Various risk assessments are given using benzo(a)pyrene as an indicator. Based on benzene soluble fractions of coke oven emissions, a risk of lung cancer is given of 9x10-5 per ng benzo(a)pyrene per m^3 at lifetime exposure. It is clearly stated that this estimation is related to a mixture of PAH and other carcinogens similar to that occurring in coke emissions.

Denmark

The Danish Environmental Protection Agency has not established standards for PAH in ambient air. As PAH are carcinogenic compounds the levels should be as low as possible, and the Danish EPA regulates PAH in the outdoor air by means of emission limits for the various sources.

2. *US federal and State Regulation of Diesel Fuel Parameters*

Recently Texas, and other states have expressed interest in reducing criteria pollutant emissions by regulating diesel fuel properties in a manner similar to ARB diesel fuel regulations. The US EPA responded to this interest by attempting to quantify the emission effects of diesel fuel parameter changes[14]. Federal law and regulations control sulfur and aromatic content and the cetane index of highway diesel fuel introduced into commerce as of October 1, 1993[15]. Except for California[16] no state had regulated similar aspects of diesel fuel until April 2000, when Texas adopted its Low Emission Diesel (LED) rule for the Dallas metropolitan area[17], and later amended the same rule to expand the geographic scope of the covered area and to further restrict sulfur levels[18]. Like the California rule (implemented in October 1993) the Texas rule (to be implemented in April, 2005[19]) controls sulfur and aromatic hydrocarbon content of diesel fuel for both highway and nonroad engines; Texas also controls the cetane number of diesel fuel[20]. In its proposed SIP revisions, Texas claims the LED rule will provide significant reductions in emissions of oxides of nitrogen (NOx). In developing the emission reduction estimates, Texas assumed its LED fuel would be similar to California diesel fuel.

B. Overview of Current Research

1. *European Studies*

Danish Studies: A review of ambient air analysis confirmed that traffic emissions are the major sources for the presence of PAH, other PAC and mutagens in street air[21]. The Danish environmental study (Environmental Project # 447, 1999) confirmed that a significant reduction of PAH and mutagens took place during the period 1992-1996. The reduction of the PAH-concentration has been estimated to about 35%. It was concluded that 2/3 of the reduction is due to the use of the improved diesel quality and 1/3 to the increased use of catalytic converters. The concentration of benzo(a)pyrene turned out to be a poor indicator for the air pollution with carcinogenic and mutagenic components.

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[14] Strategies and Issues in Correlating Diesel Fuel Properties with Emissions, EPA420-P-01-001, July 2001.

[15] Clean Air Act § 211(i); 40 CFR § 80.29.

[16] Title 13 Calif. Code of Regulations, Sections 2281- 2282.

[17] Title 30 Texas Admin. Code, Chapter 114, Sections 114.6, 114.312-317, 114.319, adopted by the Texas Natural Resource Conservation Commission (TNRCC), April 19, 2000.

[18] Title 30 Texas Admin. Code, Chapter 114, Sections 114.6, 114.312-317, 114.319, as amended by the TNRCC, December 6, 2000.

[19] Texas has proposed revising the rule to delay implementation until April, 2005 http://www.tnrcc.state.tx.us/oprd/sips/houston.html.

[20] California does not set a regulatory standard for cetane number. However, it does require use of a reference fuel with a specific cetane number (identical to the Texas regulatory standard) in determining whether alternative formulations (which do not meet the 10% aromatics content standard) have equivalent emissions reductions. Alternative fuel formulations with equivalent emissions reductions can meet the California diesel fuel requirements.

[21] Impact of Regulations of Traffic Emissions on PAH Level in the Air; Evironmental project, no. 447, Nielsen, T., et. al., June 1999. www.mst.dk/udgiv/publications/1999/87-7909-281-0/html/kolofon_eng.htm.

The objective of this investigation was to determine whether the application of diesel fuel having a low distillation end point had affected the air levels of PAH and mutagens. These new diesel qualities were expected to reduce the emissions of particulates and soot (Karonis et al., 1998) and therefore, probably also the emissions of PAH and other mutagens (Westerholm and Egebäck, 1994). Most of the PAH in the diesel exhaust is carried over from the fuel and not formed by pyrosynthesis during the combustion process (Williams et al., 1989). After the introduction of the new diesel fuel occurred in Denmark a significant reduction in the levels of PAH and especially the mutagens was observed (Nielsen, 1996, Nielsen et al. 1995b and c).

EPEFE Study: The European Programmes on Emissions, Fuels and Engine Technologies (EPEFE) - Light Duty Diesel Study (SAE 961073) measured regulated and toxic emissions. The report covered work during the period between July 1993 and March 1995. The speciation measurements were made only for a single test of each fuel/vehicle combination, therefore "a statistical analysis...was not feasible." However, reductions in polyaromatics and density showed an average 2 to 10% reduction in PM. Reductions in diesel fuel density directly corresponds to reductions in diesel aromatic content. Therefore, one can infer that this and other follow up studies reinforce the conclusion that reductions in diesel aromatics decrease PM emissions.[22]

2. *ARB Studies*

ARB Study: The study performed for ARB tested three diesel fuels in a Cummins L10 engine. The three fuels included a pre-1993 diesel fuel, a low aromatic fuel (aromatics less than 10%, and an alternative formulation (Alternative fuel formulations with equivalent emissions reductions that can meet the California diesel fuel requirements[23].) Total hydrocarbon, NOx and PM emissions were all reduced for both the low aromatic fuel and the reformulated fuel compared to the Pre-1993 fuel. It should be noted that the PM emission reduction changes from the Pre-1993 fuel were deemed statistically significant[24].

3. *Recent Diesel Fuel Emissions Studies*

"Clean Diesel" Comparisons: Total PAH, including PAH derivatives, averaged between *.076 and 0.69 mg/mile* in the exhaust of a low-emitting diesel engine using <15 PPM sulfur CARB diesel fuel and a catalyzed regenerative diesel particulate filter. In comparison conventional diesel engines using CARB diesel averaged between *2.8 and 4.34 mg/mile* total PAH emissions.[25, 26, 27]

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[22] Comparisons of Exhaust Emissions from Swedish Environmental Classified Diesel Fuel (MK1) and EPEFE reference fuel, Westerholm et. al., Enviro. Sci. Technol., 2001, 35, 1748-1754

[23] Evaluation of Factors That Affect Diesel Exhaust Toxicity, Norbeck, J. M., et. Al., Contract No. 94-312, July 24, 1998.

[24] Significant at 95% confidence limit using Fisher's Protected Least Significant Difference Test.

[25] A Comparison of Emissions for Medium-Duty Diesel Trucks Operated on California In-Use Diesel, ARCO's EC-Diesel, and ARCO EC-Diesel with a Diesel Particulate Filter. Final Report. Durbin, T., Norbeck, J.M. (2002). National Renewable Energy Laboratory contract ACL-1-30110-01

[26] Speciation of Organic Compounds from the Exhaust of Trucks and Buses: Effect of Fuel and After-Treatment on VehicleEmission Profiles, SAE 2002-01-2873, Miriam Lev-On, et. al.

[27] Comparison of Exhaust Emissions, Including Toxic Air Contaminants, from School Buses in Compressed Natural Gas, Low Emitting Diesel, and Conventional Diesel Engine Configurations, SAE 2003-01-1381, Ullman T.L. et. al.

Literature Review of Diesel Fuels: This review describes typical Fischer-Tropsch, EPA, and CARB diesel fuel properties. The paper discusses how these fuel properties impact pollutant emissions, and draws together data from known engine and chassis dynamometer studies of emissions. The review shows that diesel fuels share a set of common properties and these properties can contribute to reductions in PM compared to conventional diesel fuel. Also, reductions in diesel aromatic content reduced NOx and PM emissions compared to conventional diesel fuel.[28]

Single Cylinder Research: Recent laboratory testing of a modern single-cylinder engine demonstrates that the composition of diesel exhaust organic compounds vary significantly according to engine design and as the engine load and/or speed are changed. The majority of organic compounds were observed at idling, light, and medium loads. Diesel exhaust organic compounds emission rates at high loads were negligible. This research supports the basis for changes in diesel fuel formulation to ensure reductions diesel exhaust PAH emissions for all engine types and operating regimes.[29, 30]

C. Monoaromatic versus polyaromatic effects

A number of studies investigated the emission impacts of subcategories of aromatic compounds. In these studies, the most typical approach was to separate monoaromatic compounds (hydrocarbons containing a single benzene ring) from polyaromatics (hydrocarbons containing more than one benzene ring). A smaller set of studies made further distinctions between mono, di-, and tri-aromatic compounds. In the studies that actually measured these subcategories of aromatics, some actually made efforts to control the test fuel levels of one subcategory of aromatics separately from another subcategory of aromatics. In most cases, the polyaromatics were specifically controlled while the monoaromatics were uncontrolled.

These studies offered evidence that different types of aromatic compounds may have different impacts on emissions, particularly for PM. Some studies also concluded that mono and polyaromatic compounds might exhibit different effects for NOx.

D. Application to nonroad fleet

Nonroad compression-ignition engines are an important portion of the diesel fleet and an important contributor to inventories of regulated pollutants. Therefore, in addition to understanding the correlation of diesel fuel parameters with emissions from highway engines, it is important to understand this correlation in nonroad engines. Most nonroad engines use technologies similar to those found in highway vehicle engines, although in a given year highway vehicle technology is generally more advanced. Research suggests that most technologies used in on-road fuel applications will exhibited a similar response in off-road applications. Thus, in most cases, the distinctions between nonroad and highway vehicle

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[28] Fischer-Tropsch Diesel Fuels – Properties and Exhaust Emissions: A Literature Review, SAE 2003-01-0763, Teresa L. Alleman and Robert L. McCormick.

[29] Effects of Fuel Properties and Source on Emissions from Five Different Heavy Duty Diesel Engines, SAE 2000-01-2890, Ken Mitchell

[30] Effect of Engine Operating Conditions on Particle-Phase Organic Compounds in Engine Exhaust of a Heavy-Duty Direct-Injection (D.I.) Diesel Engine, SAE 2003-01-0342, Chol-Bum Kweon et. al.

technologies may not be important for the purpose of evaluating relative emission effects of fuel changes.

There are some concerns that the type of operation that nonroad engines experience may be sufficiently different from the operation of highway vehicles that extrapolations based on highway driving, may not be applicable to nonroad. However, there are a variety of test cycles that could represent nonroad applications that are currently being evaluated. The current body of data on nonroad engine cycles is insufficient to indicate whether the effect of changes in diesel fuel properties will affect emissions differently for nonroad engines than for highway engines. On the basis of the information we currently have, then, we believe that the relative effects exhibited by changes in on-road diesel fuel are applicable to nonroad.

E. Effects of Vehicle Technology and Operation

As mentioned previously, results from various research groups demonstrated that the magnitude of any diesel fuel property alone was generally not a good indicator for projecting the amount of pollutant emissions. This was especially true for determining NOx emissions. The results showed that diesel fuel properties, engine technologies, and driving cycle all played interactive roles in determining the amount of pollutants emitted.

1. DI and IDI Engines

In the EPEFE study, an increase in density resulted in a slight reduction of fleet averaged NOx emissions, shown in Table VI.C.1-1. However, individual vehicle responses to density increase were not consistent directionally, even though this group of light-duty vehicles was tested under the same protocol and fuels. They also varied considerably in magnitude. When the density was reduced, emissions data from individual vehicle showed that the half of the fleet with electronic injection responded with increased NOx emissions, while the opposite effect was seen with the remaining half of the fleet. This varying behavior from the light-duty fleet was also seen with NOx emissions when the cetane number of the fuel was varied. As the cetane number was increased, the NOx emissions reduced for DI (mostly electronically controlled) fleet, while the NOx emissions increased for the IDI (mostly mechanically controlled) fleet. The investigators reported that DI vehicles were primarily tuned to control NOx with resulting trade off of the other emissions (e.g., PM, HC, and CO). Consequently, vehicles with electronically controlled injection generally showed higher levels of PM, HC, and CO emissions than mechanically controlled vehicles. Because the engine technologies played such an integral part in how fuel properties would affect emissions, the fuel property should not be taken alone in determining its impact on the pollutant emission levels.

Although the magnitude changes due to fuel effects were generally of the same order between the DI and IDI fleets in the EPEFE study, the DI and IDI fleets displayed a very different sensitivity in cetane number effects on PM emissions. The investigators observed that from PM emissions DI vehicles were about four times more sensitive than those were from IDI vehicles, percentage wise. Therefore, their study indicated that under certain circumstances, vehicle technology changes might play an even more significant role than fuel property changes in affecting the amount of pollutant emissions.

2. *Sensitivity of Vehicle Response to Engine Parameters*

This chapter has thus far focused on fuel parameter studies with little discussions on engine effects such as changes to engine calibration or operating conditions. However, two studies that focus on these effects offer important insights for interpreting the previously discussed studies.

a. *Engine Operating Conditions*

Beatrice et al carried out an engine study over a 2-liter, turbocharged, DI engine equipped with an EGR system23. The fuel matrix examined consisted of 12 different fuels. Focusing on the engine sensitivity to fuel quality in their steady state testing at various operating (e.g., load, speed, and ambient temperature) conditions, they indicated that the engine sensitivity to fuel quality changes was very different depending on both the operating conditions and the individual pollutant emission under examination. They noticed the sensitivity to fuel quality changes increased at low load and speed, especially for HC emissions. With respect to PM emissions, all test conditions were found to be relevant, while particularly higher sensitivity was noted at retarded timings and during cold operation. However, this was not true for NOx whose behavior was quite flat over varying test conditions. Their study stressed the importance of the interplay between the engine operating conditions and fuel properties on pollutant emissions.

This study clearly illustrated the complex relationships between various engine management components that could impact pollutant emissions. Even though advanced injection timing should lead to higher NOx emissions, the net effect due to an increase in fuel density was NOx reduction by the co-existence of the more dominant EGR effect. Thus, all aspects of the engine systems need to be taken together to assess fuel effects on emissions.

F. Conclusions

Research shows a consistent trend across studies that an reduction in aromatics content results in low PM and PAH emissions. The studies also showed that engines with different technologies would respond differently to changes in fuel properties. The varied engine responses may have partly attributed to inconsistencies among various findings in fuel effects on pollutant emissions. Various studies demonstrated that fuel properties effect on the extent of PAH emissions clearly depended on the engine design.

Unlike results for heavy-duty vehicles, research suggests difficulty of projecting changes in light-duty vehicle emissions as a function of diesel fuel parameters. Nevertheless, there is clearly some PM benefit associated with reducing aromatics. However, the magnitude of emissions reduction is highly uncertain without a full understanding of the specific vehicle design and configurations, and such assessment would require further analysis. Diesel fuel properties, along with existing engine design or vehicle technologies, operating conditions (load, speed, ambient conditions) as well as the driving cycles all play interactive roles in influencing the amount of pollutant emissions.

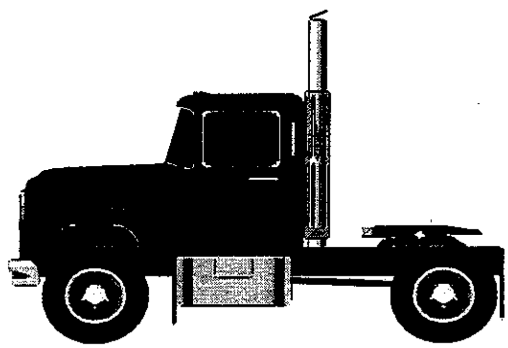
APPENDIX D

Staff Review of the Emission Benefits of California's Diesel Fuel Program

California Environmental Protection Agency

Air Resources Board

Staff Review of the Emission Benefits of California's Diesel Fuel Program



March 2003

Fuels Section
Criteria Pollutants Branch
Stationary Source Division
California Air Resources Board
1001 I Street, Sacramento, California

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Table of Contents

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I. Summary

In 1988, the Air Resources Board (ARB) staff estimated the benefits of the then-proposed regulations on the sulfur and aromatic hydrocarbon contents of motor-vehicle diesel fuel. The estimates, based on transient-cycle emission testing of only two engines, were 25-percent reduction in particulate matter (PM) emissions and seven-percent reduction in oxides of nitrogen (NOx) emissions. Also, sulfur-compound emissions would be reduced by the same percentage as the fuel sulfur reduction, assumed to be at least 80 percent.

The ARB staff has reviewed and analyzed the results of 35 different emission studies, involving 300 fuels and 73 engines, that have been conducted since the original estimates of the emission benefits were made. We find the original estimates continue to be valid, and are in close agreement with the estimates based on results of currently available emission studies. Our review determined that 31 studies were complete enough to be analyzed for PM and NOx reduction. Based on these studies the predicted emission reductions associated with California diesel fuel averaged about 26 percent and six percent, respectively for PM and NOx. Sulfur-compound emission reductions are now estimated to be at least 95 percent.

The results of these studies are quite consistent. In each study and for every engine configuration analyzed, emissions were predicted to decrease when fuel complying with the California diesel fuel regulations was used instead of conventional diesel fuel. These studies indicate that reducing sulfur content, aromatic hydrocarbon content, and specific gravity and increasing cetane number reduces PM emissions. They also show that reducing aromatic hydrocarbon content and specific gravity and increasing cetane number reduces NOx emissions from diesel engines.

The California diesel fuel regulations reduce emissions of PM and NOx because they limit the sulfur and aromatic hydrocarbons content of diesel or require changes to other properties that produce equivalent emission benefits. The studies reviewed confirm that this flexibility is possible because emission benefits accrue not only from the reduction in the content of sulfur and aromatic hydrocarbons in diesel fuel, but also from lower specific gravity and higher cetane number of complying diesel fuel. This interrelationship of multiple diesel fuel properties that affect emissions enables fuel producers to employ considerable flexibility in formulating California diesel fuel, so long as their alternative formulations provide the same environmental benefits.

II. Introduction

A. California Regulations

Motor vehicle diesel fuel sold in California must meet pollution-cutting specifications established by the Air Resources Board (ARB/Board). These specifications have resulted in California diesel fuel being the cleanest burning diesel in the United States. The ARB's diesel fuel regulations were adopted in 1988 and took effect in 1993. California diesel fuel results in significantly lower emissions than conventional diesel from diesel-powered vehicles and equipment: greater than 80 percent reduction in sulfur dioxide (SO_2), a 25 percent reduction in diesel PM, and a seven percent reduction in NO_x. California diesel fuel also reduces emissions of several toxic substances other than diesel particulate matter, including benzene and poly-nuclear aromatic hydrocarbons.

California's diesel fuel regulations contain two general provisions:

- A sulfur limit of 500 ppmw. This reduces emissions of both SO_2 and directly emitted particulate matter.
- An aromatic hydrocarbon content of ten percent for large refiners and 20 percent for small refiners. The lower level of aromatics results in reductions in emissions of both PM and NO_x.

As part of the 1988 diesel fuel rulemaking, the ARB adopted provisions that allow alternatives to the aromatic content if refiners can demonstrate through independent testing that an alternative diesel formulation provides comparable emission benefits. Most refiners have taken advantage of the flexibility provided by the alternative formulation procedure to produce diesel formulations that provide the same air quality benefits at a lower production cost and which enable greater production volumes. In 1990, the certification procedure for alternative formulations of diesel was modified to provide safeguards against certification of an alternative fuel that is inferior to the ten or 20 percent aromatic diesel fuel.

The use of California diesel fuel has significantly reduced pollution from diesel engines in California. California diesel is part of the state's core strategy of reducing air pollution through the use of clean fuels, and lower-emitting motor vehicles and off-road equipment.

B. Diesel Fuel Quality, Engine Technology, and Emissions

Diesel fuel quality is a qualitative term used to describe the combustion and emission performance of diesel fuel in a diesel engine. It is primarily a function of the fuel's sulfur content, aromatic hydrocarbon content, density (or specific gravity), and cetane number. Nitrogen content, poly-cyclic aromatic content, and distillation temperatures are additional diesel fuel quality characteristics. Generally, a fuel of superior fuel quality will be low in all of fuel quality properties except cetane number, which will be high. Cetane number indicates the readiness of a diesel fuel to ignite spontaneously. The higher the cetane number, the shorter the delay is between injection and ignition, and the lower the rate of pressure rise. Cetane number too low can result in poor combustion and high emissions under transient cycle engine operation. Any engine burning a fuel of superior quality will have lower emissions of NOx and PM relative to fuels of lesser quality burned in the same engine. Usually it is not too difficult to predict the relative NOx and PM emission behaviors of different diesel fuels, because the lower sulfur, lower aromatic hydrocarbon fuels, normally, have lower densities and higher cetane numbers.

Gaseous SO_2 and particulate sulfate emissions from diesel engines are directly proportional to the sulfur content of the fuel and the specific fuel consumption of the engine. An estimated 98 percent of the sulfur in diesel fuel is emitted from diesel engines as SO_2 and the remaining two percent is emitted as sulfate. Altogether, about 2.1 pounds of sulfur-containing compounds are emitted for every pound of sulfur in diesel fuel.[1] Sulfate emissions from diesel engines also contribute to the total PM emissions from diesel engines. The major portion of diesel PM emissions is comprised of carbonaceous material (soot) with the remainder comprised of condensed organic compounds, and sulfates, nitrates, and other condensed inorganic compounds. The sulfur content of diesel fuel has no direct impact on emissions other than sulfur-containing compounds from diesel engines. However, the refining processes of producing diesel fuel with lower sulfur content may result in other fuel composition and property changes, and the changes in these properties may cause the reduction of non-sulfur-containing emissions.

By design, an engine equipped with exhaust gas re-circulation (EGR) has lower NOx emissions than the same engine without EGR. This is true, regardless of the fuel burned. An undesirable effect of EGR is an increase in PM emissions, especially in high-load engine operation. For engines with EGR, our analysis of test data indicates that both NOx and PM are as sensitive to overall diesel fuel quality as for engines without EGR. As with PM emissions, gaseous hydrocarbon (HC) and carbon monoxide (CO) emissions also tend to decrease as the cetane number increases. For these reasons, the regulation of fuel quality will continue to be important in controlling emissions from advanced diesel engines of the future as well as being needed to maintain lower emissions from California's current motor-vehicle, stationary, marine, and other diesel engines.

C. World-Wide Fuel Charter

The automobile and engine manufacturers have an interest in promoting improved fuel qualities for gasoline and diesel fuels. Without appropriate enabling fuel-quality properties, manufacturers state that they will not be able to meet future vehicle and engine emission standards. The automobile and engine manufacturers' World-Wide Fuel Charter (December 2002) calls for diesel fuel with a very low sulfur content, an aromatic hydrocarbon content of no greater than 15 percent by weight, and a density of

[1] The sulfur dioxide molecule weighs about 2 times as much as the sulfur atom, and the sulfate complex, assumed to be $H_2SO_4{:}7H_2O$, weighs about 7 times as much as the sulfur atom.

no greater than 840 kg/m^3. It also calls for a cetane number of no less than 55, and a cetane index of no less than 52. Cetane index is an indicator of natural cetane number. The manufacturers are advocating the production of high natural cetane-number fuel, where the cetane number has been only moderately increased by the use of cetane improvement additives.

The certification of emission-equivalent formulations under the California diesel fuel regulations supports the concept that high natural cetane number with only moderate use of additives defines a good quality fuel. This will be especially true for the next generation of advanced emission control technologies.

The Texas Commission on Environmental Quality has adopted a requirement for the use of California diesel fuel in 110 counties in Texas. The requirement becomes effective in 2005. Outside of California and Texas (in the future) the cleanest burning diesel fuel may be found in Europe, as shown in Table 1. The Swedish urban diesel fuel specifications are not required standards. Instead the fuels are sold with a tax reduction to offset the increased cost of production. The European Union (EU) diesel fuel specifications are directed standards. It appears that the cetane-number specifications for Swedish urban diesel fuel are superseded by the EU cetane-number requirement of 51 for on-road use. Also, sulfur-content specifications for Swedish urban diesel will be superseded by the future EU sulfur maximum of 10 ppmw for on-road use. With their applicability to all motor vehicle diesel fuel sold in California, the California fuel standards represent the cleanest burning diesel fuel in the world, required statewide for on- and off-road use.[2]

Table 1. European Clean Diesel Fuel Specifications

Country or Countries	Sweden	Sweden	European Union
Applicability	Urban Class 1	Urban Class 2	On-road
Implementation Date	1991	1991	2000
Cetane Number	≥ 50	≥ 47	≥ 51
Dens. (g/mL) or Sp. Grav.	0.800 to 0.820	0.800 to 0.820	≤ 0.845
Aromatic Content (vol.%)	≤ 5	≤ 20	(poly-) ≤ 11 (wt.%)
Sulfur Content (ppmw)	≤ 10	≤ 50	≤ 10*

*Sulfur content maximum is 350 ppmw until 2005. Zero-sulfur (maximum 10-ppmw) requirement is phased-in beginning in 2005 with full market penetration by 2011.

[2] The Texas regulations will also require California diesel fuel for on- and off-road use.

III. Diesel Fuel Programs

A. California Diesel Fuel Certified Formulations

California's basic requirements for motor vehicle diesel fuel are 500 parts-per-million-by-weight (ppmw) maximum sulfur content and ten percent-by-volume maximum aromatic hydrocarbon content. However, 13 CCR 2282(g), "Certified Diesel Fuel Formulations Resulting in Equivalent Emissions Reductions," allows for higher maximum aromatic hydrocarbon contents for fuels that have been shown to be emission-equivalent to a specified 10-percent-aromatic reference fuel[3], as determined through prescribed laboratory engine testing and statistical comparison. The engine emission tests are typically performed on a Detroit Diesel Corporation Series-60 engine over a transient operation cycle.

Almost all motor-vehicle diesel fuel sold in California today uses the emission-equivalent alternative formulation provision to comply with the aromatic hydrocarbon regulation. Most of this fuel contains 2-ethyl-hexyl nitrate or similar cetane-number improver. Each certification includes a minimum of five fuel-quality property specifications: (1) the maximum sulfur content (not to exceed 500 ppmw); (2) the maximum total aromatic hydrocarbon content; (3) the maximum poly-cyclic aromatic hydrocarbon content; (4) the maximum nitrogen content; and (5) the minimum cetane number.

Table 2. Typical Characteristics of California Certified Diesel Fuel Formulations

Characteristic	Reference Fuel	Average of Specifications for Certified Formulations
Sulfur Content (ppmw)	≤ 500	250
Aromatic Content (vol. %)	≤ 10	22
PAH Content (wt. %)	≤ 1.4	4
Cetane Number	(natural) ≥ 48	54

Based on the certification data for the alternative formulations, California diesel fuel has an ethyl-hexyl nitrate treatment ratio of about 0.10 percent-by-weight. This means that the additized (treated) cetane number of the certified California diesel is about five higher than its natural (untreated) cetane number. As discussed later, this amount of additive is less than the lowest level added to the Heavy-Duty Engine Working Group (HDEWG) test program fuels. It also means that the nitrogen added to the fuel with the EHN treatment is about 75 ppmw on average. This amount of added nitrogen should not be significantly detrimental to achieving future NOx emission standards, such as the 0.20-g/hp-hr standard for heavy-duty diesel engines (HDEs). Overall, the cetane improvement, along with reduced aromatic hydrocarbon content and specific gravity,

[3] Small refiners are allowed a 20 percent-by-volume maximum aromatic hydrocarbon content or emission-equivalent formulation to a specified 20-percent-aromatic reference fuel.

should make the future PM emission standards, such as the 0.01-g/hp-hr standard for HDEs, easier to meet. Additional sulfur reduction, combined with catalytic after-treatment, will likely be the means of achieving future PM standards. The lower engine-out emissions of both NOx and PM due to the use of California diesel fuel should provide an additional compliance margins; which, in turn, should provide flexibility to engine and emission-control equipment designers to meet the NOx standards more easily.

B. CALIFORNIA DIESEL FUEL PROPERTIES

Estimated average diesel fuel properties, for both California and National (non-California, non-Alaska) on-road fuel were used in the work described in the next section to predict the emission benefits of the California diesel fuel regulations. The fuel properties, as presented in Table 3, are generally the same as those used by the United States Environmental Protection Agency (U.S. EPA) as California and on-highway non-California (non-Alaska) diesel fuel properties[4]. The additional properties of mono- and poly-cyclic aromatic contents were also estimated for these fuels. Overall, the estimated average fuel properties are similar to average fuel properties before and after implementation of the California diesel fuel regulations, determined from the Alliance of Automobile Manufacturer's (AAM)[5] fuel survey data for Los Angeles, as summarized in Table 4. The average properties of pre-1993 California diesel fuel are also shown in Table 3. A sulfur content of 2800 ppmw was used for pre-1993 California fuel. For comparison, Table 5 lists the fuel property values used in 1988 for predicting the future emission benefits of the California diesel fuel regulations.

C. FEDERAL PROGRAM

The U.S. EPA regulation (40 CFR 80.29) prohibits the sale or supply of diesel fuel for use in on-road motor vehicles, unless the diesel fuel has a sulfur content, by weight, no greater than 500 parts per million (ppmw). Beginning June 1, 2006 the sulfur limit is 15 ppmw. The lowering of the sulfur limit is intended to enable the use of catalytic exhaust after-treatment devices for controlling PM and NOx emissions. In addition, the regulation requires on-road motor vehicle diesel fuel to have a cetane index of at least 40 or have an aromatic hydrocarbon content of no greater than 35 percent by volume (vol. %). All on-road motor-vehicle diesel fuel sold or supplied in the United States, except in Alaska, must comply with these requirements. As previously stated, the average diesel fuel properties for national on-road diesel fuel sold outside of California and Alaska is shown in Table 3.

[4] Averages of Alliance of Automobile Manufacturers (AAM) annual-average fuel property data across years 1995 through 2000. California data actually represents Los Angeles only.
[5] Formerly known as the American Automobile Manufacturers' Association (AAMA).

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Table 3. Average California and National Diesel Fuel Properties

Property	California Average		National Average w/o CA and AK
	Pre-1993	1995-2000	1995-2000
Sulfur, ppmw	2800*	130	330
Cetane No.	45	52	45
Mono Aromatics, Wt.%	**	17	26
Poly Aromatics, Wt.%	**	6	10
Total Aromatics, Vol.%	36	22	34
Specific Gravity	0.856	0.837	0.850

* 500 ppmw or less in the South Coast Air Basin and Ventura County, effective January 1, 1985
** Not available

Table 4. AAM National Diesel Fuel Survey Data for Los Angeles

Before Implementation				After Implementation			
Period	Cet. No.[1]	Aromatic	Sp. Grav[2]	Period	Cet. No.[1]	Aromatic	Sp. Grav[2]
Win. '87	44.0	26.7	0.8545	Win. '94	51.5	23.5	0.8422
Sum. '87	47.0	37.2	0.8549	Sum. '94	52.4	24.2	0.8430
Win. '89	46.6	29.1	0.8559	Win. '95	53.2	23.7	0.8392
Sum. '89	45.9	30.0	0.8572	Sum. '95	53.6	23.4	0.8409
Win. '91	44.0	43.0	0.8587	Win. '97	50.8	20.1	0.8384
Sum. '91	46.1	41.2	0.8582	Sum. '97	53.8	20.4	0.8309
Win. '93	44.6	40.6	0.8590	Sum. '98	51.9	20.7	0.8333
Sum. '93	43.8	35.6	0.8571	Sum. '99	52.0	22.5	0.8353
Average	**45**	**36**	**0.856**	Average	**52**	**22**	**0.838**

[1] Cetane Number
[2] Specific Gravity

Table 5. California Diesel Fuel Properties Used in 1988

Property	Pre-1993	Post-1993
Sulfur	2800	500
Total Aromatics, Vol. %	31	10/20*

* 10 percent for fuel produced by large refiners and 20 percent for fuel produced by small refiners

IV. Studies and Results

A. Reviewed Emission Studies

The PM and NO_x emission reductions associated with California's regulation of the sulfur and aromatic hydrocarbon contents of diesel fuel were estimated in 1988, based on transient cycle testing of two different heavy-duty diesel engines. We have recently reviewed the emission reduction estimates relative to California's pre-regulation diesel fuel, using emission and fuel property data from 31 different test programs, involving a total of 67 different diesel engines and 282 different fuels. Table 6 summarizes the engines tested. The individual test-programs and study results are summarized in the Appendix.

B. Overall Emission Results

ARB staff has performed a "mixed-modeling" statistical analysis of emission data from the test programs to estimate the benefits of California diesel fuel. Based on data from each study and average California diesel fuel properties before and after regulation, the NO_x emission reduction estimates from each study's data vary from 0.3 to 15 percent, with an overall average of 6 percent ± 1 percent. The PM emission reduction estimates from each study's data vary from 1.8 to 88 percent, with an overall average of 26 percent ± 9 percent. Details are presented in Table 7.

The studies show that fuels with lower aromatic hydrocarbon content and specific gravity, and higher cetane number result in lower NOx emissions. Similarly, the studies showed that fuels with lower sulfur content, aromatic hydrocarbon content and specific gravity, and a higher cetane number result in lower PM emissions.

C. Heavy-Duty Engine Working Group Test Program

1. Description

In 1995, the U.S. EPA established a Heavy-Duty Engine Working Group (HDEWG) that consisted of the U.S. EPA, state agencies, oil and engine companies, academics, and other stakeholders. The main goal of the group was to assess the effect of diesel fuel properties on heavy-duty diesel engine exhaust emissions. Southwest Research Institute (SwRI) was in charge of conducting the experiment.

Overall, the experiment called for a fuel matrix design of 14 blends by controlling four fuel properties: cetane, density, mono- and poly-aromatic contents. The test engine was a Caterpillar 3176 heavy-duty diesel engine at the SwRI lab. This engine was equipped with an EGR in an attempt to simulate a 2004 prototype engine that meets the 2.5 gr/hp-hr NOx emissions standard. The engine was run in four configurations: EGR,

Table 6. Reviewed Studies: List of Engines

STUDY ID.	NO. OF FUELS	NUMBER OF ENGINES STUDIED						MODEL YEARS
		TOTAL	DETROIT	CUMMINS	CATERPILLAR	NAVISTAR	OTHER	
ACEA	5	1	1	0	0	0	0	1991
CARB-LOCO	3	1	1	0	0	0	0	1991
CARB-TOXIC	3	1	0	1	0	0	0	1993
EPEFE	11	12	0	0	0	0	12	1996
HDEWG II	19	4	0	0	4	0	0	1994, 2004
SAE1999-01-1117	7	1	0	0	0	1	0	1994
SAE1999-01-1478	22	1	1	0	0	0	0	1993
SAE1999-01-3606	2	1	0	1	0	0	0	1993
SAE2000-01-2890	10	4	1	3	0	0	0	1995, 1996, 2004
SAE790490	5	2	1	0	1	0	0	1979
SAE852078	6	1	0	0	1	0	0	1988
SAE881173	3	1	0	0	0	0	1	1988
SAE902172	11	1	0	0	0	1	0	1991
SAE902173	18	1	1	0	0	0	0	1991
SAE910735	5	3	3	0	0	0	0	1986
SAE912425	7	1	1	0	0	0	0	1991
SAE922214	8	2	0	0	0	0	2	1989, 1991
SAE922267	12	1	0	0	0	1	0	1993
SAE932685	12	1	0	0	0	0	1	1991
SAE932731	2	1	1	0	0	0	0	1991
SAE932734	14	1	1	0	0	0	0	1991
SAE932767	3	1	1	0	0	0	0	1991
SAE932800	5	1	0	1	0	0	0	1994
SAE942019	12	1	1	0	0	0	0	1991
SAE942053	4	3	1	0	0	2	0	1994
SAE961973	2	1	0	1	0	0	0	1990
SAE961974	6	3	3	0	0	0	0	1995
SAE970758	10	4	1	1	0	0	2	1991, 1994
SAE971635	9	3	0	0	0	0	3	1996
SAE972894	5	1	0	0	0	0	1	1996
SAE972898	7	1	1	0	0	0	0	1991
SAE972904	6	3	3	0	0	0	0	1993
VE 10	23	5	3	0	0	2	0	1994, 1998
VE-1_PHASE I	10	3	1	1	0	1	0	1987, 1988
VE-1_PHASE II	13	1	1	0	0	0	0	1991
TOTALS	**300**	**73**	**28**	**9**	**6**	**8**	**22**	

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Table 7. Reviewed Studies: Estimated Effects of Fuel Properties on Emissions

SUMMARY OF REVIEWED STUDIES ON DIESEL ENGINE EMISSIONS AND THE EFFECTS OF FUEL PROPERTIES				AVE. CA FUEL vs. AVE. PRE-REG. CA FUEL**	
STUDY ID.	NUMBER OF FUELS	FUEL PARAMETERS	NUMBER OF ENGINES	PREDICTED CHANGE PM (%)	PREDICTED CHANGE NOx (%)
ACEA	5	cet.no, S, arom, dist.Ts, sp.grav.	1	-43.4	-3.3
CARB-LOCO	3	cet.no, S, arom, dist.Ts, sp.grav.	1	-21.7	-6.2
CARB-TOXIC	3	cet.no, S, arom, dist.Ts, sp.grav.	1	-18.2	-4.1
EPEFE	11	cet.no, S, arom, dist.Ts, sp.grav.	12	-49.2	-6.0
HDEWG II	19	cet.no, S, arom, dist.Ts, sp.grav.	4	Not Meas'd	-5.3
SAE1999-01-1117	7	cet.no, S, arom, sp.grav.	1	-50.4	-4.2
SAE1999-01-1478	22	cet.no, S, arom, dist.Ts, sp.grav.	1	-3.9	-5.1
SAE1999-01-3606	2	cet.no, S, arom, dist.Ts, sp.grav.	1	-21*	-5.1
SAE2000-01-2890	10	cet.no, S, arom, dist.Ts, sp.grav.	4	-23.2	-5.4
SAE790490	5	cet.no, S, arom, dist.Ts, sp.grav.	2	-13.5	-5.7
SAE852078	6	cet.no, S, arom, dist.Ts, sp.grav.	1	-58.7	-5.3
SAE881173	3	cet.no, S, arom, dist.Ts, sp.grav.	1	Not Meas'd	Not Meas'd
SAE902172	11	cet.no, S, arom, dist.Ts, sp.grav.	1	-18.7	-6.4
SAE902173	18	cet.no, S, arom, dist.Ts, sp.grav.	1	-4.8	-5.8
SAE910735	5	cet.no, S, arom, dist.Ts, sp.grav.	3	-20.9	-0.3
SAE912425	7	cet.no, S, arom, dist.Ts, sp.grav.	1	-22.0	Not Meas'd
SAE922214	8	cet.no, S, arom, dist.Ts, sp.grav.	2	-68.3	-10.2
SAE922267	12	cet.no, S, arom, dist.Ts, sp.grav.	1	-73.3	-8.8
SAE932685	12	cet.no, S, arom, dist.Ts, sp.grav.	1	-88.3	-5.9
SAE932731	2	cet.no, S, arom, dist.Ts, sp.grav.	1	Aromatic Dif. Insignificant	
SAE932734	14	cet.no, S, arom, dist.Ts, sp.grav.	1	-11.8	-3.6
SAE932767	3	cet.no, S, arom, dist.Ts, sp.grav.	1	-1.8	-3.3
SAE932800	5	cet.no, S, arom, dist.Ts, sp.grav.	1	-71.7	-5.2
SAE942019	12	cet.no, S, arom, dist.Ts, sp.grav.	1	-14.6	-4.7
SAE942053	4	cet.no, S, arom, dist.Ts, sp.grav.	3	-2.5	-5.8
SAE961973	2	cet.no, S, arom, dist.Ts, sp.grav.	1	-5.8	-8.4
SAE961974	6	S	3	Identical Comp. Except S	
SAE970758	10	cet.no, S, arom, dist.Ts, sp.grav.	4	-17.0	-7.7
SAE971635	9	cet.no, S, arom, dist.Ts, sp.grav.	3	-5.4	-15.1
SAE972894	5	cet.no, S, arom, dist.Ts, sp.grav.	1	-7.7	-4.8
SAE972898	7	cet.no, S, arom, dist.Ts, sp.grav.	1	-6.8	-5.6
SAE972904	6	cet.no, S, arom, dist.Ts, sp.grav.	3	-5.2	-9.4
VE 10	23	cet.no, S, arom, dist.Ts, sp.grav.	5	-10.2	-6.7
VE-1_PHASE I	10	cet.no, S, arom, dist.Ts, sp.grav.	3	-31.7	-6.4
VE-1_PHASE II	13	cet.no, S, arom, dist.Ts, sp.grav.	1	-2.8	-6.8
TOTALS	**300**		**73**	**-25.6**	**-6.0**

* Average of extrapolations for cetane no., aromatic content, and sp. gravity

** See Table 2 for average fuel properties

EGR with fuel injection timing retarded, EGR with advanced timing, and no EGR. It should be noted that the EGR-equipped engine could not be tuned to meet the 2.5 g/hp-hr NOx emission standard in a transient FTP test cycle. However, the engine could meet the NOx standard in steady-state operation. Therefore, all test runs were performed at 8 different steady-state operational modes instead of the transient test cycle.

2. Results

The HDEWG Program found NOx emissions to be sensitive to both aromatic hydrocarbon content and fuel density when the test engine was operated with EGR. NOx emissions were found to decrease as aromatic hydrocarbon content decreased and as fuel density decreased. These results are typical of the results of other diesel fuel effects studies. Aromatic and other high-density hydrocarbons tend to burn hotter due to lower product mass and specific heat, hence lower product heat capacity, than for the lighter hydrocarbons. Higher peak combustion temperatures result in higher specific NOx emissions, given a constant thermal efficiency.[6]

Since aromatic hydrocarbon content and fuel density are physically related properties, these fuel properties are normally strongly correlated among diesel fuels, density decreasing with decreasing aromatic hydrocarbon content. Also, natural cetane number is highly correlated to fuel density, natural cetane number increasing with decreasing density. This is why cleaner burning diesel fuels tend to have relatively low aromatic hydrocarbon contents and lower densities and relatively high natural cetane numbers. However, the program found that NOx emissions stayed the same or increased mildly with the addition of the cetane improver, 2-ethyl-hexyl nitrate (EHN),[7] as aromatic content and other properties stayed the same. Since EHN contains nitrogen, which contributes to NOx emissions, albeit an undetermined amount, it is difficult to draw any conclusions regarding the impact of cetane number on NOx emissions for these tests.

Enough nitrogen was added through cetane improvers to the natural fuels to influence and reverse the sign of the NOx emission results as a function of cetane number. However, it should be noted that for the additized test fuels, all additive amounts were greater than the amounts typically added to California diesel fuel.

Unfortunately, the HDEWG Program did not study PM emissions. Steady-state testing does not provide an accurate prediction of transient test results for PM emissions.[8] However, the results of the HDEWG Program do verify the reduction of HC and CO

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[6] 2544 Btu/hp-hr / Specific Fuel Consumption (lbs/hp-hr) / Lower Heating Value (Btu/lb)

[7] The five base fuels with natural cetane numbers of 42.1 to 42.8 were improved with two different levels of EHN, creating five 47.7 to 48.1 cetane-number fuels at 0.14 to 0.20 percent-by-weight EHN and five 52.2 to 53.2 cetane-number fuels at 0.56 to 0.63 percent-by-weight EHN.

[8] PM emissions are more sensitive to fuel quality under transient operation.

emissions with increasing cetane number. Also, other studies indicate the increase in PM emissions with EGR and the sensitivity of PM emissions to fuel quality.

D. THE EFFECTS OF CETANE IMPROVERS

The studies reviewed indicate that there is a diminishing returns relationship between increased cetane improver concentrations and reductions in the emissions of NOx. In fact, at very high concentrations of cetane improver, with more nitrate additive, the nitrogen in the cetane improver may actually lead to increasing NOx emissions. However, these levels are significantly beyond any levels used in CARB diesel.

One study was specifically designed to examine the relationship between emissions and cetane improvers. The study report, entitled "The Effects of 2-Ethylhexyl Nitrate and Di-tertiary-butyl Peroxide on the Exhaust Emissions from a Heavy-Duty Engine," was published by the Society of Automotive Engineers (SAE 1999-01-1478). This study also examined whether the nitrogen in the (2-ethylhexyl nitrate, or EHN) cetane improvement additive contributes to NOx emissions. The study concluded, "the nitrogen in EHN does not contribute to NOx emissions at typical treat rates. [At the highest treat rate[9],] while not statistically significant, there was on average slightly more NOx emitted from EHN compared to DTBP treated fuels. Even at this high treat rate NOx emissions were still significantly lower than with unadditized fuel." This study indicates that, while the NOx emission benefits of cetane improvement are limited, increasing cetane number alone does result in lower NOx emissions.

[9] 0.75 percent-by-volume ≈ 0.85 percent-by-weight

V. NOx Emission Models

A. HDEWG Program Model

As part of the HDEWG Program described earlier, a mathematical model for NOx, was developed assuming a linear function of fuel properties, based on the data from the engine configured with EGR and normal injection timing. The independent variables are mono- and poly-cyclic aromatic hydrocarbon contents, density (kg/m^3), and cetane number. The mono- and poly-cyclic aromatic coefficients are about the same, the poly-cyclic coefficient being only 18 percent higher than the mono-cyclic coefficient.

As expected, the model predicts NOx emissions to decrease with decreasing aromatic hydrocarbon content and fuel density. The cetane number coefficient is positive, meaning increasing NOx emissions with increasing cetane number, which is the opposite of what is indicated by most other studies on NOx emissions and fuel property effects. This may be partly due to the nitrogen content of the cetane additive and the high concentration of additive used as described in section IV.C.2. This may also be partly due to the database being too limited as described below in section V.D. Table 8 summarizes the model coefficients, replacing the density coefficient with a specific gravity coefficient[10].

The HDEWG model may have limited applicability, because it is based on data from only one engine operated in one prototype configuration. Nevertheless, the model estimates about a 5-percent reduction in NOx emissions due to the use of California diesel fuel.

Table 8. Property Coefficients for NOx Emission Models

Model	Intercept	Mono-AHC (wt. %)	Poly-AHC (wt. %)	Total AHC (vol. %)	Sp. Grav.	Cetane No.	T50 (°F)
HDEWG[1]	-1.334	0.00646	0.00763	[3]	4.13	0.00337	[3]
EPA[2]	0.50628	[3]	[3]	0.002922	1.3966	[4] -0.002779	-0.0004023
EPA EGR[2]	-0.13383	[3]	[3]	0.002922	1.3966	[4] 0.001172	-0.0004023

[1] NOx (g/hp-hr) = Intercept + Σ(Coefficient * Fuel Property)
[2] NOx (g/hp-hr) = $e^{[\text{Intercept} + \Sigma(\text{Coefficient} * \text{Fuel Property})]}$
[3] Fuel property not used in model.
[4] For EPA models, the fuel property is (Cetane Number - Natural Cetane Number).

[10] Fuel Density (kg/m^3) @ 15 °C ≈ 1000 * Specific Gravity @ 60 °F/60 °F.

B. U.S. EPA UNIFIED MODEL

The EPA developed NOx emission models for five different engine technology groups. For predicting the emission benefits that the implementation of California diesel fuel regulation will have in Texas, the five models were then simplified into a single "default" model for engines without EGR and a model for engines with EGR. Total aromatic hydrocarbon content, specific gravity, cetane number difference[11], and 50-percent distillation temperature[12] (T50) are the independent variables in EPA's NOx models.

The EPA modeling estimates a 6-percent NOx reduction for engines without EGR and a 5-percent NOx reduction for engines with EGR, due to the use of California diesel fuel.[13]

C. U.S. EPA CETANE NUMBER MODEL

A recent analysis of data from NOx studies on additized fuels indicates that NOx response to cetane number boost is nonlinear. NOx emission reductions flatten out or, for high natural cetane-number fuels, begin to diminish at extremely high additized cetane improvement. This analysis is documented in the US EPA's draft technical report, *The Effect of Cetane number Increase Due to Additives on NOx Emissions from Heavy-Duty Highway Engines.*

EPA's cetane number (CN) model for NOx is

$$\ln(\text{NOx, g/hp-hr}) = 1.79883 - 0.015151*(\text{CN-Natural CN}) + 0.000169*(\text{CN-Natural CN})^2 - 0.006014*(\text{Natural CN}) + 0.000223*(\text{CN-Natural CN})*(\text{Natural CN}).$$

A linear model of emissions with cetane number improvement should only apply over a limited range of cetane number boost, no more than 5 or 6 cetane numbers. The HDEWG program's emission modeling does not adequately define the relationship between NOx emissions, natural cetane number, and additized cetane improvement. Superimposing a linear relationship over a range where the response is inherently non-linear may lead to results that are very difficult to interpret.

[11] Cetane Number Difference = Cetane Number - Natural (Unadditized) Cetane Number.

[12] The temperature at which 50 percent of the fuel volume is distilled

[13] With cetane number differences of 0.8 and 4.4, and T50s of 505 °F and 502 °F, for national on-road and California diesel fuels, respectively

D. ARB STAFF ANALYSIS OF U.S EPA DATABASE

The regression coefficients for the NOx model in the HDEWG study were generated from the test data that were based on one engine using different EGR and fuel injection timing configurations. The test data show a good relationship between NOx emissions, as the dependent variable, and all independent variables but cetane number. The results show that NOx emissions increase with increasing cetane number. This seemingly contradictory result may arise when the model building efforts are limited to a small number of fuels and only a single test engine. Correlation among fuel properties, particularly with those that were not controlled in the experiment, and insufficient data to account for engine-to-engine variation in emission response to fuel properties of lesser significance may be to blame. If the fuel properties are correlated, then it may be very difficult to properly interpret individual responses. Simply put, in a mathematical model designed to best fit an array of known values of a dependent variable, if one of two or more correlated independent variables becomes an under-estimator; then, another variable must become an over-estimator. For a relatively weak independent variable (e.g., cetane number) the model may reverse the sign of the actual physical effect. Furthermore, if there are latent variables, influential properties that are not included as part of the analysis, the individual fuel property effects could be influenced and lead to misleading interpretations.

To better understand how the results from the engine in the HEDWG study compares to engines from other studies the staff used the U.S. EPA Diesel Fuel Effects database to generate a model for each engine in the database. Regression coefficients were estimated using the log of the data and using a modeling approach similar to the one used in the HDEWG study. The HDEWG study evaluated density, cetane, and mono- and poly-cyclic aromatics. Since most studies included in the U.S. EPA Diesel Fuel Effects database did not separate mono- and poly-cyclic aromatics, total aromatics were used as a replacement. Estimates for each regression coefficient for each engine are presented in Table 8. From Table 8 it is evident that the aromatic hydrocarbon coefficients are consistently greater than zero and, for the majority of engines studied, the cetane number coefficients are negative and the specific gravity coefficients are positive.

Based on staff's analysis of the pooled data, as summarized in Table 9, the new cetane number regression coefficients for the HDEWG data are negative with respect to NOx emissions. This is different from the HDEWG results where the signs of the coefficients where not consistent. A benefit to this type of analysis is that it allows estimates to be generated for the other HDEWG engine operating configurations. It should be noted that all of the EGR engine configurations resulted in relatively high aromatic hydrocarbon and specific gravity coefficients, as indicated in Table 8. It should also be noted that, when the HDEWG engine was operating with EGR and either timing advanced or retarded, the cetane number improvement effect was strongly beneficial for NOx.

Table 9. Diesel Model Random Effect Standardized Coefficients
By Study and Engine

Study Id.	Engine*	Intercept	Cetane Number	Total Aromatic	Spec. Gravity	% NOx Change**
ACEA	DDC-SWRI	1.4696	-0.0069	0.0458	-0.0158	-5.0
CARB-LOCO	06RE001123	1.5000	-0.0124	0.0270	0.0126	-5.6
CARB-TOXIC	34705128	1.5374	-0.0061	0.0293	0.0097	-4.9
EPEFE	V_-2	1.4523	-0.0147	0.0186	0.0265	-5.9
	V_+2	1.7403	-0.0133	0.0186	0.0207	-5.3
	V_STD	1.6225	-0.0108	0.0226	0.0177	-5.3
	X_-2	1.4930	-0.0116	0.0251	0.0161	-5.5
	X_+2	1.7696	-0.0060	0.0318	0.0009	-4.5
	X_STD	1.6140	-0.0102	0.0213	0.0200	-5.2
	Y_-2	1.5275	-0.0056	0.0328	0.0046	-4.9
	Y_+2	1.6988	-0.0053	0.0320	0.0024	-4.6
	Y_STD	1.6209	-0.0056	0.0383	-0.0062	-4.7
	Z_-2	1.4409	-0.0090	0.0248	0.0185	-5.4
	Z_+2	1.8003	-0.0047	0.0359	-0.0060	-4.3
	Z_STD	1.6171	-0.0069	0.0393	-0.0083	-4.8
HDEWG II	HDEWG EGR	0.9077	-0.0011	0.0284	0.0266	-5.6
	HDEWG EGR T2	1.0392	-0.0192	0.0249	0.0239	-6.9
	HDEWG EGR T3	0.8195	-0.0214	0.0301	0.0197	-7.4
	HDEWG No EGR	1.3486	-0.0071	0.0255	0.0199	-5.4
SAE1999-01-1478	1999-01-1478-1	1.5424	-0.0114	0.0225	0.0188	-5.4
SAE2000-01-2890	04 SWRI/CAT 10.3	0.8730	-0.0173	0.0299	0.0201	-7.0
	95 CAT 3406E	1.6116	-0.0131	0.0220	0.0179	-5.5
	95 CUMMINS N14	1.7669	0.0070	0.0445	-0.0152	-3.3
	96 SERIES 50	1.8639	-0.0067	0.0313	-0.0004	-4.5
SAE902172	DTA466 PROTO	1.5612	-0.0183	0.0253	0.0121	-6.0
SAE902173	902173-1	1.3998	-0.0097	0.0259	0.0174	-5.5
SAE910735	AIR RESTRICTION	2.1797	0.0091	0.0342	-0.0073	-2.5
	BASELINE	2.3171	0.0087	0.0245	0.0052	-2.4
	THROTTLE DELAY	2.3188	0.0031	0.0264	0.0006	-2.8
SAE922214	3	1.8095	-0.0188	0.0135	0.0259	-5.8
SAE922267	922267-1	1.5594	-0.0264	0.0231	0.0138	-6.8
SAE932685	932685-1	1.7146	-0.0107	0.0276	0.0074	-5.1
SAE932731	S60 PROTO	1.3901	-0.0088	0.0404	-0.0055	-5.3
SAE932734	932734-1	1.4149	-0.0081	0.0318	0.0078	-5.3
SAE932767	932767-1	1.3883	-0.0176	0.0255	0.0158	-6.2
SAE932800	932800-N14	1.4263	-0.0138	0.0333	0.0031	-5.7
SAE942019	S60 PROTO	1.4594	-0.0131	0.0217	0.0214	-5.7
SAE970758	A	1.6292	-0.0061	0.0234	0.0177	-4.9
	B	1.6349	-0.0078	0.0205	0.0219	-5.1
SAE971635	8460.41-10	1.6165	-0.0137	0.0153	0.0288	-5.6
	8460.41-8.7	1.5462	-0.0110	0.0274	0.0113	-5.4
	8460.41-9.2	1.5763	-0.0083	0.0232	0.0183	-5.1
SAE972894	972894-1	1.5165	-0.0087	0.0296	0.0091	-5.2
SAE972898	S60-0/98	1.5286	-0.0129	0.0151	0.0308	-5.7
SAE972904	S60-0	1.5101	-0.0231	0.0165	0.0259	-6.6
	S60-3	1.3457	-0.0286	0.0186	0.0245	-7.3
	S60-5	1.2701	-0.0352	0.0223	0.0180	-7.9
VE 10	VE_10_1	1.5695	-0.0103	0.0277	0.0105	-5.3
	VE_10_2	1.3757	-0.0143	0.0229	0.0212	-6.0
	VE_10_3	1.5328	-0.0140	0.0174	0.0268	-5.7
	VE_10_4	1.4196	-0.0217	0.0165	0.0283	-6.6
	VE_10_5	1.3925	-0.0214	0.0187	0.0255	-6.6
VE-1_PHASE I	DDC 60	1.5605	-0.0204	0.0325	0.0003	-6.1
	NIC 7.3	1.5092	-0.0031	0.0568	-0.0324	-4.5
	NTCC 400	1.5032	-0.0025	0.0463	-0.0160	-4.5
VE-1_PHASE II	6R-510/6067G740	1.4995	-0.0254	0.0294	0.0048	-6.7

HDEWG Ave. -6.5%

w/ EGR

*Not all engines used, as some had insufficient data

**Computed as NOx emissions difference between CARB and pre-CARB diesels, relative to pre_CARB fuel, in percent

VI. Predicted NOx Emission Benefits

In order to put the new U.S. EPA regression equations in a better perspective, staff estimated the NOx emission benefits of the HDEWG engine for each of its four different operating configurations along with engines from other studies. Table 8 also presents the predicted NOx emission percent change associated with the use of a California diesel fuel relative to a pre-1993 diesel fuel, for each engine of each study. The first column lists the engines of each study in the pooled data, followed by linear regression coefficients as shown in the next three columns, as noted earlier. The last column shows the predicted NOx emission changes in percent. The range in predicted NOx emission benefits of California diesel fuel is 2 to 8 percent. As shown (highlighted) in the table, the HDEWG engine, operated in four different configurations, would produce an average NOx emission reduction of about 7 percent. This compares to the simple analysis in chapter III, which gave an estimate of about 6 percent for the NOx reduction.

Appendix A. SUMMARY OF STUDY RESULTS

ACEA	Kleinschek, G., K. Richter, A. Roj, M. Signer, H.J. Stein, "Influence of Diesel Fuel Quality on Heavy-Duty Diesel Engine Emissions," ACEA Heavy-Duty Diesel Truck Manufacturers, March 20, 1997, BE/ACEA/30	
CARB-LOCO	Fritz, S.G., "Diesel Fuel Effects on Locomotive Exhaust Emissions," Southwest Research Institute Final Report, prepared for California Air Resources Board in October, 2000.	For EMD and GE locomotives, CARB fuel reduced composite NOx emissions by an average of 3% and 4% from levels for on-highway fuel, respectively. Compared to the high-sulfur, nonroad diesel fuel, average composite NOx emissions were 6-7 percent lower with CARB fuel.
CARB-TOXIC	Treux, Timothy J., J.M. Norbeck, M.R. Smith, "Evaluation of Factors That Affect Diesel Exhaust Toxicity," report sponsored by the California Air Resources Board, July 24, 1998	Reductions in NOx emission rates with the low aromatic (Aromatic HC-Vol% of 10 max) and reformulated fuels (Aromatic HC-Vol% of 20-25) range from 2.6 to 7.6% compared to the pre-1993 fuel (Aromatic HC-Vol% of 33).
EPEFE	Signer, M., P. Heinze, R. Mercogliano, H. J. Stein, "European Programme on Emissions, Fuels and Engine Technologies (EPEFE) – Heavy-Duty Diesel Study," SAE 961074.	Fuel density was the most influential property to reduce NOx (3.6%). Other fuel properties contributed also: T95 (1.7%), polyaromatics (1.7%) and cetane number (0.6%). Polyaromatics was the only fuel property to reduce PM (3.6%).
HDEWG II	Matheaus, Andrew C., T. W. Ryan III, R. Mason, G. Neely, R. Sobotowski, "Gaseous Emissions from A Caterpillar 3176 (With EGR) Using A Matrix of Diesel Fuels (Phase 2)," Final Report under EPA Contract Number 68-C-98-169, September, 1999.	NOx decreases with decreases in either density or aromatic content. Cetane number has very little effect on NOx emissions.
SAE1999-01-1117	Clark, Nigel N., C. M. Atkinson, G. J. Thompson, R. D. Nine, "Transient Emissions Comparisons of Alternative Compression Ignition Fuels," SAE 1999-01-1117.	The biodiesel fuel and blends showed the ability to reduce PM markedly, but NOx rose slightly. The addition of isobutanol to the MG reduced PM further, but raised CO and HC albeit to levels still well below regulatory limits.
SAE1999-01-1478	Schwab, Scott D., G. H. Guinther, T.J. Henly, K. T. Miller, "The Effects of 2-Ethylhexyl Nitrate and Di-Teritary-Butyl Peroxide on the Exhaust Emissions from a Heavy-Duty Diesel Engine," SAE 1999-01-1478.	Cetane improvers EHN and DTBP lowered CO, NOx, and particulate emissions.
SAE1999-01-3606	Cheng, A. S., R. W. Dibble, "Emissions Performance of Oxygenate-in-Diesel Blends and Fischer-Tropsch Diesel in a Compression Ignition Engine," SAE 1999-01-3606.	Results showed that all test fuels with blends of DMM and DEE of 5, 10, 15, and 30% by volume, reduced PM when data was averaged across the nine engine operating modes.
SAE2000-01-2890	Mitchell, K., "Effects of Fuel Properties and Source on Emissions from Five Different Heavy-Duty Diesel Engines," SAE 2000-01-2890.	NOx emissions from three engines showed the same relative decrease with decrease in total aromatics. The effect of cetane number on NOx emissions was not consistent amongst the engines.

SAE790490	Hare, C. T., R. L. Bradow, "Characterization of Heavy-Duty Diesel Gaseous Particulate Emissions, and Effects of Fuel Composition," SAE 790490.	Regulated gaseous emissions (HC, CO, NOx,) from the two test engines differed from each other in a relatively consistent manner. Limited fuel effects were apparent in emissions from both engines, mostly between the No. 2 fuels as a group and the No. 1 fuel
SAE852078	Barry, E. G., L. J. McCabe, D. H. Gerke, J. M. Perez, "Heavy-Duty Diesel Engine/Fuels Combustion Performance and Emissions – A Cooperative Research Program," SAE.	Polycylic Aromatic Hydrocarbon levels increased with increasing fuel aromatic content, but changes below 35%aromatic were not significant as compared to changes up to 50%.
SAE881173	Knuth, Hans Walter, Hellmut Garthe, "Future Diesel Fuel Compositions – Their Influence on Particulates," SAE 881173.	The gaseous emissions, particularly CO and HC, are unfavorably influenced by low cetane numbers being associated with increased aromaticity in the diesel fuel. The emission of particulates is increased by low cetane numbers.
SAE902172	Sienocki, E., R. E. Jass, W. J. Slodowsky, C. I. McCarthy, A. L. Krodel, "Diesel Fuel Aromatic and Cetane Number Effects on Combustion and Emissions from a Prototype 1991 Diesel Engine, " SAE 902712.	Increasing cetane number and reducing aromatic content resulted in lower emissions of hydrocarbons and NOx. HC emissions were reduced by reducing fuel aromatic content or by increasing cetane number. A 10 cetane number increase was equivalent to either a 2 vol% reduction in poly-aromatics, or an estimated 4 vol% reduction in total aromatics.
SAE902173	Cunningham, Lawrence J., Timothy J. Henly, Alexander M. Kulinowski, "The Effects of Diesel Ignition Improvers in Low-Sulfur Fuels on Heavy-Duty Diesel Emissions," SAE 902173.	Cetane imporvers lower HC and CO emissions and, in some cases NOx and particulate emissions. CO and HC emissions decreased as cetane number increased.
SAE910735	Ullman, Terry L., David M. Human, "Fuel and Maladjustment Effects on Emissions from a Diesel Bus Engine," SAE 910735.	Except for HC emissions, regulated emissions were affected more by state-of-tune than by variation in test fuel properties. However, fuel properties did have significant effects on regulated properties, such that lower emissions were generally favored when the fuel had a low 90% boiling point, low aromatic content, high cetane number, and low sulfur level.
SAE912425	Lange, W. E. "The Effects of Fuel Properties on Particulates Emissions in Heavy-Duty Truck Engines Under Transient Operating Conditions," SAE 912425.	Increasing fuel sulfur content and/or fuel density increases total particulate mass. Increasing ignition quality did not have any effect on particulates emissions in this engine
SAE922214	Asaumi, Y., M. Shintani, Y. Watanabe, "Effects of Fuel Properties on Diesel Engine Exhaust Emissions Characteristics," SAE 922214	Engine test results show that reducing the fuel sulfur content decreases particulate levels. Enriching aromatic content in fuel causes an increase in NOx, CO, and THC emissions.

SAE922267	McCarthy, Christopher I., Warren J. Slodowsky, Edward J. Sienicki, Richard E. Jass, "Diesel Fuel Property Effects on Exhaust Emissions from a Heavy-Duty Diesel Engine that Meets 1994 Emissions Requirements," SAE 922267.	Reducing aromatic content reduced NOx and particulate emissions, but had no effect on HC or CO emissions. Increasing cetane number reduces all regulated diesel emissions species.
SAE932685	Lange, W. W., A. Schafer, A. Le'Jeune, D. Naber, A. A. Reglitzky, M. Gairing, "The Influence of Fuel Properties on Exhaust Emissions from Advanced Mercedes Benz Diesel Engines," SAE 932685.	Increasing cetane number reduced NOx emissions whereas total aromatics content had no influence on NOx emissions. Mono-aromatics content, distillation and cetane number did not affect particulates emissions.
SAE932731	Gonzalez D., Manuel A. Guillermo, G. Rodriguez, Roberto Galiasso, Edilberto Rodriguez, "A Low Emission Diesel Fuel: Hydrocracking Production, Characterization and Engine Evaluations," SAE 932731.	Fuel H (10 wt% aromatics), as compared to the high sulfur and high aromatics diesel fuel A, (37.5 wt% aromatics) showed lower HC, CO and NOx emissions.
SAE932734	Liotta, Jr., Frank J., Daniel M. Montaivo, "The Effect of Oxygenated Fuels on Emissions from a Modern Heavy-Duty Diesel Engine," SAE 93274.	The addition of an oxygenate to the fuel reduces CO and HC emissions. Non-regulated aldehyde and ketone emissions are also reduced with the addition of an oxygenate.
SAE932767	Liotta, Jr., Frank J., "A Peroxide Based Cetane Improvement Additive with Favorable Fuel Blending Properties," SAE 932767.	The peroxide based additive used to added to the fuels, reduced HC, CO, NOx and particulate matter emissions. Aldehyde and ketone emissions were also reduced. The peroxide additive lowered NOX emissions mores than the 2-ethlhexl nitrate cetane improvement additive.
SAE932800	Rosenthal, M. Lori, Tracy Bendinsky, "The Effects of Fuel Properties and Chemistry on the Emissions and Heat Release of Low-Emission Heavy-Duty Diesel Engines," SAE 932800.	The results of this study clearly show that aromatic content is the dominant fuel property that can be used to reduce emission levels.
SAE942019	Nandi, Manish K., David C. Jacobs, Frank J. Liotta, Jr., H. S. Kesling, Jr., "The Performance of a Peroxide Based Cetane Improvement Additive in Different Diesel Fuels," SAE 942019.	HC, CO, PM, and NOx are reduced significantly by treating a variety of fuels with either of cetane additives tested in this study.
SAE942053	Mitchell, K., D. E. Steere, J. A. Taylor, B. Manicom, J. E. Fisher, E. J. Sienicki, C. Chiu, P. Williams, "Impact of Diesel Fuel Aromatics on Particulate, PAH and Nitro-PAH Emissions," SAE 942053.	A catalyst lowered PAH emissions form 62%-76%. The Catalyst also Reduced HC by an average of 33% and CO by an average of 4%. The catalyst had no effect on NOx emissions
SAE961973	Geiman, Richard A., Patrick B. Cullen, Peter R. Chant, Philip N. Carlson, Venkatesh Rao, "Emission Effects on Shell LOW NOX Fuel on a 1990 Model Year Heavy Heavy-Duty Diesel Engine," SAE 961973.	Transient testing showed that the Shell LOW NOX fuel lowers NOX, HC and CO emissions. At steady-state testing, using the non-road cycle, showed that it decreased PM and HC emissions. Again at steady-state testing with a generator Shell LOW NOX Fuel increased HC and CO emissions.

SAE961974	Daniels, Teresa L., Robert L. McCormick, Michael S. Graboski, Philip N. Carlson, Venkatesh Rao, Gary W. Rich, "The Effect of Diesel Sulfur Content and Oxidation Catalysts on Transient Emissions at High Altitude from a 1995 Detroit Diesel Series 50 Urban Bus Engine," SAE 961974.	Lowering fuel sulfur from 500 to 5 ppm reduces total PM emissions by 6% without a catalyst. A larger PM reduction results from the use of an oxidation catalyst at 500 ppm sulfur than from lowering the sulfur in the fuel to 5 ppm.
SAE970758	Tamanouchi, Mitsuo, Jiroki Morihisa, Shigehisa Yamada, Jihei Lida, Takanobu Sasaki, Harufusa Sue, "Effects of Fuel Properties on Exhaust Emissions for Diesel Engines With and Without Oxidation Catalyst and High Pressure Injection," SAE 970758.	As cetane number increased, THC and CO levels decreased. Aromatic content and density exhibited a good correlation with NOx, with NOx levels exhibiting increase following corresponding increases in these two parameters.
SAE971635	Stradling, Richard, Paul Gadd, Meinrad Signer, Claudio Operti, "The Influence of Fuel Properties and Injection Timing on the Exhaust Emissions and Fuel Consumption of an Iveco Heavy-Duty Diesel Engine,"	To get a NOx reduction of 0.1 g/kWh a 0.3 degree crank retardation of the injection timing or a 6 kg/m^3 reduction in density or a 8.5% reduction in total aromatics can be done to achieve this goal.
SAE972894	Lange, W. W., J. A. Cooke, P. Gadd, H. J. Zurner, H. Schlogl, and K. Richter, "Influence of Fuel Properties on Exhaust Emissions from Advanced Heavy-Duty Engines Considering the Effect of Natural and Additive Enhanced Cetane Number," SAE 972894.	Increasing cetane number from 51 to 61 did not affect particulates or HC emissions over either test cycle, but reduced CO emissions by about 6-7%. The new test cycle showed improved emissions of NOx by about 1.6% NO emissions of about 0-8% were noticed due mainly to part load conditions in the test cycles.
SAE972898	Schabert, Paul W., Ian S. Myburgh, Jacobus J. Botha, Piet N. Roets, Carl L. Viljeon, Luis P. Dancuart, Michael E. Starr, "Diesel Exhaust Emissions Using Sasol Slurry Phase Distillate Process Fuels," SAW 972898.	HC, CO, and NOx emissions with the CARB fuel were lower by 40%, 14%, and 15% respectively, when compared to the US 2-D fuel. PM was the same with both fuels.
SAE972904	Starr, Michael E., "Influence on Transient Emissions at Various Injection Timings, Using Cetane Improvers, Bio-Diesel, and Low Aromatic Fuels," SAE 972904.	CARB fuel resulted in the highest NOx and PM levels at each timing in this study. CARB fuel had the lowest Nox level at each timing, but bio-diesel had the lowest PM.
VE 10	Spreen, Kent B., T. L. Ullman, R. L. Mason, "Effects of Fuel Oxygenates, Cetane Number, and Aromatic Content on Emissions From 1994 and 1998 Prototype Heavy-Duty Diesel Engines," CRC Contract No. VE-10. Project VE-10.	Increasing cetane number reduced HC, CO, and NOx. Reducing aromatic content lowered NOx. Oxygen in the fuel reduced CO and particulate emissions, but tended to slightly increase NOx emissions.
VE-1_PHASE I	Ullman, Terry L., "Investigation of the Effects of Fuel Composition and Injection and Combustion System Type on Heavy-Duty Diesel Exhaust Emissions," CRC Contract CAPE 32-80, Project VE-1.	Transient emissions of NOx, particulate matter, soluble organic fraction, and hydrocarbons increased as aromatic content increased from 10 percent to 40 percent. Emissions of NOx decreased as cetane number increased.
VE-1_PHASE II	Ullman, Terry L., R. L. Mason, D. A. Montalvo, "Study of Fuel Cetane Number and Aromatic Content Effects on Regulated Emissions from a Heavy-Duty Diesel Engine," CRC Contract No. VE-1, Project VE-1.	Reducing aromatic hydrocarbon content reduced transient emissions of NOx and particulate matter. Increasing cetane number reduced transient emissions of NOx, particulate matter, and hydrocarbons.

APPENDIX E

Staff Analysis of Future Emission Benefits of California's Diesel Fuel Program

VI. 2000-2020 Statewide Diesel NOx and PM Emission Reductions: Mobile Source

To estimate statewide NOx and PM emission reductions from on-road diesel vehicles and off-road diesel engines, CY 2000-2020, staff used the ARB's EMFAC2002 model (version 2.2) and OFFROAD model.

The on-road vehicles were categorized into four groups, uncontrolled and Tier I-III groups, based on the engine standards that apply to heavy heavy-duty diesel trucks, while the off-road engines were lumped together into one group. Table 10 shows this grouping, along with emission reduction factors by pollutant and source category. These factors were bifurcated according to diesel fuel regulations: the current (500 ppmw S and 10 percent aromatics) and proposed (15 ppmw S). For example, it can be seen in Table 10, in 2006 and beyond no additional NOx emission benefits from on-road vehicles were estimated due to the proposed 15 ppmw S diesel fuel regulations, but these vehicles would produce an additional 4 percent PM emission benefits, except in Tier III group.

Using these assumptions, Table 11 shows 2000-2020 statewide NOx emission reductions. These reductions range from 110 tons per day (tpd) in 2000 to 35 tpd in 2020, as shown in Figure 3. The importance of the 10 percent aromatic requirement in the current diesel regulations in the future can be seen in Figure 4, where older group of vehicles (uncontrolled) still account for one half of the total on-road emission reductions in 2010-2020. Similarly, the off-road engines are the major contributors in the overall emission reductions, increasing from about 50 percent of total mobile source in 2010 to 65 percent in 2020.

Unlike NOx, the proposed 15 ppmw S regulations would provide additional PM_{10} emission reductions from on-road vehicles, about 0.5 tpd in 2010 to 0.2 tpd in 2020 (Table 12). However, off-road engines were not included in this analysis due to uncertainty of when the proposed low sulfur regulations would take effect in this source category. Figure 3 shows the combined statewide PM_{10} reductions due to the current and proposed diesel fuel regulations. As can be seen in Figure 4, off-road engines would be the main source of PM_{10} emissions reductions from mobile source in the future.

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Table 10. Diesel Fuel Emission Reduction Factors

By Pollutant, Source Category, and Technology Group

Oxides of Nitrogen:

HD Diesel Engine Tech Group (Emission Standards, Model Year)	Emission Reduction Factors (500 ppmw S) (Calendar Year 1993-2006)
On-Road:	
Uncontrolled (>4 g/bhphr NOx, >0.1 g/bhphr PM; pre 1998)	7%
Tier I (4 g/bhphr NOx, 0.1 g/bhphr PM; 1998-2003)	7%
Tier II (2 g/bhphr NOx, 0.1 g/bhphr PM; 2004-2006)	6%
Off-Road:	
All tech groups	7%

HD Diesel Engine Tech Group (Emission Standards, Model Year)	Additional Emission Reduction Factors (15 ppmw S)* (Calendar Year 2006-beyond)
On-Road:	
Uncontrolled (>4 g/bhphr NOx, >0.1 g/bhphr PM; pre 1998)	0%
Tier I (4 g/bhphr NOx, 0.1 g/bhphr PM; 1998-2003)	0%
Tier II (2 g/bhphr NOx, 0.1 g/bhphr PM; 2004-2006)	0%
Tier III (0.2 g/bhphr NOx, 0.01 g/bhphr PM; post-2006)	0%
Off-Road:	
All tech groups	same as above

Particulate Matter:

HD Diesel Engine Tech Group (Emission Standards, Model Year)	Emission Reduction Factors (500 ppmw S) (Calendar Year 1993-2006)
On-Road:	
Uncontrolled (>4 g/bhphr NOx, >0.1 g/bhphr PM; pre 1998)	25%
Tier I (4 g/bhphr NOx, 0.1 g/bhphr PM; 1998-2003)	25%
Tier II (2 g/bhphr NOx, 0.1 g/bhphr PM; 2004-2006)	25%
Off-Road:	
All tech groups	same as above

HD Diesel Engine Tech Group (Emission Standards, Model Year)	Additional Emission Reduction Factors (15 ppmw S)* (Calendar Year 2006-beyond)
On-Road:	
Uncontrolled (>4 g/bhphr NOx, >0.1 g/bhphr PM; pre 1998)	4%
Tier I (4 g/bhphr NOx, 0.1 g/bhphr PM; 1998-2003)	4%
Tier II (2 g/bhphr NOx, 0.1 g/bhphr PM; 2004-2006)	4%
Tier III (0.2 g/bhphr NOx, 0.01 g/bhphr PM; post-2006)	0%
*Off-Road:***	
All tech groups	same as above

*Relative to uncontrolled diesel fuel

**Off-road model (recreation vehicles, off-road equipment, and farm equipment) does not include the proposed 15 ppmw S regulations.

Table 11. 2000-2020 Statewide Mobile Source NOx Emissions Reduction, Annual Average

Diesel Engines by Source Category and Technology Group

(EMFAC 2002, Ver. 2.2 and Emisssion Inventory Model, Base Year 2001)

Source Category / Tech Group			NOx Emission Reduction (tons/day) 500 S	15 S	Total
2000					
On-Road:	Uncontrolled, pre-1998		48	n/a	48
	Tier I, 1998-2003		12	n/a	12
		On-Road Subtotal	61	n/a	61
Off-Road:	All tech groups		49	n/a	49
		Total	**110**	**n/a**	**110**
2005					
On-Road:	Uncontrolled, pre-1998		33	n/a	33
	Tier I, 1998-2003		19	n/a	19
	Tier II, 2004-2006		4	n/a	4
		On-Road Subtotal	56	n/a	56
Off-Road:	All tech groups		45	n/a	45
		Total	**100**	**n/a**	**100**
2010					
On-Road:	Uncontrolled, pre-1998		19	0	19
	Tier I, 1998-2003		14	0	14
	Tier II, 2004-2006		5	0	5
	Tier III, post-2006		n/a	0	0
		On-Road Subtotal	38	0	38
Off-Road:	All tech groups		35	0	35
		Total	**73**	**0**	**73**
2015					
On-Road:	Uncontrolled, pre-1998		10	0	10
	Tier I, 1998-2003		8	0	8
	Tier II, 2004-2006		4	0	4
	Tier III, post-2006		n/a	0	0
		On-Road Subtotal	22	0	22
Off-Road:	All tech groups		27	0	27
		Total	**49**	**0**	**49**
2020					
On-Road:	Uncontrolled, pre-1998		6	0	6
	Tier I, 1998-2003		4	0	4
	Tier II, 2004-2006		2	0	2
	Tier III, post-2006		n/a	0	0
		On-Road Subtotal	12	0	12
Off-Road:	All tech groups		23	0	23
		Total	**35**	**0**	**35**

Figure 1
2000-2020 Statewide Total NOx Emissions Reduction, Annual Average
Mobile Source
(From uncontrolled to 15 ppmw S diesel fuel)

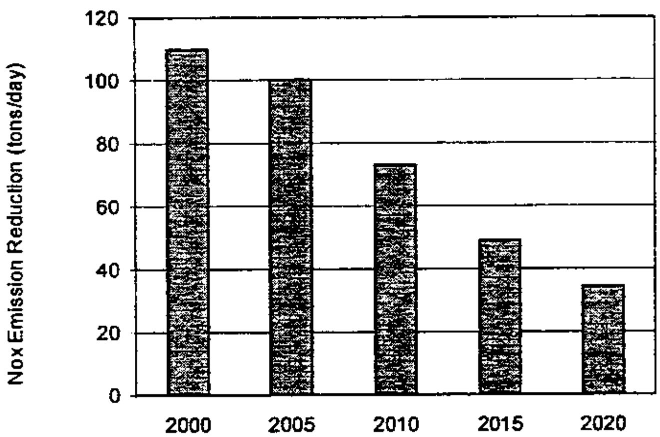


Figure 2
2000-2020 Statewide Total NOx Emissions Reduction, Annual Average
Mobile Source
Diesel Engines By Source Cetegory and Technology Group
(From uncontrolled to 15 ppmw S diesel fuel)

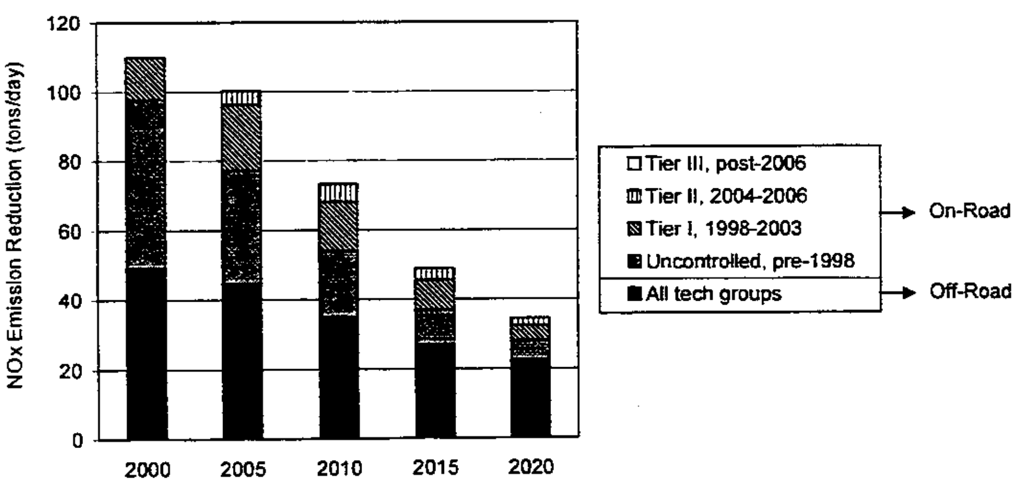


Table 12. 2000-2020 Statewide Mobile Source PM10 Emissions Reduction, Annual Average
Diesel Engines by Source Category and Technology Group
(EMFAC 2002, Ver. 2.2 and Emisssion Inventory Model, Base Year 2001)

Source Category / Tech Group			PM10 Emission Reduction (tons/day) 500 S	15 S	Total
2000					
On-Road:	Uncontrolled, pre-1998		5.1	n/a	5.1
	Tier I, 1998-2003		0.5	n/a	0.5
		On-Road Subtotal	5.5	n/a	5.5
Off-Road:	All tech groups		12.8	n/a	12.8
		Total	**18.3**	**n/a**	**18.3**
2005					
On-Road:	Uncontrolled, pre-1998		3.2	n/a	3.2
	Tier I, 1998-2003		1.0	n/a	1.0
	Tier II, 2004-2006		0.4	n/a	0.4
		On-Road Subtotal	4.6	n/a	4.6
Off-Road:	All tech groups		11.5	n/a	11.5
		Total	**16.0**	**n/a**	**16.0**
2010					
On-Road:	Uncontrolled, pre-1998		1.8	0.3	2.0
	Tier I, 1998-2003		0.8	0.1	0.9
	Tier II, 2004-2006		0.5	0.1	0.6
	Tier III, post-2006		n/a	0.0	0.0
		On-Road Subtotal	3.1	0.5	3.6
*Off-Road:**	All tech groups		9.0	n/a	9.1
		Total	**12.1**	**0.5**	**12.7**
2015					
On-Road:	Uncontrolled, pre-1998		0.9	0.2	1.1
	Tier I, 1998-2003		0.5	0.1	0.6
	Tier II, 2004-2006		0.4	0.1	0.5
	Tier III, post-2006		n/a	0.0	0.0
		On-Road Subtotal	1.8	0.3	2.1
*Off-Road:**	All tech groups		7.1	n/a	7.1
		Total	**8.9**	**0.3**	**9.2**
2020					
On-Road:	Uncontrolled, pre-1998		0.5	0.1	0.6
	Tier I, 1998-2003		0.3	0.0	0.3
	Tier II, 2004-2006		0.2	0.0	0.3
	Tier III, post-2006		n/a	0.0	0.0
		On-Road Subtotal	1.0	0.2	1.2
*Off-Road:**	All tech groups		5.7	n/a	5.7
		Total	**6.7**	**0.2**	**6.9**

*Off-road model does not include the proposed 15 ppmw S regulations

Figure 3
2000-2020 Statewide Total PM_{10} Emission Reduction, Annual Average
Mobile Source
(From uncontrolled to 15 ppmw S diesel fuel)

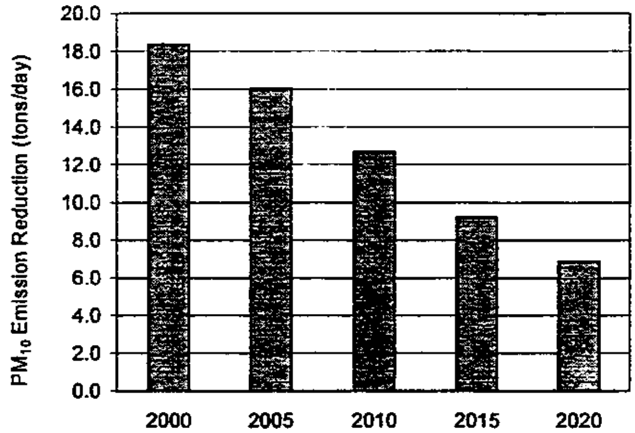
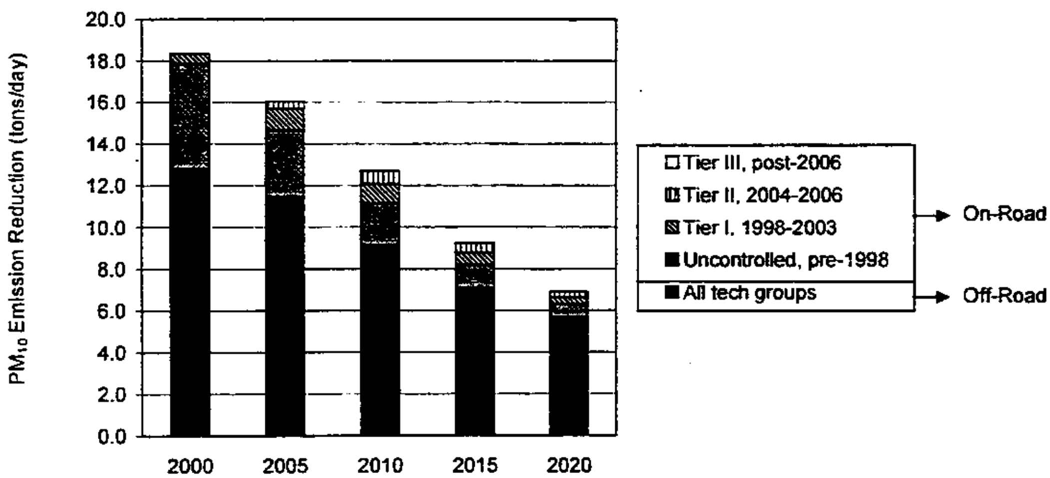


Figure 4
2000-2020 Statewide Total PM_{10} Emissions Reduction, Annual Average
Mobile Source
Diesel Engines By Source Cetegory and Technology Group
(From uncontrolled to 15 ppmw S diesel fuel)



APPENDIX F

Effects of Changes in Diesel Fuel Properties on Emissions

The Effects of Changes in Diesel Fuel Properties on Emissions

Recent studies have shown other diesel fuel properties (e.g., fuel density, T50, and T90) that are not included in the California diesel fuel regulations can also affect two primary diesel engine emissions, NOx and PM10.

The U.S. EPA has developed regression models that relate fuel properties to engine emissions. Staff used a NOx model[1] (see Appendix D, Table 8, EPA Model), as follows:

NOx (g/bhp-hr) = exp(0.50628 - 0.002779*Cetane Difference + 0.002922*Aromatics + 1.3966*Specific Gravity-0.0004023*T50) ....Eqn [1]

This equation was used to demonstrate the effects of specific gravity (density) and/or aromatic content (vol%) changes on NOx emissions. Particularly, Eqn [1] was used to compare NOx emissions from new fuel specifications to a baseline or reference fuel such that the ratio would describe how much new fuel emissions increase or decrease relative to the baseline fuel. If all other properties are the same, except specific gravity, Eqn [1] can be simplified, as follows:

Ratio = exp(1.3966*Delta Specific Gravity)...Eqn [2]

where delta specific gravity is the difference in specific gravity between new and baseline fuel.

Figure 1 exhibits specific gravity and NOx emissions change relationship. The slope of this graph explains how much reduction in specific gravity for one percent decrease in NOx. From the figure, it can be seen a 0.007 decrease in specific gravity reduces NOx emissions by about one percent. Similarly, Figure 2 shows aromatic content (vol%) and NOx emissions relationship. On average, every one percent of NOx emissions decrease is associated with a 3.4 volume percent reduction of aromatic content. In a more complex case, the model could also be used to find a trade-off between fuel density and aromatic content to maintain the same NOx emissions, as shown in Figure 3.

Similar results were also found using a NOx model developed by the U.S. EPA Heavy-Duty Engine Working Group (HDEWG)[2] (see Appendix D, Table 8, HDEWG Model), which employed different form and used slightly different independent variables, shown below:

NOx (g/bhp-hr) = -1.334 + 0.00646*Mono Aromatics (wt%) + 0.00763*Poly Aromatics (wt%) + 4.13*Specific Gravity + 0.00337*Cetane Number.....................Eqn [3]

All else equal, using Eqn [3] it can be shown that a 0.006 (compared to 0.007 in Eqn [1]) decrease in specific gravity reduces NOx emissions by one percent.

[1] Adopted from the U.S. EPA's staff discussion document, *Strategies and Issues in Correlating Diesel Fuel Properties with Emissions*, Table III.B.3-2, page 30

[2] Mason, R.L., et al., *EPA HDEWG Program – Statistical Analysis,* SAE Technical Paper No. 2000-01-1859, June 2000.

Figure 1. Diesel Fuel Specific Gravity and NOx Emissions Relationship (U.S. EPA Model)

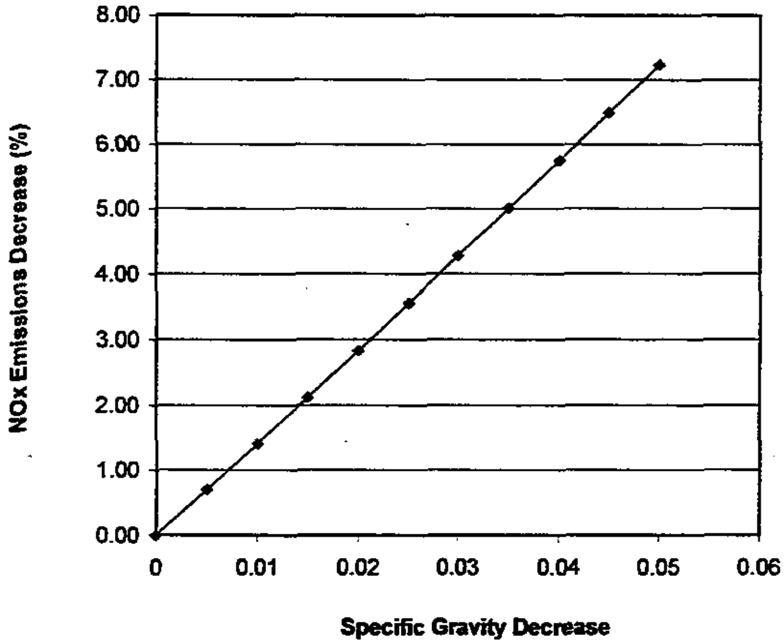


Figure 2. Diesel Fuel Aromatic Content and NOx Emissions Relationship (U.S. EPA Model)

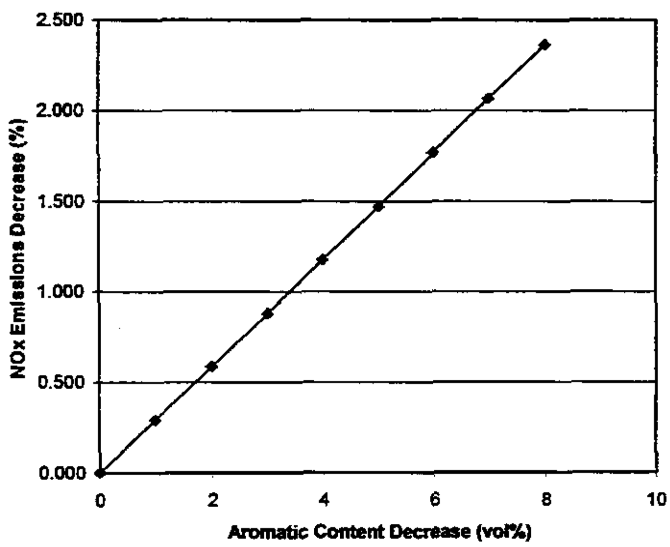
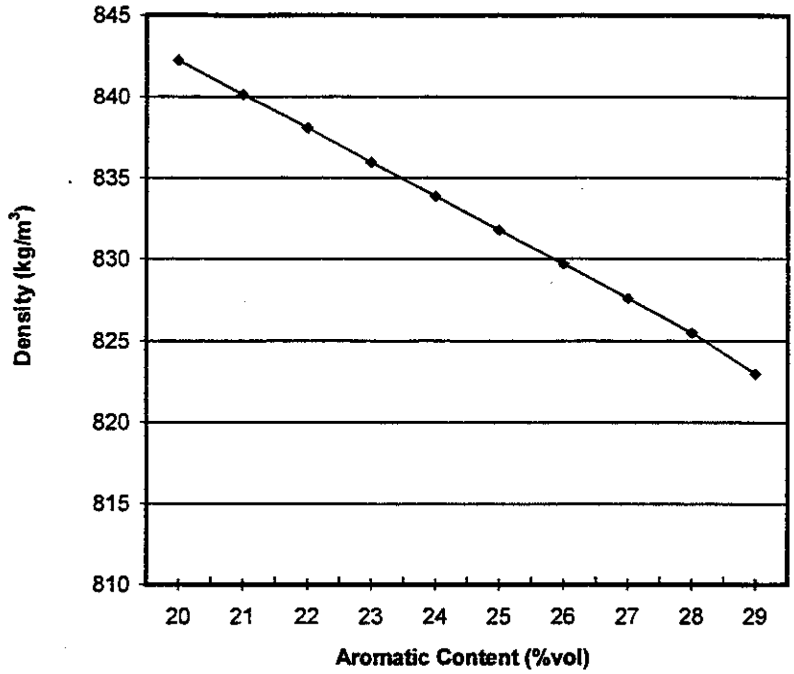


Figure 3. Diesel Fuel Density and Aromatic Content Trade-Off for NOx Emissions Equivalency (U.S. EPA Model)

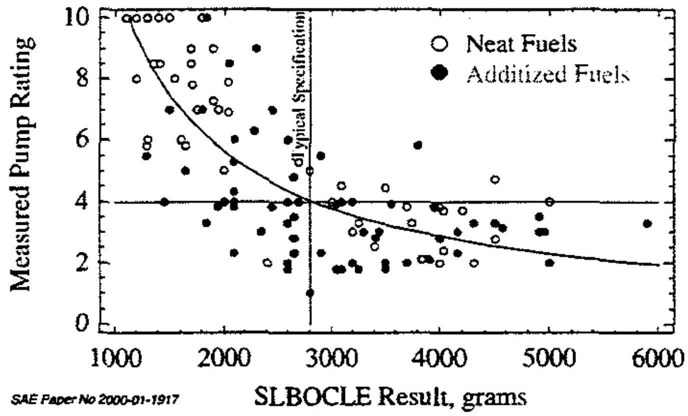


APPENDIX G

Diesel Fuel Lubricity: Pump Wear Data

Pump wear data for conventional heavy-duty diesel engine fuel injection systems are shown in Figure 1 below as a function of diesel fuel lubricity level as indicated by the Scuffing Load Ball on Cylinder Lubricity Evaluator (SLBOCLE) test. An acceptable pump wear rating for these pumps is a pump wear rating or four or less. These data support a SLBOCLE scuffing load of 3100 grams or higher as being protective of conventional pumps.

Figure 1 Pump Wear Data for Conventional Pumps[1]



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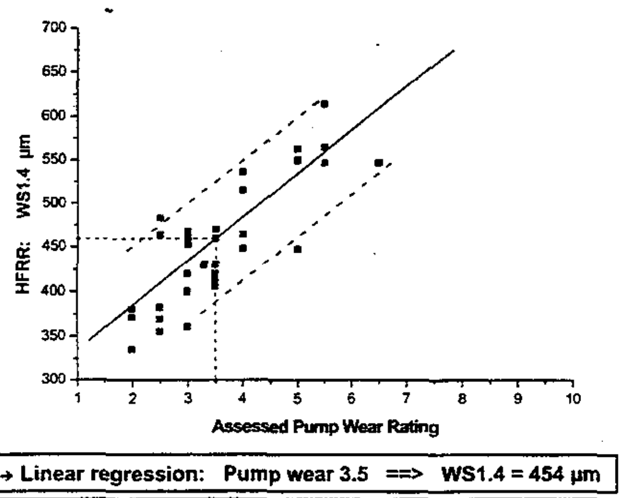
Pump wear data for advanced technology high pressure pumps are shown in Figure 2 below. The diesel fuel lubricity as measured by the High Frequency Reciprocating Rig (HFRR) test is shown as a function of measured Bosch wear rating. An acceptable wear rating for these pumps is a value of 3.5 or less. These data indicate that fuels that produce maximum wear scar diameters of approximately 460 microns or less result in acceptable wear ratings.

Figure 2 Pump Wear Data for Advanced Technology Pumps[a, 2]



[a] Used by permission from Bosch Corp, May 2003

1 ASTM ballot, Sub Committee: D02.E0, Revision of D-975-01 Specification for Diesel Fuel Oils to include a lubricity specification, Background & Supporting Documents & References", Issue Date April 25, 2003.

2 Meyer, Klaus and Livingston, Thomas C., Bosch Corporation, CARB Fuels Workshop Presentation, " Diesel Fuel Lubricity Requirements for Light Duty Fuel Injection Equipment", Sacramento, CA, Feb. 20, 2003.

APPENDIX H

Refining Technology for Low Sulfur Diesel Production

Refining Technology for Low Sulfur Diesel Production

I. Introduction

Diesel fuel is a middle distillate petroleum product that is generally heavier than jet fuel and lighter than fuel oil. Distillate refers to a range of similar products including kerosene, diesel fuel, No. 2 heating oil and jet fuel. The diesel fuel produced by a refinery is a blend of all the appropriate available refinery streams. The primary refinery components produced for blending diesel are non-hydrotreated straight run diesel, hydrotreated straight run diesel, non-hydrotreated light cat cycle oil (LCCO) from the FCC, hydrotreated LCCO, non-hydrotreated coker diesel, hydrotreated coker diesel, hydrocracker diesel, and gas oil hydrotreater diesel.[1]

The blendstocks used to produce CARB diesel differ from the rest of the nation. As shown in Table 1[2], the results of the 1996 NPRA/API survey of 10 California refineries indicated that CARB diesel fuel is made primarily from hydrotreated and hydrocracked distillates in roughly equal proportions (48 and 47 percent, respectively) with small fractions of hydrotreated cracked stock (2 percent) and hydrotreated coker gas oil (3 percent). Table 2 shows the sulfur content of the different blendstocks used to produce California diesel and Table 3 compares average highway diesel fuel properties by geographic area.

II. Sulfur Compounds in Distillate

Sulfur containing compounds in distillate can be classified according to the ease with which they are desulfurized.[3] Sulfur contained in paraffins or aromatics with a single aromatic ring are relatively easy to desulfurize. The sulfur atom is in a geometric position where it can readily make physical contact with the surface of the catalyst. The more difficult compounds are the aromatics consisting of two aromatic rings, particularly dibenzothiophenes. Dibenzothiophene contains two benzene rings which are connected by a carbon-carbon bond and two carbon-sulfur bonds (both benzene rings are bonded to the same sulfur atom). This compound is essentially flat and the carbon atoms bound to the sulfur atom hinder the approach of the sulfur atom to the catalyst surface. Nevertheless, today's catalysts are very effective in desulfurizing dibenzothiophenes, as long as only hydrogen is attached to the carbon atoms bound directly to the sulfur atom. However, when hydrogen of the aromatic ring is substituted with methyl or ethyl groups, these groups can hinder the approach of the sulfur atom to the catalyst surface when the alkyl groups are next to the sulfur atom. This steric hindrance reduces the effectiveness of the catalytic hydrogenation reaction.

Most straight run distillates (or straight run light gas oil (SRLGO)) contain relatively low levels of these sterically hindered compounds. LCO contains the greatest concentration of sterically hindered compounds, and is generally more difficult to desulfurize than coker distillate which is in turn more difficult to treat than straight run distillate.[4] In addition, cracked stocks, particularly LCO, have a greater tendency to form coke on the catalyst, which deactivates the catalyst and requires its replacement.

Generally, conventional desulfurization is much slower for sterically hindered compounds than it is for those that aren't. Slower reactions mean that either the volume of the reactor must be much larger, or that the rate of reaction must somehow be increased. The latter implies either a more active catalyst, higher temperature, or higher pressure.

III. Hydrodesulfurization

A. Hydrotreating

Catalytic hydrotreating is a hydrogenation process used to remove contaminants such as nitrogen, sulfur, oxygen, and metals from liquid petroleum fractions. Typically hydrotreating is done prior to processes such as catalytic reforming so that the catalyst is not contaminated by untreated feedstock. Hydrotreating is also used prior to catalytic cracking to reduce sulfur and improve product yields, and to upgrade middle-distillate petroleum fractions into finished kerosene, diesel fuel, and heating fuel oils. In addition, hydrotreating converts olefins and aromatics to saturated compounds. Hydrotreating for sulfur removal is called hydrodesulfurization.

Liquid distillate from the crude unit is mixed with hydrogen-rich make up gas and recycle gas, heated and pumped to temperatures of 300-380°C and pressures of 500-700 psia, and reacted over a catalyst. Hydrogen reacts with the sulfur and nitrogen compounds in the distillate, forming hydrogen sulfide and ammonia. The resulting vapor is separated from the desulfurized distillate, then the desulfurized distillate is usually mixed with other distillate streams in the refinery to produce diesel fuel and heating oil.

The vapor still contains valuable hydrogen, because the reaction requires the use of a significant amount of excess hydrogen to operate efficiently and practically. However, the vapor also contains a significant amount of hydrogen sulfide and ammonia, which inhibit the desulfurization and denitrogenation reactions and must be removed from the system. Thus, the hydrogen leaving the reactor is usually mixed with fresh hydrogen and recycled to the front of the reactor for reaction with fresh distillate feed. To avoid a build up of hydrogen sulfide and ammonia in the system, the hydrogen sulfide and ammonia are either chemically scrubbed from the hydrogen recycle stream or purged with a portion of the of the recycle stream as a mixture of hydrogen, hydrogen sulfide and ammonia. The latter method of preventing the build up is less efficient since it leads to higher levels of hydrogen sulfide and ammonia in the reactor, but it avoids the cost of building and operating a scrubber.

Desulfurization processes in use today in the U.S. generally use only one reactor, due to the need to only desulfurize diesel fuel to 500 ppm or lower. However, a second reactor can be used, particularly to meet lower sulfur levels. Instead of liquid distillate going to the diesel fuel/heating oil pool after the first reactor, it would simply be mixed with fresh hydrogen and sent to the second reactor.

A few refineries also currently hydrotreat their distillate more severely than is typical, but not as severely as hydrocracking. Their intent is to remove the sulfur, nitrogen and metallic contaminants and at the same time saturate most of the aromatics present. This is done primarily in Europe to meet very stringent specifications for both sulfur and aromatics applicable to certain diesel fuels. This severe hydrotreating process is also used in the U.S. to "upgrade" petroleum streams which are too heavy or too low in quality to be blended into the diesel pool. The effect is to crack some of the material to lower molecular weight compounds and saturate some of the aromatics to meet the distillation and cetane requirements. A different catalyst which encourages aromatic saturation is used in lieu of one that simply encourages contaminant removal.

B. Hydrocracking

Hydrocracking is a two-stage process combining catalytic cracking and hydrogenation, wherein heavier feedstocks are cracked in the presence of hydrogen to produce more desirable products. The process employs high pressure, high temperature, a catalyst, and hydrogen. Hydrocracking is used for feedstocks that are difficult to process by either catalytic cracking or reforming, since these feedstock are characterized usually by a high polycyclic aromatic content and/or high concentrations of the two principal catalyst poisons, sulfur and nitrogen compounds.

In the process, nearly all of the contaminants are removed and olefins and aromatics are saturated into paraffins and naphthenes. Outside the U.S., this process is commonly used to produce distillate from heavier, less marketable refinery streams.

The hydrocracking process largely depends on the nature of the feedstock and the relative rates of the two competing reactions, hydrogenation and cracking. Heavy aromatic feedstock is converted into lighter products under a wide range of very high pressures (1,000-2,000 psi) and fairly high temperatures (750°-1,500° F), in the presence of hydrogen and special catalysts. When the feedstock has a high paraffinic content, the primary function of hydrogen is to prevent the formation of polycyclic aromatic compounds. Another important role of hydrogen in the hydrocracking process is to reduce tar formation and prevent buildup of coke on the catalyst. Hydrogenation also serves to convert sulfur and nitrogen compounds present in the feedstock to hydrogen sulfide and ammonia.

IV. Catalyst Technology

Because moderate sulfur reduction is often all that is currently required in distillate hydrotreating, catalysts have been developed almost exclusively for contaminant removal. The most commonly used desulfurization catalyst consists of a mixture of cobalt and molybdenum (Co/Mo) which interacts primarily with the sulfur atom and encourage the reaction of sulfur with hydrogen. The CoMo catalyst is very effective in the desulfurizing of distillate, straight run or cracked which contain relatively low levels of the sterically hindered sulfur compounds.

With the 15 ppm sulfur cap there is now a need to desulfurize sterically hindered aromatic sulfur compounds and this has led to greater interest in catalysts that encourage saturation (hydrogenation) of the aromatic rings. This generally improves the quality of the diesel fuel produced from this distillate. These catalysts also indirectly encourage the removal of sulfur from sterically hindered compounds by eliminating one or both of the aromatic rings contained in dibenzothiophene. Without one or both of the rings, the molecule is much more flexible and the sulfur atom can approach the catalyst surface much more easily. Thus, the desulfurization rate of sterically hindered compounds is greatly increased through the hydrogenation route. The most commonly used hydrogenation/desulfurization catalyst consists of a mixture of nickel and molybdenum (Ni/Mo). There is a significant additional cost involved in this method of desulfurization, primarily due to the consumption of additional hydrogen. Consequently, the EPA expects refiners to choose desulfurization processes that minimize the amount of aromatics saturation.

V. Hydrogen Sulfide Scrubbing

During the hydrotreating process, hydrogen reacts with sulfur-containing compounds in the distillate to form hydrogen sulfide (H_2S). The desulfurized distillate is separated from the mixed stream leaving the reactor to yield a gaseous stream containing H_2, some hydrocarbons, and the H_2S by-product. This acid gas stream is sent to an amine absorber unit where the H_2S is removed by the circulating amine stream (MEA, DEA, MDEA). Many refineries have mul;tiple amine absorbers served by a common regeneration unit. The stripped gas or liquid is removed overhead, and the amine is sent to a regenerator where the acidic components are stripped by heat and reboiling action and disposed of, and the amine is recycled.[5]

VI. Sulfur Recovery

The sulfur in the acid gas from the amine regeneration unit is removed first by a Claus sulfur recovery unit that achieves 92 to 96 percent of the overall sulfur recovery and then by a tailgas cleanup unit that can increase overall sulfur recovery to 99.9 percent.

Sulfur recovery converts hydrogen sulfide in sour gases and hydrocarbon streams to elemental sulfur. The most widely used recovery system is the Claus process, which uses both thermal and catalytic-conversion reactions. A typical process produces elemental sulfur by burning hydrogen sulfide under controlled conditions. Knockout pots are used to remove water and hydrocarbons from feed gas streams. The gases are then exposed to a catalyst to recover additional sulfur. Sulfur vapor from burning and conversion is condensed and recovered. The tail gas from the Claus unit contains H_2S, SO_2, CS_2, S vapor and entrained S liquid. Most tail gas cleanup processes hydrogenate/hydrolyze the sulfur compounds to H2S, and then either recover or convert the H2S. The H2S recovery is usually by a selective amine while the H2S conversion may use a liquid redox or catalytic process.[5]

Table 1[a]

Volume Fraction of CARB Diesel From Each Blendstock Component

Diesel Blendstock	Percent of CARB Diesel Fuel Per Blendstock Type				
	Naphtha	Light Distillate	Heavy Distillate	Light Gas Oil	All Boiling Fractions Combined
Straight Run	-	-	-	-	0.0
Cracked, Unhydrotreated	-	-	-	-	0.0
Non-Cracked, Hydrotreated	-	-	48.0	-	48.0
Cracked and Hydrotreated	-	-	1.6	-	1.6
Hydrocracked	-	1.9	45.4	-	47.3
Coker Streams, Unhydrotreated	-	-	-	-	0.0
Coker Streams, Hydrotreated	-	-	3.1	-	3.1
Total					100.0

Table 2[b]

Sulfur Content (ppm) by Boiling Fractions of Blendstocks

Diesel Blendstock	Sulfur Content (ppm)			
	Naphtha	Light Distillate	Heavy Distillate	Light Gas Oil
Straight Run	—	1,034	6,360	—
Cracked, Unhydrotreated	—	—	—	—
Non-Cracked, Hydrotreated	—	255	162	375
Cracked and Hydrotreated		97	80	—
Hydrocracked	—	7	10	—
Coker Streams, Unhydrotreated	—	—	—	—
Coker Streams, Hydrotreated	—	70	151	—

[a] Data from Table 4B (pages 1 and 2) of 1997 API/NPRA report on survey of refining operations and product quality.

[b] Data from Table 4B (pages 3 and 4) of 1997 API/NPRA report on survey of refining operations and product quality

Table 3[a]
Average Highway Diesel Fuel Parameter Levels by Geographic Area

Fuel Parameter		PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 (OC)*	California		U.S. (OC)*
							CARB	EPA	
API Gravity		34.6	34.2	34.3	36.2	33.8	36.5	33.6	34.4
Sulfur, ppmw		340	350	360	330	280	140	200	340
Cetane Number Unadditized		-	42.9	43.8	-	46.5	50.1	42.6	44.1
Cetane Additive (ppmv)		0	83	2	12	0	274	183	27
Cetane Number [additized]		-	-	-	-	-	53.8	-	-
Pour Point (F) [additized]		[10]	[10]	[2]	0	[2]	8	6	[5]
Pour Point Depressant Additive (ppmw)		7	47	7	11	0	0	0	19
Distillation (°F)	T10	426	427	436	405	432	440	447	431
	T30	458	470	478	435	472		-	471
	T50	497	505	514	495	521	531	525	510
	T70	549	549	557	519	554		-	551
	T90	609	600	610	598	611	623	612	606
Aromatics (Vol %)		28.9	25.8	37.0	27.1	-	18.2	28.8	32.3
Polynuclear Aromatics (Vol %)							2.8		

* Outside of California

[1] Moncrieff, T. Ian, Montgomery, W. David, Ross, Martin T., Charles River Associates Inc., Ory, Raymond E., Carney, Jack T., Baker and O'Brien Inc., An Assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel, A study prepared by Charles River and Associates Inc. and Baker and O'Brien Inc. for the American Petroleum Association, August 2000.

[2] Final Report, 1996 American Petroleum Institute/National Petroleum Refiners Association, Survey of Refining Operations and Product Quality, July 1997.

[a] Final Report, 1996 American Petroleum Institute / National Petroleum Refiners Association, Survey of Refining Operations and Product Quality, July 1997.

[3] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, Chapter IV. December 2000, Chapter IV.

[4] Mayo, S.W., "Mid-Distillate Hydrotreating: The Perils and Pitfalls of Processing LCO," Akzo Nobel Catalysts.

[5] Robert A. Meyers, Handbook of Petroleum Processes. 2d ed., McGraw Hill, 1996, Chapter 11.

APPENDIX I

Diesel Engine Lubricating Oils

Diesel Engine Lubricating Oils

I. Introduction

The significance of the sulfur contribution from lubricating oils to engine exhaust emissions becomes apparent with reducing diesel fuel sulfur to 15 ppm. Diesel fuel with 15 ppm sulfur enables the use of control technologies to meet the new 2007 model year emissions standards for heavy-duty diesel (HDD) vehicles.[1, 2] The sulfur contribution from lubricating oils has been estimated to be up to 7 ppm in the exhaust thus increasing sulfur by about 50%.[3, 4] This increase in sulfur can significantly decrease the effectiveness of exhaust after treatment devices for reducing NOx and particulate matter (PM).

In addition to sulfur, lubricating oils contain other compounds and material that are possible sources of after treatment degradation. These compounds, containing calcium, phosphorus, zinc, magnesium and other metals, are found in the lubricating oil additives.[5, 6] Also, the inorganic components in these compounds, being incombustible, contribute to the ash content of the oil. Ash concentrations in lubricating oils can range from 1 to 1.3% of the finished product.[7]

II. Impact of Sulfur on After Treatment Devices

A. NOx Adsorbers

NOx adsorbers that are being developed for treating diesel exhaust are extremely sensitive to sulfur poisoning due to the similarity in chemical properties of sulfur oxide (SO_2) and nitrogen oxide. Sulfur oxide in the exhaust can react with the adsorptive media to form stable sulfates, thus reducing the adsorbing capabilities of the system.[1, 8] Increasing sulfur concentration in the exhaust from 15 ppm to 22 ppm due to contribution from the lubricating oils can reduce the effectiveness of the NOx adsorber performance by 20 to 30% after 150 hours of operation, based on results from the Diesel Emission Control – Sulfur Effects Program.[8]

B. Catalyzed Diesel Particulate Filters

Sulfur can also inhibit the effectiveness of catalyzed diesel particulate filters (CDPF) through several mechanisms. The best understood mechanism is the catalytic oxidation of exhaust SO_2 to SO_3. SO_3 combines with water to produce sulfuric acid that adds to the PM.[1] Increasing sulfur concentration in the exhaust from 15 ppm to 22 ppm due to contribution from the lubricating oils can result in approximately a 35% increase in PM.[2, 9] Additionally, the sulfur can reduce the regeneration capability of the filter by two different mechanisms depending on the type of catalyzed diesel particulate filter involved.

In a catalytic particulate filter, the catalyst is applied directly to the filter material, whereas in a continuously regenerating diesel particulate filter, the catalyst is upstream of the filter. In the case of a catalytic particulate filter, SO_2 acts to increase the minimum temperature requirement for the filter to properly regenerate itself. This temperature requirement is referred to as the balance point temperature where the rate of combustion of particulate caught in the filter exceeds the rate of particulate deposition. If the temperature of the exhaust gas is lower than the balance point temperature, then PM accumulates in the filter, thus the filter is unable to fully regenerate itself. The continuously regenerating diesel particulate filter relies on a strong oxidant, NO_2, to oxidize the PM caught in the trap. A platinum catalyst upstream of the filter oxidizes NO to

NO_2. Sulfur oxides poison the catalyst by occupying catalyst sites. Thus, the sulfur inhibits the formation of NO_2,[1] lowering the PM oxidation rate and allowing PM accumulation. PM accumulation can lead to reduced engine performance, due to the increased pressure drop of the trap, and ultimately failure of the trap.[2]

III. Impact of Ash on After Treatment Devices

Inorganic compounds from lubricating oil additives are oxidized in the combustion chamber and generate metal oxide ash particles. The particles collect on the diesel particulate filter and are not removed by filter regeneration because they are not combustible. As the ash particles accumulate, they reduce the porosity of the filter. This reduced porosity, or filter blockage, increases the back pressure to the engine which reduces engine efficiency. The increased pressure drop across the filter can also lead to the structural failure of the filter. Periodically the ash must be removed by mechanically cleaning the filter with compressed air or water.

IV. Lubricant Formulation

A. Sulfur

Diesel engine lubricating oils are comprised of approximately 80-85% base oil with the remainder made up of performance additives. The sulfur concentration in the base oil, measured in the finished product (base plus additive), can range from essentially zero (synthetic oils) up to 4,000 ppm. The sulfur in the base oil exists as a contaminant and can be reduced by hydrotreating. Performance additives are the major source of sulfur and ash content in lubricating oils. The additives are used to modify or enhance the properties of the base oil and include detergents, dispersants, oxidation and corrosion inhibitors, antioxidants, viscosity modifiers, antiwear agents, and pour point depressants. Sulfur-containing additives include the anti-wear agents, detergents, corrosion inhibitors, friction modifiers, and anti-oxidants. The sulfur in these additives, in the form of sulfonates, phenol sulfide salts and thiophosphonates, are vital to the performance of the additives.[3, 10] Anti-wear agents are the main source of sulfur in the additives and are primarily zinc dithiopshosphates or ZDDP. While there are non-sulfur containing additives, substitutes for most sulfur containing additives have not been developed.

The sulfur content of current engine lubricating oils can range from 2,500 ppm to as high as 8,000 ppm by weight.[4] Various estimates of the lubricating oil sulfur contribution to the exhaust have been made and vary from nearly zero up to 7 ppm.[4]

The worst case estimate of 7 ppm assumed nominal HDD vehicle fuel and oil consumption rates of 6 miles/gallon and 1 quart per 2,000 miles respectively. Also assumed was a high lubricating oil sulfur content of 8,000 ppm and that all of the lubricating oil sulfur reaches the exhaust stream.[3, 4] This assumption is conservative considering that under normal operation, only a small percentage of the oil consumed by open crankcase ventilation heavy duty diesel engines travels past piston rings and valves and burns in the combustion chamber. The remainder of the consumed oil is lost through evaporation by being emitted through the crankcase ventilation tube and is not combusted. In closed crankcase ventilation systems the evaporated oil is recovered.[4]

The United States Environmental Protection Agency (EPA) estimated a 1 ppm sulfur contribution from the lubricating oil to the exhaust based on the Phase I HD emission standards for PM.[4] They assumed that all of the consumed lubricating oil in the exhaust is emitted as diesel PM and that it makes up 30% of the PM. They set the PM emission rate at the 0.1 g/bhp-hr PM emission rate for all classes of heavy duty diesel vehicles, allowing them to calculate a lubricating oil consumption rate. They combined these assumptions with a nominal specific fuel consumption of 136 g/bhp-hr and lubricating oil fuel sulfur concentration of 5,000 ppm to estimate a lubricating oil sulfur contribution to the exhaust of 1 ppm.

The EPA also analyzed sulfate PM results from the Diesel Emission Control – Sulfur Effects (DECSE) Program to evaluate the contribution of lubricating oil to sulfur in the exhaust. The DECSE used fuel with sulfur levels of 3 ppm and 30 ppm and lubricating oil with a sulfur content of approximately 3,500 ppm. They extrapolated the data to zero fuel sulfur to estimate the sulfur contribution of the lubricating oil and determined that the contribution was not measurable. They concluded from this evaluation that although some amounts of sulfur from lubricating oils are present in the exhaust, it is not likely a significant fraction of the total sulfur, even at fuel sulfur levels of 15 ppm.[4]

B. Ash

Ash content in lubricating oil controls the acidification rate of the oil (maintains total base number, or TBN control). The acidification rate of the oil is due largely to the sulfur content of the fuel and the sulfuric acid that it forms. Without the ability to control acidification of the lubricating oil, engine wear increases significantly. However the proposed lowering of sulfur in diesel fuel will require less of a need for TBN control or less ash content in the lubricating oils. Consequently, manufacturers are investigating with the lubricant industry the potential of lower ash oils for use in engines operated on low sulfur diesel fuel and equipped with particulate traps. However, manufacturers are concerned about potential use of possible low ash oils in fleets using high sulfur diesel if the proposed 15 ppm sulfur requirements are phased in over time.[11] This should not be a concern for California since the proposed 15 ppm sulfur requirement will not be phased in.

V. Research Efforts

There are two major research efforts seeking data on the impact of lubricating oils and lubricant additives on emissions and emission control devises. These efforts are not restricted to sulfur effects but will investigate the different chemical compounds that are found in both the lubricant base stock and additives. The lubricants work group of the Advanced Petroleum-Based Fuels Program Diesel Emission Control - Sulfur Effects (APBF-DECSE) program directs one of these efforts. The other effort has been initiated by a private research consortium formed by the Southwest Research Institute (SwRI). This consortium, called Diesel Aftertreatment Sensitivity to Lubricant/Non-Thermal Catalyst Deactivation (DASL/N-TCD), intends to compliment the research directed by the APBF-DEC lubricants workgroup.

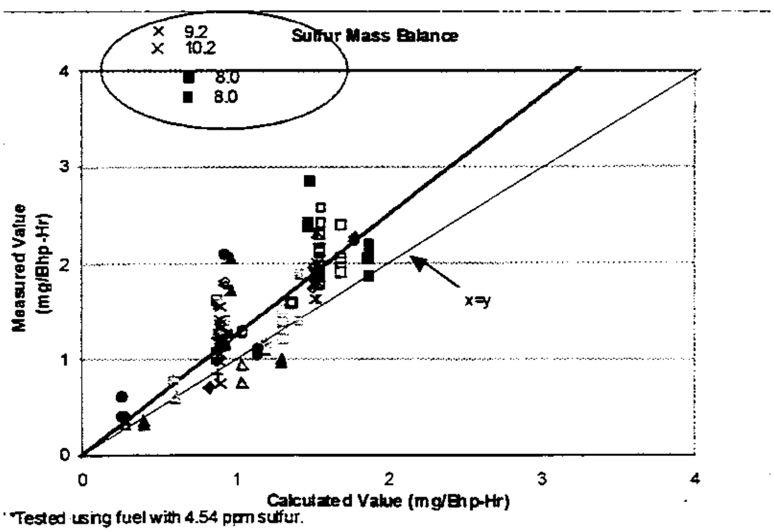
A. APBF Program

The APBF Program is a joint effort of the U.S. Department of Energy's Office of Heavy Vehicle Technologies and Office of Advanced Automotive Technologies. This program is focused on meeting emissions standards and improving compression ignition (CI) efficiency. The lubricants work group of the APBF-DEC program has defined a two-phase plan for testing. The objective of the testing is to determine which, if any, lubricating oil-derived emissions components are detrimental to the performance or the durability of diesel emission control devices.[12] The investigation includes assessing the contribution of lubricating oils to both the soluble and insoluble fraction of the PM, approaches to reduce the contribution of lubricating oils to PM through both reduced oil consumption and determining oils less likely to produce PM, and the impacts of fuel changes on engine lubricating oil requirements.[13]

The first phase of the tests, characterizing the effect of lubricating oils on engine out emissions from a multi-cylinder engine without a catalyst, has been completed.[14,15] Tests were performed on four different oil basestocks and approximately 12 additive packages containing various levels of ash, sulfur, phosphorous, selected metals and other key components.[12] Emissions measurements included PM, total and/or non-methane hydrocarbons, carbon monoxide, oxides of nitrogen, and SO_2. The PM analysis included total PM mass, soluble organic fraction including fuel/lubricant contribution, sulfate fraction, polycyclic aromatic hydrocarbons (PAH) content, and metals. Engine oil consumption was determined for each test-operating mode and checked routinely throughout the test program.[14]

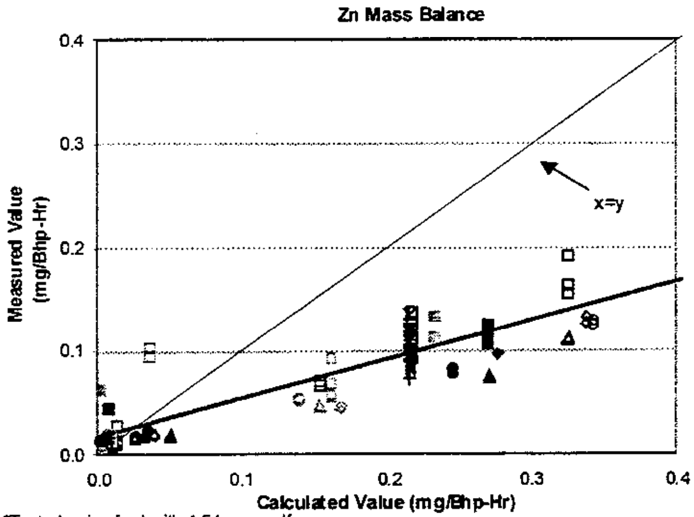
Preliminary results from Part 1 have shown that emissions of sulfur, zinc, phosphorous and calcium are proportional to their concentrations in the oils, as illustrated for sulfur and zinc in Figure 1 and Figure 2 respectively, below. These figures, which give the measured sulfur and zinc emissions as a function of calculated emissions, based on oil consumption and oil sulfur and zinc levels, show linear relationships. However, the unexpectedly high sulfur emissions for some oil formulations, shown in Figure 1, indicate that there may be a formulation dependency for some formulations. For these oils, the emissions were several times higher than expected based on the oil consumption and oil sulfur content. This indicates that simple constraints on content may not be sufficient. Another preliminary conclusion is that emissions of zinc and calcium are lower than expected from measured oil consumption. Figure 2, which shows zinc emissions, illustrates, that zinc emissions were approximately 40% of what would be expected. One possible explanation is that the zinc, derived from the anti-wear additives, is surface active and the missing zinc is possibly lost to a surface.

Figure 1 Preliminary APBF-DEC Phase I Test Results: Sulfur Mass Balance[15]



*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

Figure 2 Preliminary APBF-DEC Phase I Test Results: Zinc Mass Balance[15]



*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

The second phase of the program will focus on evaluating the impact of lubricating oil-derived species on the emission control systems. A Cummins 2003 ISB engine with a production EGR system is expected to be used for this Phase II testing. It is expected that the project will focus on impacts on NO_x adsorber catalyst systems.

B. DASL Consortium

The DASL/N-TCD consortium was formed from two previously separate consortiums. The two parts of the new consortium are concerned with similar subjects but with different emphases. They were combined into one program due to an apparent reduction in research funding available in the corporate community. The two segments of the new consortium will retain their individual emphasis but share funding, allowing work to begin in both areas while reducing overall membership costs.

The DASL segment of the consortium, formulated with the intention of complimenting the APBF-DEC lubricants program, intends to initiate their investigation with lubricating oil and additive effects on catalyzed PM filters. The PM filter will normally be upstream of any additional after treatment devices, such as a NOx adsorber or a selective catalytic reduction (SCR) system. The importance of investigating the effect of ash on these downstream aftertreatment devices is reduced since the PM filter will prevent lubricating oil ash from reaching them. However, since sulfur can pass through the PM filter, it will still be an issue with these other devices.[16] A possible track for their study may be to accelerate "aging" of the emissions control system with extra-high doses of the lubricating oil components, then compare results with lubricating oils using normal additive concentrations. The results are expected to give engine and emission control system manufacturers insight into the magnitude of the potential problems and help oil additive/component makers in formulating future additive packages.[17]

VI. ASTM Proposed Engine Oil Category

An ASTM Heavy Duty Engine Oil Classification Panel has been formed to develop a new engine oil classification, called Proposed Category 10, for use with advanced after treatment technology. This effort will be exploring the performance of oil formulations with reduced sulfur, phosphorous and sulfated ash. Oil licensing for this new classification is scheduled for mid 2006.

VII. Future Activities

Staff will continue to gather information on the effect of the sulfur and ash content of lubricating oils on emissions and the performance of the emission control system. Staff will follow the APBF-DEC lubricants work group test program that will provide data on the emissions impact of different lubricating oil formulations on aftertreatment devices. Staff will investigate the development of non-sulfur containing additive packages, the effect of removing sulfur from the lubricating oil on oil performance, and the effect of other compounds in non-sulfur containing replacement additives on aftertreatment devices.

References

[1] "The Impact of Sulfur in Diesel Fuel on Catalyst Emission Technology", Manufacturers of Emission Control Association, March 15, 1999.

[2] U.S.EPA; December 2000. Regulatory Impact Analysis: Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Chapter III Pg. 2. EPA420-R-00-026. Assessment and Standards Division, Office of Transportation and Air Quality, United States Environmental Protection Agency.

[3] Whitacre, Shawn. "Catalyst Compatible" Diesel Engine Oils, DECSE Phase II, Presentation at DOE/NREL Workshop "Exploring Low Emission Diesel Engine Oils." January 31, 2000.

[4] U.S.EPA; December 2000. Regulatory Impact Analysis: Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Chapter III. pp 96 – 98. EPA420-R-00-026. Assessment and Standards Division, Office of Transportation and Air Quality, United States Environmental Protection Agency.

[5] "Diesel Catalysts", DieselNet Technology Guide, accessed January 26, 2001, www.dieselnet.com/tech/cat_d_deactiv.html

[6] Merkel, G.A., Cutler, W.A., Warren, C.J., "Thermal Durability of Wall-Flow Ceramic Diesel Particulate Filters", SAE 2001-01-0190

[7] Telephone conversation with Shawn Whitacre of Cummins, January 31, 2001.

[8] Phase 1 Interim Data Report No. 2: NOx Adsorber Catalysts" , Diesel Emission Control Sulfur Effects (DECSE) Program, October 1999, p6, 23.

[9] "Phase I Interim data Report No. 4: Diesel Particulate Filters – Final Report", Diesel Emission Control Sulfur Effects (DECSE) Program, January 2000, pg 3.

[10] "Lubrication Theory and Practice", accessed May 1, 2003, www.lubrizol.com/referencelibrary/lubtheory/prop.htm

[11] "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements", Federal Register: January 18, 2001 (Volume 66, Number 12) (Rules and Regulations Page 5084).

[12] APBF-DEC Quarterly Update, Advanced Petroleum-Based Fuels – Deisel Emissions Control (APBF-DEC) Program, No. 2, Spring 2001.

[13] Multiyear Program Plan Advanced Petroleum-Based Fuels (APBF) RD&T for Compression-Ignition, Direct-Injection Engines and Emission Control Systems, Office of Advanced Automotive Technologies, Office of Heavy Vehicle Technologies, Energy Efficiency and Renewable Energy, November 1, 2000.

[14] Statement of Work, Advanced Petroleum Based Fuels – Diesel Emission Control Lubricants Project, National Renewable Energy Laboratory, December 20, 2000.

[15] Lanning, Lisa, ATL, Orban, John, Battelle, Tsai, Hsing-Chuan, Battelle, APBF-DEC, JCAP, C AFE Joint Meeting Presentation, "APBF-DEC Lubricants Project Status Report and Preliminary Findings", October 9, 2002.

[16] Telephone conversation with Dr. Gorden Bartley of SouthWest Research Institute, March 29, 2001.

[17] "SwRI forms research consortium on diesel aftertreatment sensitivity to lubricants", January 31, 2001, www.dieselnet.com/news/0101swri.html

APPENDIX J

Effect of Low Sulfur Diesel Fuel on Greenhouse Gas Emissions

■

IMPACT OF THE PROPOSED AMENDMENTS ON THE GREENHOUSE EFFECT

Earth's atmospheric gases serve to maintain higher terrestrial surface temperatures than would occur if the Earth had no atmosphere. This phenomenon is known as the "greenhouse effect," as the gases have a warming effect similar to the glass of a greenhouse in transmitting incoming solar radiation and blocking outgoing terrestrial radiation. The combustion of fossil fuels results in the formation of carbon dioxide (CO_2) and water vapor (H_2O), along with the release of chemical potential energy as heat. Carbon dioxide and water vapor are known as greenhouse gases (GHGs), due to their transparency to sunlight and their opacity to certain wavelengths of infrared radiation emitted from the Earth's surface. Other GHGs include methane (CH_4), carbon monoxide (CO), ozone (O_3), and nitrous oxide (N_2O).

By the end of the twentieth century, scientists around the world had become concerned that GHGs emitted by processes of anthropic origin are the cause of what seems to be global warming. The contribution of anthropically generated GHGs, emitted since 1765, to global warming is known as "radiative forcing." The radiative forcing for CO_2 is estimated to be 1.56 Watts per square meter (W/m^2). The total radiative forcing for all GHGs except water is estimated to be 2.45 W/m^2. Since H_2O condenses at atmospheric temperatures, and because clouds reflect some wavelengths of solar radiation, the effect of water vapor emissions on global warming is uncertain. The heat released in the combustion of fossil fuels and in the condensation of water vapor has a direct local warming effect on the atmosphere. However, this effect is not as persistent as radiative forcing.

Figure H-1 presents a simplified life-cycle schematic for refinery fuel products showing the various processes from which GHGs are emitted. Implementation of the proposed amendments will cause increases in GHG emissions for various processes in the life-cycle of California diesel fuel. These changes are due to an increase in gas production, hydrogen production process chemistry, and an increase in refinery process electricity and fuel requirements, compared to the current statewide diesel fuel composite. Methane emissions are expected to increase due to natural gas production and distribution losses. Methane losses will be small compared to the additional carbon dioxide emissions generated due to the additional gas production and refinery processing; however, methane emissions have 21 times the radiative forcing impact as carbon dioxide emissions. A smaller amount of additional methane and nitrous oxide will be emitted in the natural gas combustion process. We have estimated the incremental carbon dioxide emissions and carbon dioxide equivalent (CO_2 Eq.) methane and nitrous oxide emissions, which will result from the production of low-sulfur California diesel fuel. These emission increases should be substantially offset by a reduction in CO_2 emissions due to combustion of the low-sulfur, lower carbon diesel fuel. There should be no change in GHG emissions due to distribution of the low-sulfur California diesel fuel.

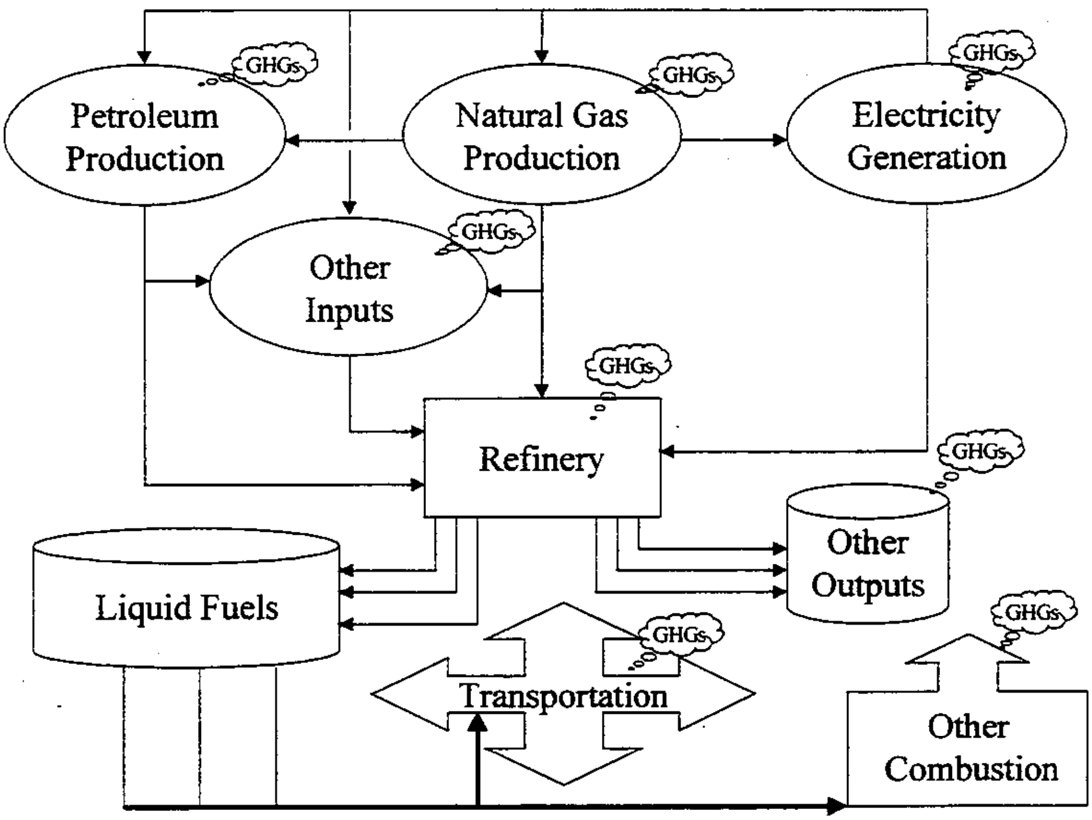


Figure 1: Life-Cycle Schematic for GHG Emissions for Refinery Products

Carbon Dioxide Emission Assumptions and Analysis

Table H-1. Table of Gross Assumptions
CARB Diesel Production and Delivery ($\rightarrow C_{14}H_{27}S_{0.00074}$) is assumed to be 80 percent efficient with respect to carbon dioxide emissions; i.e., approximately 25 percent more CO_2 emissions are attributable to the use of CARB Diesel than its end use combustion[1]. Additional CO_2 Eq. emissions include 2 percent of CO_2 from production and 1 percent of CO_2 from combustion.
Natural Gas Production and Delivery ($\rightarrow 0.775CH_4 + 0.160C_2H_6 + 0.065CO_2$) is assumed to be 91 percent efficient with respect to carbon dioxide emissions; i.e., approximately 10 percent more CO_2 emissions are attributable to the use of natural gas than its end use combustion[1]. Additional CO_2 Eq. emissions of 6.5 percent weight of gas are lost as CH_4 or emitted as CH_4 and N_2O in combustion.
Sulfur Reduction Model $\mathbf{C_{14}H_{27}S_{0.00074}} + 0.025H_2 =$ $0.974926C_{14}H_{27.334345} + 0.024334C_{14}H_{14} + 0.00074C_{14}H_{14}S + 0.025H_2$ $\rightarrow 0.974926C_{14}H_{27.334345} + 0.05C_7H_8 + 0.000074C_{14}H_{14}S + 0.000666S$ $= 1.025\mathbf{C_{13.658537}H_{26.390244}S_{0.000072195122}} + 0.000666S$
Additional energy will be required for gas production, compression, and heating; steam production; heat input for endothermic reactions; and hydrogen compression and heating. These additional energy requirements will result in CO_2 (and CO_2 equivalent) emissions due to the production, distribution, and combustion of natural gas. No additional energy will be required for pumping or heating of distillate blending components, no heat will be recovered from exothermic reactions, and energy consumption associated with the additional sulfur recovery and handling will be relatively insignificant.

Table H-2. Combustion Data for Fuels and Fuel Components	Natural Gas	CARB Diesel	Dibenzyl	Dibenzyl Sulfide	Toluene	Low-S CARB
CO_2 Factors (lbmols/lbmol)	1.16	14	14	14	7	13.6585
CO_2 Factors (lbs/lb)	2.540	3.1535	3.381	2.875	3.344	3.1530
Net Heating Value (Btus/lbmol)	368000	3602800	3092000	3398000	1610000	3517850
Net Heating Value (Btus/lb)	18300	18439	17000	15850	17500	18452
CO_2 Factors (lbmols/mmBtu)	3.15	3.8859	4.53	4.12	4.35	3.8826
CO_2 Factors (lbs/mmBtu)	139	171.02	199	181	191	170.88

[1] This analysis does not account for energy loss due to incomplete combustion or the impacts of carbon monoxide (CO) or soot emissions on global warming; however, we expect that these factors will be offset substantially by the associated reduction in CO_2 emissions.

Table H-3. Heats of Formation of Reactants and Products Involved in Hydrogen Production, Hydrodesulfurization, and Sulfur Production					
Compound	Formula	Weight	State	Btu/lbmol	Btu/lb
Methane	CH_4	16.04	Gas	-32000	-2000
Ethane	C_2H_6	30.07	Gas	-36000	-1200
Water	H_2O	18.02	Gas	-104000	-5769
Carbon Monoxide	CO	28.01	Gas	-47510	-1696
Carbon Dioxide	CO_2	44.01	Gas	-169200	-3844
Hydrogen	H_2	2.02	Gas	0	0
Dibenzyl	$C_{14}H_{14}$	182.26	Gas	58300	320
Dibenzyl Sulfide	$C_{14}H_{14}S$	214.33	Gas	83000	390
Toluene	C_7H_8	92.14	Gas	21500	230
Hydrogen Sulfide	H_2S	34.08	Gas	-8810	-259
Oxygen	O_2	32.00	Gas	0	0
Sulfur Dioxide	SO_2	64.06	Gas	-127600	-1992
Sulfur	S	32.07	Liquid	795	25
Water	H_2O	18.02	Gas	-104000	-5769

Table H-4. Reactions and Heats of Reactions Involved in Hydrogen Production, Hydrodesulfurization, and Sulfur Production			
Process	Reaction	Btu/lbmol	Btu/lb
Steam Reforming & Shift Conversion	$\mathbf{CH_4} + H_2O \rightarrow CO + 3H_2$	88500	5520
	$\mathbf{C_2H_6} + 2H_2O \rightarrow 2CO + 5H_2$	149000	4950
	$CO + H_2O \rightarrow \mathbf{CO_2} + H_2$	17700	402
Hydrotreatment & desulfurization	$\mathbf{C_{14}H_{14}} + H_2 \rightarrow 2C_7H_8$	-15300	-84
	$\mathbf{C_{14}H_{14}S} + 2H_2 \rightarrow 2C_7H_8 + H_2S$	-48800	-228
Sulfur Production	$2H_2S + 2O_2 \rightarrow SO_2 + \mathbf{S} + 2H_2O$	-317200	-9890
	$2H_2S + SO_2 \rightarrow 3\mathbf{S} + 2H_2O$	-20100	-628

Table H-5. Process Conditions and Energy Requirements				
Process Reactants	From	To	Btu/lbmol	Btu/lb
Natural Gas	1 atm, 80 °F	600 psig, 1500 °F	22200	1100
Reformer Steam	1 atm, 60 °F	600 psig, 1500 °F	31807	1765
Conversion Steam	1 atm, 60 °F	600 psig, 650 °F	23304	1293
Hydrogen	Cooled to 80 °F (constant volume)	900 psig, 800 °F	5070	2510

Based on the composition of natural gas, the steam reforming and shift conversion reactions, and the process reactant energy requirements; we can combine all of the direct CO_2 emissions, energy requirements, and indirect CO_2 and CO_2 Eq. emissions into a single equation for the production of high-pressure hydrogen gas from natural gas and water.

22200 Btu[2] +
0.775 CH_4 + 0.775*(31807 Btu[2]) + 0.775 H_2O + 0.775*(88500 Btu[3]) +
0.160 C_2H_6 + 0.320*(31807 Btu[2]) + 0.320 H_2O + 0.160*(149000 Btu[3]) +
1.095*(23304 Btu[2]) + 1.095 H_2O + 1.095*(17700 Btu[3]) +
0.065 CO_2 + 2.325*(5070 Btu[2]) + 0.800*(5070 Btu[2]) + 1.095*(5070 Btu[2])

→ 2.325 H_2 + 0.800 H_2 + 1.095 CO_2 + 1.095 H_2 +
{[22200 + (0.775 + 0.320)*(31807) + 0.775*(88500) + 0.160*(149000) + 1.095*(23304 + 17700) +(2.325 + 0.800 + 1.095)*(5070)] Btu
/(process energy efficiencies)/(natural gas production efficiency)}
*[CO_2 + CO_2 Eq. emission factors] +
0.065 CO_2

Assuming that gas compression and heating combined is 32 percent efficient[4], gross heat basis, and that steam production and process heating are each 80 percent efficient, gross heat basis; applying the efficiency of gas production and delivery, the CO_2 emission factor for the combustion of natural gas, and the CO_2 Eq. emission factor for CH_4 and N_2O emissions;

→ 4.22 H_2 + 1.16 CO_2 +
[22200/0.32/0.91 + 172156/0.80/0.91 + 21395/0.32/0.91] Btu/1.105
*[0.00000315 CO_2/Btu + (0.065/44.01/18300) CO_2 Eq./Btu],

where the gross energy requirements have been divided by 1.105 for application net energy CO_2 factors; and simplifying,

→ 4.22 H_2 + 1.16 CO_2 direct process emissions +
(1.10 CO_2 + 0.03 CO_2 Eq.) indirect process emissions,

→ 4.22 H_2 + 2.29 (CO_2 + CO_2 Eq.) total emissions.

For every molecule of high-pressure hydrogen gas produced for hydrotreating, 0.543 molecules of carbon dioxide and carbon dioxide equivalent are emitted to the

[2] Taken from Table H-5.
[3] Taken from Table H-4.
[4] We have based the assumption on a 50 percent energy transfer due to gas compression, assumed to be 20 percent efficient, and a 50 percent energy transfer due to heating, assumed to be 80 percent efficient (0.50/0.20 + 0.50/0.80 = 1.00/0.32).

atmosphere. On a mass basis, 11.8 pounds of carbon dioxide, and equivalent, are emitted per pound of high-pressure hydrogen gas produced.

From the sulfur reduction model and combustion data for CARB Diesel, the sulfur reduction will require 0.0250 molecules of hydrogen per molecule of CARB Diesel or 0.0140 pounds of hydrogen per million Btu of CARB Diesel. The additional hydrogen production will result in additional CO_2 and CO_2 Eq. emissions of 0.166 pounds per million Btu of CARB Diesel. This represents and increase of 0.0767 percent over the estimated 216 pounds per million Btu[5], currently emitted in the production, delivery, and combustion of CARB Diesel.

From the sulfur reduction model and combustion data, we estimate that the combustion of low-sulfur CARB Diesel will emit 170.88 pounds of CO_2 per million Btu of fuel. This is 0.14 pounds per million Btu less than the 171.02 pounds per million Btu emitted in the combustion of the current fuel. This reduction represents a 0.065 percent decrease in CO_2, and equivalent, emissions attributable to the production, distribution, and use of CARB Diesel, and will substantially offset the emission increase due to the production of the low-sulfur fuel. The net CO_2, and equivalent, emission increase is therefore expected to be about 0.026 pounds per million Btu, a 0.012 percent increase in emissions from California diesel fuel use[6].

The outcome of this analysis is sensitive to efficiency assumptions. If the energy transfer processes for hydrogen production are, on average, 20 percent more efficient than assumed; then, the additional CO_2 and CO_2 Eq. emissions from those processes will be 16.7 percent less than estimated. The production and use of low-sulfur CARB Diesel will then result in a net CO_2, and equivalent, emission increase of about 0.012 pounds per million Btu from the current statewide composite diesel fuel. This represents only a 0.0057 percent increase in CO_2, and equivalent, emissions from California diesel fuel use.

[5] [1.02*0.25 + 1.01*1.00]*(171.02 lbs/mmBtu) = 216.34 lbs/mmBtu

[6] Changes to GHG emissions other than carbon dioxide, which may occur due to combustion of low-sulfur CARB Diesel, have not been studied but would likely have a minor impact on the analysis.

Other Effects

Because suspended PM scatters solar radiation, a substantial portion of the radiation incident to the Earth's trosposphere is returned to space, thereby decreasing the net insolation at the Earth's surface. Due to this phenomenon, particulate sulfate is estimated to exert a global average cooling effect of -0.67 W/m^2. However, particulate black carbon (BC) (soot) from diesels and other sources absorbs solar radiation, as well as terrestrial infrared radiation, thereby warming the atmosphere. In addition to these direct scattering and absorption effects, there are also indirect effects associated with diesel PM and other aerosols. Tropospheric PM emissions may affect the size distribution of cloud droplets, altering the radiative properties of clouds and increasing their reflectivities. Particulate matter may also inhibit rainfall by increasing cloud lifetimes.

Black carbon aerosol causes positive climate forcing (warming) that is very uncertain in magnitude, but appears to be about 0.5 to 1 W/m^2. Black carbon may be the second most important component of global warming after CO_2, in terms of direct radiative forcing. The reduction of diesel particulate emissions with exhaust after-treatment or other means will help to reduce the BC component of global warming. Reducing soot emissions has the potential to slow global warming sooner than reducing carbon dioxide, methane, or other GHGs; because soot has a major impact on global warming and has a very short atmospheric lifetime compared to carbon dioxide. Reducing soot emissions has the additional benefit of reducing human health risk.

Nitrous oxide is produced as a byproduct of NO reduction and CO/HC oxidation on noble metal catalysts in gasoline vehicle exhaust systems. The effects of catalyzed diesel particulate filters and other diesel exhaust after-treatment devices on N_2O emissions are unknown. To the extent that regulated- pollutant, emission-equivalent diesel engines may replace gasoline engines in the future, a reduction or less rapid increase in N_2O emissions may result. Catalyzed after-treatment of diesel engines for PM control should also reduce methane and other hydrocarbon (HC) emissions from diesel engines.

APPENDIX K

Low Sulfur Diesel Fuel and Water Quality

EFFECT OF THE PROPOSED AMENDMENTS ON WATER QUALITY

A. Introduction

California refiners are expected to meet the proposed 15 ppm sulfur content limit for diesel fuel by increasing their hydrotreating capacity. This hydrotreating for sulfur removal is called hydrodesulfurization. With the low sulfur limit additional hydrotreating will be needed to desulfurize the more difficult higher molecular weight aromatic sulfur compounds consisting of two aromatic rings. A key objective of hydrotreating for sulfur removal is to minimize hydrogen consumption and cracking reactions while achieving the desired sulfur reduction.[i] The newest hydrotreating catalysts are highly selective and allow sulfur removal while minimizing cracking reactions and the amount of aromatics saturation. Therefore, the impact of the additional hydrotreating on other fuel components and specifications is much reduced. However, some conversion of aromatic compounds to aliphatic compounds, and the conversion of the more polar sulfur-containing compounds to less polar hydrocarbons, should reduce the water solubility of the low sulfur fuel compared with the current diesel fuel.

B. Solubility of Low Sulfur Diesel Fuel

1. Background

Diesel fuels contain many different hydrocarbon compounds. Most of these compounds contain carbon numbers between 10 and 22. Table 1 below lists of typical compounds found in diesel fuels.

Hydrocarbon compounds in diesel fuel can be classified according to the ease with which they can be desulfurized. The aliphatic (n- and isoparaffins) and aromatic compounds with a single aromatic ring are relatively easy to desulfurize. While compounds that contain two or more rings are much more difficult to desulfurize. This is due to the fact that the aliphatic and single-ring aromatic molecules are sufficiently flexible so that the sulfur atom is in a position where it can make physical contact with the surface of the catalyst during the desulfulrization process. The more difficult compounds are contained in aromatics consisting of two aromatic rings. These compounds are typically in the C_{12}-C_{16} boiling range, particularly dibenzothiophenes ($C_{12}H_{14}$).

Table 1

Typical Diesel Fuel Hydrocarbons

Compound	Chemical formula	Hydrocarbon Class
Napthalene	$C_{10}H_8$	Aromatic
Tetralin	$C_{10}H_{12}$	Aromatic
cis-Decalin	$C_{10}H_{18}$	Napthene
1,3-Diethylbenzene	$C_{10}H_{14}$	Aromatic
n-Butylcyclohexane	$C_{10}H_{20}$	Napthene
n-Pentylcyclopentane	$C_{10}H_{20}$	Napthene
Decane	$C_{10}H_{22}$	n-Paraffin
Anthracene	$C_{14}H_{10}$	Aromatic
1-Pentylnathalene	$C_{15}H_{18}$	Aromatic
n-Nonylcylohexane	$C_{15}H_{30}$	Naphthene
n-Decylcyclopentane	$C_{15}H_{30}$	Naphthene
n-Pentadecane	$C_{15}H_{32}$	n-Paraffin
2-Methyltetradecane	$C_{15}H_{32}$	Isoparaffin
1-Decylnaphthalene	$C_{20}H_{28}$	Aromatic
n-Tetradecylcylohexane	$C_{20}H_{34}$	Naphthene
n-Tetradecylclopentane	$C_{20}H_{40}$	Naphthene
n-Pentadecylcyclopentane	$C_{20}H_{40}$	Naphthene
Eicosane	$C_{20}H_{42}$	Naphthene
2-Methylnonadecane	$C_{20}H_{42}$	n-Paraffin

Source: Technical Review: Diesel Fuels, Chevron Products Company

2. *Properties*

Typically, the solubilities of aromatic compounds in water are much higher than the solubilities of aliphatic compounds. The solubilities of aromatics that contain sulfur (thioaromatics) are expected be to somewhat higher than the solubilities of aromatic hydrocarbons, because sulfur-containing compounds are slightly more polar. However, the overall solubility of diesel fuel is not expected to change significantly due to the removal of sulfur compounds.

Assuming that only the sulfur is removed and no cracking occurs, then all of the thioaromatics are converted aromatics. This would result in a decrease in the water solubility of the fuel. If cracking does occur during the desulfurization process, some or all of the thioaromatic compounds could be converted to aliphatics, and aliphatic compounds are orders of magnitude less soluble in water than aromatic compounds. Table 2 below shows the water solubility of petroleum hydrocarbons by carbon number range and structure type.

Table 2: Water Solubility of Total Petroleum Hydrocarbons by Carbon Number Range (mg/l)

Carbon Number Range	Aliphatics	Aromatics
>C8-C10	0.430000	65.000
>C10-C12	0.034000	25.000
>C12-C16	0.000760	5.800
>C16-C21	-	0.650
>C16-C35	0.000003	-
>C21-C35	-	0.0066

3. *Effect on Water Quality*

The California and national diesel fuel regulations implemented in 1993 reduced the sulfur content of diesel fuel from about 3000 ppmw to about 300 ppmw (about 140 ppmw in California). As of this date, there are no reports of groundwater contamination related to the lower-sulfur diesel fuel. The proposed regulation would reduce the sulfur content from about 140 ppmw to less than 15 ppmw, a much smaller change in fuel sulfur content and solubility properties than caused by the previous sulfur reduction. Therefore, we do not anticipate that there would be any impacts on ground water associated with proposed low-sulfur diesel fuel.

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i Moncrief, T. Ian., Montgomery, W. David., Ross, Martin T., Charles River Associates Inc., Ory, Raymond E., Carney, Jack T., Baker and O'Brien Inc., An Assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel, A study prepared by Charles River Associates Inc. and Baker and O'Brien Inc. for the American Petroleum Institute. August 2000.

APPENDIX L

Questionnaires Presented to California Refiners Producing Diesel Fuel

Questionnaires Presented to California Refiners Producing Diesel Fuel

To develop the cost estimates for the proposed amendments, staff sent out two surveys to California refineries producing California diesel fuel. The first survey was sent in April of 2001 and a second survey was sent out in March of 2003. The purpose for a second survey was to allow refineries to update any changes to the status of their low sulfur diesel production plans since the submission of their original survey.

(Survey #1 – April 2001)
Ultra-Low-Sulfur Diesel Survey Questions

Production

1. What is your current diesel production (CARB, EPA, high sulfur)?
   Please report monthly production figures by refinery and grade for calendar year 2000.

2. What is your current diesel capacity (CARB, EPA, high sulfur)?

   A. Do you currently have the ability to produce ultra-low-sulfur (<15 PPM Sulfur)? If so, how many BBL/day?
   B. Do you currently produce ultra-low-sulfur diesel? If so, how many BBL/day?
   C. Do you plan to produce ultra-low-sulfur diesel prior to 2006? If so, how many BBL/day?

3. When do you expect to convert CARB diesel production to ultra-low-sulfur diesel?

4. What change in the production/capacity of diesel fuel (compared to current production levels) do you foresee at your facilities when ultra-low-sulfur diesel is required? If 100% of your diesel production will not be ultra-low-sulfur diesel, what percentage will be the quality of the other production?

Equipment

5. What new equipment, if any, is planned for the production of ultra-low-sulfur diesel?

6. What modifications to existing equipment, if any, are planned for the production of ultra-low-sulfur diesel? What operational changes, if any, will be needed to produce ultra-low-sulfur diesel?

7. What changes in the diesel production stream, if any, are planned for the production of ultra-low-sulfur diesel?

8. What possible obstacles are foreseen in your production of ultra-low-sulfur diesel?

Costs

9. What is your estimate of the total costs for the modifications and operational changes needed to produce ultra-low-sulfur diesel (please itemize by cost)?

(Survey #2 – March 2003)
Ultra Low Sulfur Diesel Survey Questions

Production

1. What is your current diesel capacity (California low-sulfur, EPA on-road, EPA off-road)?

2. Do you currently have the ability to produce ultra low sulfur diesel (<15 ppm sulfur)? If so, how many BBL/day?

3. When do you expect to convert diesel production to ultra low sulfur diesel?

4. What change in the production/capacity of diesel fuel (compared to current production levels) do you foresee at your facilities when California ultra low sulfur diesel is required?

Equipment

5. What new equipment, if any, is needed for the production of California ultra low sulfur diesel?

6. How long do you expect the implementation period to take:
   A. Engineering
   B. Construction
   C. Equipment Shakedown

7. What modifications to existing equipment, if any, are planned for the production of California ultra low sulfur diesel?

8. What changes in the diesel production stream, if any, are planned for the production of California ultra low sulfur diesel?

Distribution

9. How much transmix do you currently generate from shipments of California low sulfur diesel through:
   A. Proprietary pipelines?
   B. Common carrier pipelines?

10. Will the amount of transmix generated be increased as a result of California ultra low sulfur diesel fuel? If there is a change, by how much?

Lubricity

11. What tests do you currently use for determining the lubricity level of your fuel?

12. What is the minimum lubricity level to which your fuel must conform? Do you retest your fuel after additization?

13. What is your average cost (cents/gallon) for lubricity additization?

14. What would be the incremental cost to additize to a higher lubricity level?
    A. Based on SBOCLE: __________________cents/gallon/gm increase.
    B. Based on HFRR: __________________cents/gallon/micron decrease.

Costs

15. What is your estimate of the total costs for the modifications and operational changes needed to produce both on- and off-road California ultra low sulfur diesel (please itemize by cost)?

APPENDIX M

Economic Impacts of Proposed Regulations on the Agricultural Sector

Economic Impacts of Proposed Regulations on the Agricultural Sector

In estimating the potential economic impacts of low sulfur diesel fuel on the agricultural sector, staff first identified the principal harvested commodities of the State, based on both the numbers of harvested acres as well as total commodity values. For the purposes of this analysis, harvested commodities are considered crops that are grown and either picked or harvested by hand or machine. Staff also identified principal livestock commodities, based on their commodity values, to estimate the potential economic impacts of low sulfur diesel to this category within the agricultural sector.

The tables below summarize staffs findings in the analysis of the economic impacts of the proposed regulations on the harvested commodities, including field crops, fruits and nuts, and vegetables and melons, cattle for dairy milk, and cattle for beef production categories.

HARVESTED CROPS:

FIELD, FRUITS & NUTS, VEGETABLES & MELONS

Summary of Harvested Commodities Fuel Operating Costs 2001

SECTOR / Commodities	Harvested Acres	Crop values ($1,000)	% of State Agricultural Total Value	Gasoline: Average gal/acre	Gasoline: Average price/gal*	Gasoline: Avg Total Gasoline cost/acre	Gasoline: Estimated Total Gasoline Use (kgal/year)	Diesel: Average gal/acre	Diesel: Average price/gal*	Diesel: Avg Total Diesel cost/acre	Diesel: Estimated Total Diesel Use (kgal/year)	Total Fuel cost/acre	Average Total Operating Costs / Acre (w/o fuel)**	Average Total Operating Costs / Acre**	Fuel Costs as % of Total Operating Costs	Diesel Fuel Costs as % of Total Operating Costs	Total Operating costs / Acre with 3 ¢ increase in diesel fuel	% change due to 3 ¢ diesel increase
FIELD CROPS																		
Beans, Dry	89,000	$52,589	0.19%	2.1	$1.06	$2.2	187	20.1	$0.83	$16.7	1,789	$18.9	$489	$508	3.72%	3.28%	$509	0.12%
Corn, All	475,000	$56,668	0.21%	0.8	$1.06	$0.8	380	21.3	$0.83	$17.7	10,118	$18.5	$545	$564	3.29%	3.14%	$564	0.11%
Cotton, All	864,000	$706,137	2.56%	0.8	$1.06	$0.8	691	40.2	$0.83	$33.4	34,733	$34.2	$664	$698	4.90%	4.78%	$699	0.17%
Hay, All	1,540,000	$588,931	2.14%	2.4	$1.06	$2.5	3696	22.0	$0.83	$18.3	33880	$20.8	$600	$621	3.35%	2.94%	$621	0.11%
Rice, All	471,000	$209,227	0.76%	1.1	$1.06	$1.2	518	22.3	$0.83	$18.5	10,503	$19.7	$496	$516	3.82%	3.59%	$516	0.13%
Wheat, All	461,000	$96,189	0.35%	0.6	$1.06	$0.6	277	13.2	$0.83	$11.0	6,085	$11.6	$149	$161	7.22%	6.82%	$161	0.25%
Sub-Total	3,900,000	$1,709,741	6.20%	1.3	$1.06	$1.38	5,749	23.2	$0.83	$19.2	97,108	$20.6	$491	$511	4.03%	3.76%	$512	0.15%
FRUITS & NUTS																		
Almonds	525,000	$731,880	2.65%	8.3	$1.06	$8.8	4,358	17.8	$0.83	$14.8	9,345	$23.6	$1,604	$1,628	1.45%	0.91%	$1,628	0.03%
Grapes																		
Raisin	235,000	$401,690	1.46%	3.8	$1.06	$4.0	893	26.1	$0.83	$21.7	6,134	$25.7	$1,164	$1,190	2.16%	1.82%	$1,190	0.07%
Table	88,000	$434,793	1.58%	4.6	$1.06	$4.9	405	26.8	$0.83	$22.2	2,358	$27.1	$6,011	$6,038	0.45%	0.37%	$6,039	0.01%
Wine	480,000	$1,817,140	6.59%	10.8	$1.06	$11.4	5,184	22.4	$0.83	$18.6	10,752	$30.0	$2,172	$2,202	1.36%	0.84%	$2,203	0.03%
Lemons	49,500	$247,042	0.90%	24.3	$1.06	$25.8	1,203	14.4	$0.83	$12.0	713	$37.7	$6,275	$6,313	0.60%	0.19%	$6,313	0.01%
Nectarines	36,500	$127,642	0.46%	11.4	$1.06	$12.1	416	77.4	$0.83	$64.2	2,825	$76.3	$9,661	$9,737	0.78%	0.66%	$9,740	0.02%
Oranges, All	194,500	$571,446	2.07%	24.2	$1.06	$25.7	4,707	11.6	$0.83	$9.6	2,256	$35.3	$3,748	$3,783	0.93%	0.25%	$3,784	0.01%
Peaches, All	67,800	$227,554	0.83%	8.0	$1.06	$8.5	542	42.9	$0.83	$35.6	2,909	$44.1	$5,514	$5,558	0.79%	0.64%	$5,559	0.02%
Pistachios	78,000	$159,390	0.58%	10.5	$1.06	$11.1	819	12.2	$0.83	$10.1	952	$21.3	$1,248	$1,269	1.67%	0.80%	$1,270	0.03%
Prunes	86,000	$146,843	0.53%	14.2	$1.06	$15.1	1,221	10.7	$0.83	$8.9	920	$23.9	$2,646	$2,670	0.90%	0.33%	$2,670	0.01%
Strawberries	26,400	$841,031	3.05%	25.0	$1.06	$26.5	660	81.1	$0.83	$67.3	2,141	$93.8	$24,729	$24,823	0.38%	0.27%	$24,825	0.01%
Walnuts	196,000	$341,600	1.24%	13.7	$1.06	$14.5	2,685	18.9	$0.83	$15.7	3,704	$30.2	$1,700	$1,730	1.75%	0.91%	$1,731	0.03%
Misc Fruits/Nuts***	47,000	$140,311	0.51%	13.2	$1.06	$14.0	620	30.2	$0.83	$25.1	1,419	$39.1	$5,539	$5,578	0.70%	0.45%	$5,579	0.02%
Sub-Total	2,109,700	$6,188,362	22.4%	13.2	$1.06	$14.02	23,713	30.2	$0.83	$25.06	46,428	$39.1	$5,539	$5,578	0.70%	0.45%	$5,579	0.02%
VEGS & MELONS																		
Broccoli	129,000	$438,118	1.59%	2.3	$1.06	$2.4	297	35.9	$0.83	$29.8	4,631	$32.2	$3,426	$3,458	0.93%	0.86%	$3,459	0.03%
Cantaloupe	56,800	$252,277	0.92%	24.9	$1.06	$26.4	1,414	36.1	$0.83	$30.0	2,050	$56.4	$2,749	$2,805	2.01%	1.07%	$2,806	0.04%
Cauliflower	42,500	$185,197	0.67%	6.5	$1.06	$6.9	276	36.6	$0.83	$30.4	1,556	$37.3	$5,439	$5,476	0.68%	0.55%	$5,477	0.02%
Celery	25,500	$259,865	0.94%	4.0	$1.06	$4.2	102	43.9	$0.83	$36.4	1,119	$40.7	$6,448	$6,489	0.63%	0.56%	$6,490	0.02%
Garlic	26,000	$140,166	0.51%	24.9	$1.06	$26.4	647	36.1	$0.83	$30.0	939	$56.4	$8,398	$8,454	0.67%	0.35%	$8,455	0.01%
Lettuce, All	228,000	$1,370,004	4.97%	9.1	$1.06	$9.6	2,075	27.0	$0.83	$22.4	6,156	$32.1	$3,118	$3,150	1.02%	0.71%	$3,151	0.03%
Onions	40,400	$184,224	0.67%	18.3	$1.06	$19.4	739	48.4	$0.83	$40.2	1,955	$59.6	$3,422	$3,482	1.71%	1.15%	$3,483	0.04%
Peppers, Bell	22,000	$147,305	0.53%	7.1	$1.06	$7.5	156	37.1	$0.83	$30.8	816	$38.3	$5,566	$5,604	0.68%	0.55%	$5,605	0.02%
Tomatoes																		
Fresh Market	41,000	$269,452	0.98%	2.1	$1.06	$2.2	86	46.4	$0.83	$38.5	1,902	$40.7	$4,935	$4,976	0.82%	0.77%	$4,977	0.03%
Processing	254,000	$496,808	1.80%	1.2	$1.06	$1.3	305	71.3	$0.83	$59.2	18,110	$60.5	$1,227	$1,287	4.70%	4.60%	$1,290	0.17%
Misc. Veg/Melons***	185,000	$995,727	3.61%	10.0	$1.06	$10.6	1,850	41.9	$0.83	$34.8	7,752	$45.4	$4,473	$4,518	1.00%	0.77%	$4,519	0.03%
Sub-Total	1,050,200	$4,739,143	17.2%	10.0	$1.06	$10.64	7,948	41.9	$0.83	$34.76	46,987	$45.4	$4,473	$4,518	1.00%	0.77%	$4,519	0.04%
Total	**7,059,900**	**$12,637,246**	**46%**	**10**	**$1.06**	**$10.3**	**$37,410**	**33**	**$0.83**	**$27.5**	**$190,523**	**$37.7**	**$4,139**	**$4,176**	**0.90%**	**0.66%**	**$4,177**	**0.05%**
% of state total	**25%**					or	**2.4** kb/day			or	**12.4** kb/day							

* Average price per gallon in 2001

** Includes inflation adjustment for data from previous years.

*** Assumes values will be similar to averages from other commodities within same category.

**** State-wide total harvested acres of 27,800,000 acres; with a total value of $27.6 billion dollars

Calculation of Average for Miscellaneous Commodity

Fruits & Nuts	13.2	$1.06	$14.0	1,924	30.2	$0.83	$25.1	3,751	$39.1	$5,539	$5,578	1.10%	0.67%
Veggies & Melons	10.0	$1.06	$10.6	610	41.9	$0.83	$34.8	3,924	$45.4	$4,473	$4,518	1.38%	1.12%
Field Crops	1.3	$1.06	$1.4	958	23.2	$0.83	$19.2	16,185	$20.6	$491	$511	4.38%	4.09%

283

Costs for Producing Almonds* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : SJV North	Organic, Sprinkler Irrigation	$1,760	4.2	$0.98	$4	0.23%	21.2	$0.71	$15	0.85%	$1,779
1992 : SJV North	Organic, Flood Irrigation	$1,625	4.2	$0.98	$4	0.25%	25.1	$0.71	$18	1.08%	$1,647
1995 : Sacramento	Sprinkler Irrigated	$1,257	9.0	$1.17	$11	0.82%	15.0	$0.85	$13	1.00%	$1,280
1997 : SJV South	Surface Irrigation	$1,527	7.3	$1.30	$9	0.61%	22.4	$0.97	$22	1.40%	$1,558
1998 : SJV North	Sprinkler Irrigation	$1,465	9.0	$1.22	$11	0.74%	19.8	$0.78	$15	1.03%	$1,491
1998 : SJV North	Flood Irrigation	$1,463	9.0	$1.22	$11	0.74%	21.1	$0.78	$16	1.10%	$1,490
2001 : Sacramento Valley	Low-Volume Sprinkler	$1,262	9.4	$1.51	$14	1.10%	11.7	$1.26	$15	1.14%	$1,291
2002 : SJV North	Flood Irrigation	$1,384	10.4	$1.51	$16	1.11%	15.1	$1.26	$19	1.34%	$1,419
2002 : SJV North	Micro-Sprinkler Irrigation	$1,429	10.6	$1.51	$16	1.10%	12.6	$1.26	$16	1.09%	$1,461
2002 : SJV North	Organic, Sprinkler Irrigation	$1,428	10.2	$1.51	$15	1.06%	13.7	$1.26	$17	1.18%	$1,461
	Average	$1,460	8.3	$1.29	$10.8	0.72%	17.8	$0.98	$17.5	1.18%	$1,488

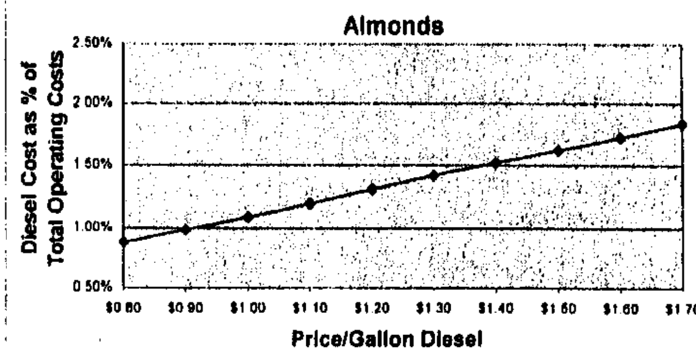
* Based on data from the UC Cooperative Extension on the costs to produce almonds in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : SJV North	Organic, Sprinkler Irrigation	2,221	4.2	$1.06	$4	0.20%	21.2	$0.83	$18	0.79%	$2,243
1992 : SJV North	Organic, Flood Irrigation	2,051	4.2	$1.06	$4	0.21%	25.1	$0.83	$21	1.00%	$2,077
1995 : Sacramento	Sprinkler Irrigated	1,460	9.0	$1.06	$10	0.64%	15.0	$0.83	$12	0.84%	$1,482
1997 : SJV South	Surface Irrigation	1,685	7.3	$1.06	$8	0.45%	22.4	$0.83	$19	1.09%	$1,711
1998 : SJV North	Sprinkler Irrigation	1,591	9.0	$1.06	$10	0.59%	19.8	$0.83	$16	1.01%	$1,617
1998 : SJV North	Flood Irrigation	1,589	9.0	$1.06	$10	0.59%	21.1	$0.83	$17	1.08%	$1,616
2001 : Sacramento Valley	Low-Volume Sprinkler	1,262	9.4	$1.06	$10	0.78%	11.7	$0.83	$10	0.76%	$1,282
2002 : SJV North	Flood Irrigation	1,363	10.4	$1.06	$11	0.80%	15.1	$0.83	$12	0.90%	$1,386
2002 : SJV North	Micro-Sprinkler Irrigation	1,407	10.6	$1.06	$11	0.79%	12.6	$0.83	$10	0.73%	$1,429
2002 : SJV North	Organic, Sprinkler Irrigation	1,406	10.2	$1.06	$11	0.76%	13.7	$0.83	$11	0.80%	$1,428
	Average	$1,604	8.3	$1.06	$8.8	0.54%	17.8	$0.83	$14.8	0.91%	$1,627

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	525,000	$853,984,933	$0.80	$7,464,240	0.87%
	525,000	$854,917,963	$0.90	$8,397,270	0.98%
	525,000	$855,850,993	$1.00	$9,330,300	1.09%
	525,000	$856,784,023	$1.10	$10,263,330	1.20%
	525,000	$857,717,053	$1.20	$11,196,360	1.31%
	525,000	$858,650,083	$1.30	$12,129,390	1.41%
	525,000	$859,583,113	$1.40	$13,062,420	1.52%
	525,000	$860,516,143	$1.50	$13,995,450	1.63%
	525,000	$861,449,173	$1.60	$14,928,480	1.73%
	525,000	$862,382,203	$1.70	$15,861,510	1.84%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing almonds.

Costs for Producing Beans* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1995 : San Luis Obispo	Garbanzo	$213	0.4	$1.20	$1	0.21%	25.7	$1.15	$30	12.16%	$243
1998 : SJV	Large Lima Beans	$588	1.1	$1.22	$1	0.21%	26.7	$0.78	$21	3.42%	$610
1998 : SJV	Baby Lima Beans	$562	1.1	$1.22	$1	0.22%	25.8	$0.78	$20	3.46%	$583
1999 : Sacramento	Common Dry Varieties	$446	2.5	$1.02	$3	0.55%	19.4	$0.62	$12	2.61%	$461
2001 : SJV South	Blackeye, Single Cropped	$519	3.7	$1.51	$6	1.03%	12.0	$1.26	$15	2.81%	$540
2001 : SJV South	Blackeye, Double Cropped	$446	3.7	$1.51	$6	1.20%	11.0	$1.26	$14	2.98%	$465
	Average	$462	2.1	$1.28	$2.6	0.55%	20.1	$0.98	$19.6	4.05%	$484

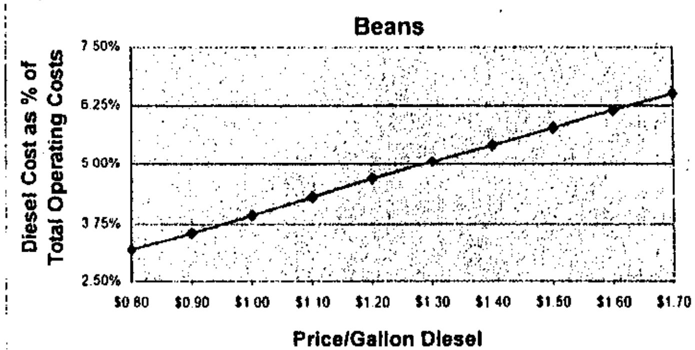
* Based on data from the UC Cooperative Extension on the costs to produce beans in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1995 : San Luis Obispo	Garbanzo	$247	0.4	$1.06	$0	0.17%	25.7	$0.83	$21	7.92%	$269
1998 : SJV	Large Lima Beans	$639	1.1	$1.06	$1	0.17%	26.7	$0.83	$22	3.35%	$662
1998 : SJV	Baby Lima Beans	$610	1.1	$1.06	$1	0.18%	25.8	$0.83	$21	3.39%	$633
1999 : Sacramento	Common Dry Varieties	$475	2.5	$1.06	$3	0.53%	19.4	$0.83	$16	3.26%	$493
2001 : SJV South	Blackeye, Single Cropped	$519	3.7	$1.06	$4	0.73%	12.0	$0.83	$10	1.87%	$533
2001 : SJV South	Blackeye, Double Cropped	$446	3.7	$1.06	$4	0.85%	11.0	$0.83	$9	1.99%	$459
	Average	$489	2.1	$1.06	$2.2	0.43%	20.1	$0.83	$16.7	3.28%	$508

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	89,000	$45,173,640	$0.80	$1,431,951	3.17%
	89,000	$45,352,633	$0.90	$1,610,945	3.55%
	89,000	$45,531,627	$1.00	$1,789,938	3.93%
	89,000	$45,710,621	$1.10	$1,968,932	4.31%
	89,000	$45,889,615	$1.20	$2,147,926	4.68%
	89,000	$46,068,609	$1.30	$2,326,920	5.05%
	89,000	$46,247,603	$1.40	$2,505,914	5.42%
	89,000	$46,426,596	$1.50	$2,684,908	5.78%
	89,000	$46,605,590	$1.60	$2,863,901	6.14%
	89,000	$46,784,584	$1.70	$3,042,895	6.50%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing beans.

Costs for Producing Broccoli* in California

			Gasoline				Diesel				
Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	Total Operating Costs per Acre
1999 : Ventura County	Broccoli	$2,480	4.0	$1.20	$5	0.19%	39.6	$0.72	$29	1.14%	$2,513
2001 : Monterey County	Fresh Market	$4,216	0.7	$1.51	$1	0.02%	32.1	$1.26	$40	0.95%	$4,257
	Average	$3,348	2.3	$1.36	$3.2	0.09%	35.9	$0.99	$35.5	1.05%	$3,385

* Based on data from the UC Cooperative Extension on the costs to produce broccoli in selected counties.

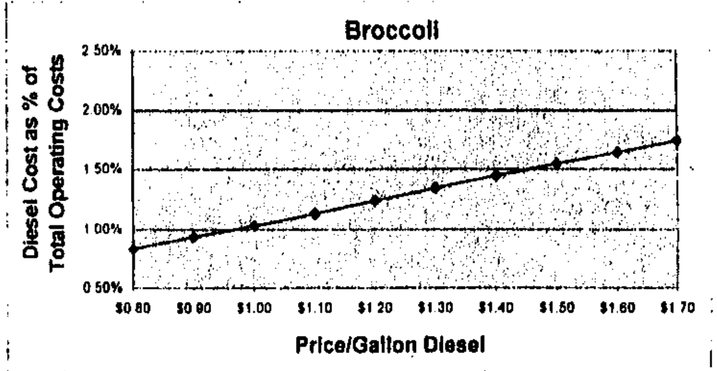
Adjusted to 2001 to Reflect Inflation*

			Gasoline				Diesel				
Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	Total Operating Costs per Acre
1999 : Ventura County	Broccoli	$2,636	4.0	$1.06	$4	0.16%	39.6	$0.83	$33	1.23%	$2,673
2001 : Monterey County	Fresh Market	$4,216	0.7	$1.06	$1	0.02%	32.1	$0.83	$27	0.63%	$4,243
	Average	$3,426	2.3	$1.06	$2.5	0.07%	35.9	$0.83	$29.8	0.86%	$3,458

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	129,000	$445,941,941	$0.80	$3,700,752	0.83%
	129,000	$446,404,535	$0.90	$4,163,346	0.93%
	129,000	$446,867,129	$1.00	$4,625,940	1.04%
	129,000	$447,329,723	$1.10	$5,088,534	1.14%
	129,000	$447,792,317	$1.20	$5,551,128	1.24%
	129,000	$448,254,911	$1.30	$6,013,722	1.34%
	129,000	$448,717,505	$1.40	$6,476,316	1.44%
	129,000	$449,180,099	$1.50	$6,938,910	1.54%
	129,000	$449,642,693	$1.60	$7,401,504	1.65%
	129,000	$450,105,287	$1.70	$7,864,098	1.75%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing broccoli.



Costs for Producing Cantaloupe* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : SJV	Cantaloupe	$2,243	0.7	$0.98	$1	0.03%	29.2	$0.71	$21	0.92%	$2,264
	Average	$2,243	0.7	$0.98	$0.6	0.03%	29.2	$0.71	$20.7	0.92%	$2,264

* Based on data from the UC Cooperative Extension on the costs to produce cantaloupe in selected counties.

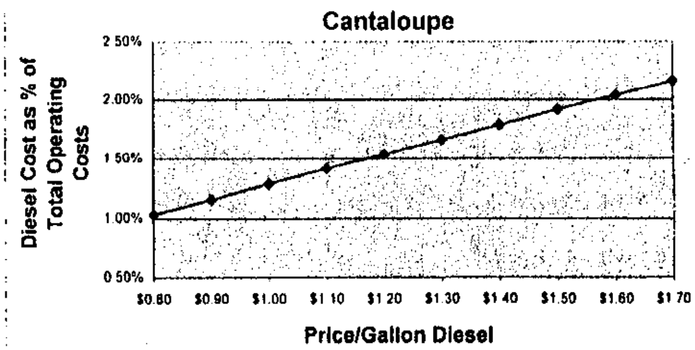
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : SJV	Cantaloupe	$2,749	24.9	$1.06	$26	0.94%	36.1	$0.83	$30	1.07%	$2,805
	Average	$2,749	24.9	$1.06	$26.4	0.94%	36.1	$0.83	$30.0	1.07%	$2,805

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	56,800	$159,255,872	$0.80	$1,640,384	1.03%
	56,800	$159,460,920	$0.90	$1,845,432	1.16%
	56,800	$159,665,968	$1.00	$2,050,480	1.28%
	56,800	$159,871,016	$1.10	$2,255,528	1.41%
	56,800	$160,076,064	$1.20	$2,460,576	1.54%
	56,800	$160,281,112	$1.30	$2,665,624	1.66%
	56,800	$160,486,160	$1.40	$2,870,672	1.79%
	56,800	$160,691,208	$1.50	$3,075,720	1.91%
	56,800	$160,896,256	$1.60	$3,280,768	2.04%
	56,800	$161,101,304	$1.70	$3,485,816	2.16%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing cantaloupe.



287

Costs for Producing Cauliflower* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic Cauliflower	$5,110	11.7	$0.98	$11	0.22%	32.8	$0.71	$23	0.45%	$5,145
2001 : Central Coast	Fresh Market	$4,616	1.4	$1.51	$2	0.04%	40.3	$1.26	$51	1.09%	$4,669
	Average	$4,863	6.5	$1.25	$8.1	0.17%	36.6	$0.99	$36.0	0.73%	$4,907

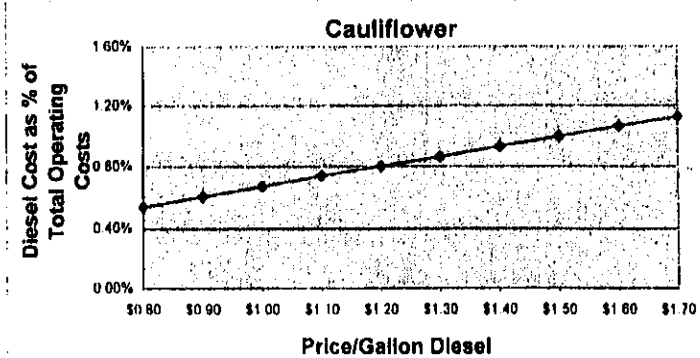
* Based on data from the UC Cooperative Extension on the costs to produce cauliflower in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic Cauliflower	$6,263	11.7	$1.06	$12	0.20%	32.8	$0.83	$27	0.43%	$6,302
2001 : Central Coast	Fresh Market	$4,616	1.4	$1.06	$1	0.03%	40.3	$0.83	$33	0.72%	$4,651
	Average	$5,439	6.5	$1.06	$6.9	0.13%	36.6	$0.83	$30.3	0.55%	$5,477

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	42,500	$232,715,512	$0.80	$1,243,040	0.53%
	42,500	$232,870,892	$0.90	$1,398,420	0.60%
	42,500	$233,026,272	$1.00	$1,553,800	0.67%
	42,500	$233,181,652	$1.10	$1,709,180	0.73%
	42,500	$233,337,032	$1.20	$1,864,560	0.80%
	42,500	$233,492,412	$1.30	$2,019,940	0.87%
	42,500	$233,647,792	$1.40	$2,175,320	0.93%
	42,500	$233,803,172	$1.50	$2,330,700	1.00%
	42,500	$233,958,552	$1.60	$2,486,080	1.06%
	42,500	$234,113,932	$1.70	$2,641,460	1.13%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing cauliflower.

Costs for Producing Celery* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1999 : Ventura County	Fresh Market	$6,066	4.0	$1.20	$5	0.08%	43.9	$0.72	$32	0.52%	$6,102
	Average	$6,066	4.0	$1.20	$4.8	0.08%	43.9	$0.72	$31.6	0.52%	$6,102

* Based on data from the UC Cooperative Extension on the costs to produce celery in selected counties.

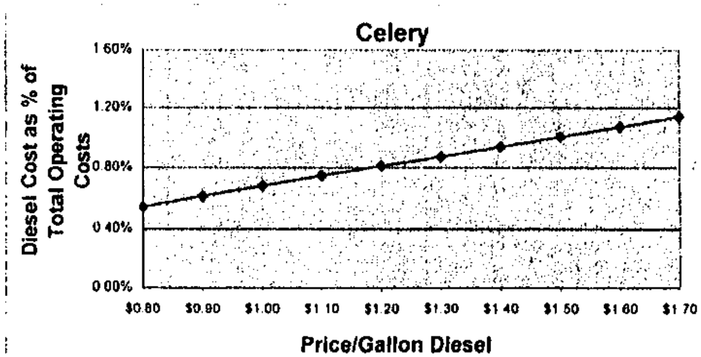
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1999 : Ventura County	Fresh Market	$6,448	4.0	$1.06	$4	0.07%	43.9	$0.83	$36	0.56%	$6,489
	Average	$6,448	4.0	$1.06	$4.2	0.07%	43.9	$0.83	$36.4	0.56%	$6,489

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	25,500	$165,424,522	$0.80	$894,948	0.54%
	25,500	$165,536,391	$0.90	$1,006,817	0.61%
	25,500	$165,648,259	$1.00	$1,118,685	0.68%
	25,500	$165,760,128	$1.10	$1,230,554	0.74%
	25,500	$165,871,996	$1.20	$1,342,422	0.81%
	25,500	$165,983,865	$1.30	$1,454,291	0.88%
	25,500	$166,095,733	$1.40	$1,566,159	0.94%
	25,500	$166,207,602	$1.50	$1,678,028	1.01%
	25,500	$166,319,470	$1.60	$1,789,896	1.08%
	25,500	$166,431,339	$1.70	$1,901,765	1.14%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing celery.



289

Costs for Producing Corn* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1999 : SJV	Field Corn	$571	0.6	$1.02	$1	0.10%	21.7	$0.62	$13	2.30%	$585
2000 : Sacramento / Yolo	Field Corn	$346	0.8	$1.49	$1	0.30%	26.2	$1.26	$33	8.69%	$380
2001 : SJV	Corn Silage	$673	1.0	$1.51	$1	0.21%	16.1	$1.26	$20	2.92%	$695
	Average	$530	0.8	$1.34	$1.0	0.19%	21.3	$1.05	$22.3	4.04%	$553

* Based on data from the UC Cooperative Extension on the costs to produce corn in selected counties.

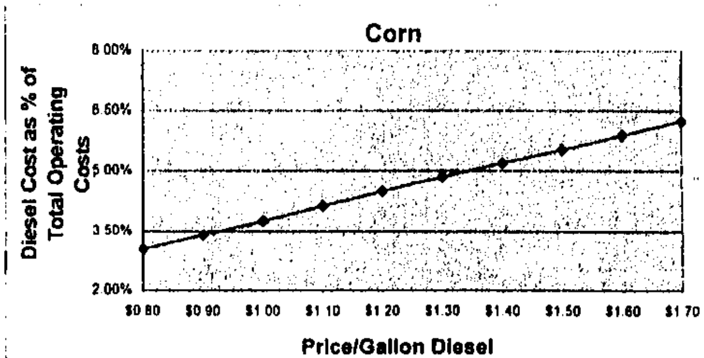
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1999 : SJV	Field Corn	$607	0.6	$1.06	$1	0.10%	21.7	$0.83	$18	2.88%	$626
2000 : Sacramento / Yolo	Field Corn	$356	0.8	$1.06	$1	0.22%	26.2	$0.83	$22	5.75%	$378
2001 : SJV	Corn Silage	$673	1.0	$1.06	$1	0.15%	16.1	$0.83	$13	1.95%	$688
	Average	$545	0.8	$1.06	$0.8	0.15%	21.3	$0.83	$17.7	3.14%	$564

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	475,000	$267,508,163	$0.80	$8,111,733	3.03%
	475,000	$268,522,130	$0.90	$9,125,700	3.40%
	475,000	$269,536,096	$1.00	$10,139,667	3.76%
	475,000	$270,550,063	$1.10	$11,153,633	4.12%
	475,000	$271,564,030	$1.20	$12,167,600	4.48%
	475,000	$272,577,996	$1.30	$13,181,567	4.84%
	475,000	$273,591,963	$1.40	$14,195,533	5.19%
	475,000	$274,605,930	$1.50	$15,209,500	5.54%
	475,000	$275,619,896	$1.60	$16,223,467	5.89%
	475,000	$276,633,863	$1.70	$17,237,433	6.23%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing corn.



Costs for Producing Cotton* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1995 : SJV North	Organic Cotton	$624	1.6	$1.15	$2	0.28%	26.4	$0.75	$20	3.07%	$646
1997 : Palo Verde Valley	Cotton	$435	1.6	$1.40	$2	0.45%	52.9	$0.95	$50	10.32%	$487
1999 : SJV	Pima Varieties	$663	0.5	$1.02	$0	0.07%	44.4	$0.62	$28	3.98%	$691
1999 : SJV	30" Row Acala Variety	$607	0.5	$1.02	$0	0.08%	42.4	$0.62	$26	4.14%	$634
1999 : SJV	40" Row Acala Variety	$643	0.5	$1.02	$0	0.07%	41.1	$0.62	$25	3.81%	$669
1999 : SJV	Transgenic, Herbicide-Resistant	$637	0.5	$1.02	$0	0.07%	39.3	$0.62	$24	3.68%	$662
2002 : Sacramento	California Upland	$743	0.5	$1.51	$1	0.09%	35.2	$1.26	$44	5.63%	$788
	Average	$622	0.8	$1.16	$0.9	0.14%	40.2	$0.78	$31.3	4.78%	$654

* Based on data from the UC Cooperative Extension on the costs to produce cotton in selected counties.

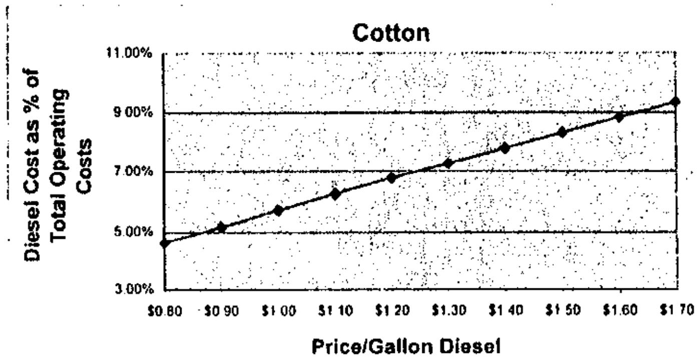
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1995 : SJV North	Organic Cotton	$726	1.6	$1.06	$2	0.23%	26.4	$0.83	$22	2.93%	$749
1997 : Palo Verde Valley	Cotton	$479	1.6	$1.06	$2	0.31%	52.9	$0.83	$44	8.36%	$525
1999 : SJV	Pima Varieties	$705	0.5	$1.06	$1	0.07%	44.4	$0.83	$37	4.96%	$742
1999 : SJV	30" Row Acala Variety	$646	0.5	$1.06	$1	0.07%	42.4	$0.83	$35	5.16%	$681
1999 : SJV	40" Row Acala Variety	$684	0.5	$1.06	$1	0.07%	41.1	$0.83	$34	4.75%	$718
1999 : SJV	Transgenic, Herbicide-Resistant	$677	0.5	$1.06	$1	0.07%	39.3	$0.83	$33	4.59%	$710
2002 : Sacramento	California Upland	$731	0.5	$1.06	$1	0.07%	35.2	$0.83	$29	3.84%	$761
	Average	$664	0.8	$1.06	$0.8	0.12%	40.2	$0.83	$33.4	4.78%	$698

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	864,000	$602,177,560	$0.80	$27,804,014	4.62%
	864,000	$605,653,061	$0.90	$31,279,515	5.16%
	864,000	$609,128,563	$1.00	$34,755,017	5.71%
	864,000	$612,604,065	$1.10	$38,230,519	6.24%
	864,000	$616,079,567	$1.20	$41,706,021	6.77%
	864,000	$619,555,068	$1.30	$45,181,522	7.29%
	864,000	$623,030,570	$1.40	$48,657,024	7.81%
	864,000	$626,506,072	$1.50	$52,132,526	8.32%
	864,000	$629,981,573	$1.60	$55,608,027	8.83%
	864,000	$633,457,075	$1.70	$59,083,529	9.33%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing cotton.



Costs for Producing Garlic* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic Garlic	$6,852	24.9	$0.98	$24	0.35%	36.1	$0.71	$26	0.37%	$6,902
	Average	$6,852	24.9	$0.98	$24.4	0.35%	36.1	$0.71	$25.6	0.37%	$6,902

* Based on data from the UC Cooperative Extension on the costs to produce garlic in selected counties.

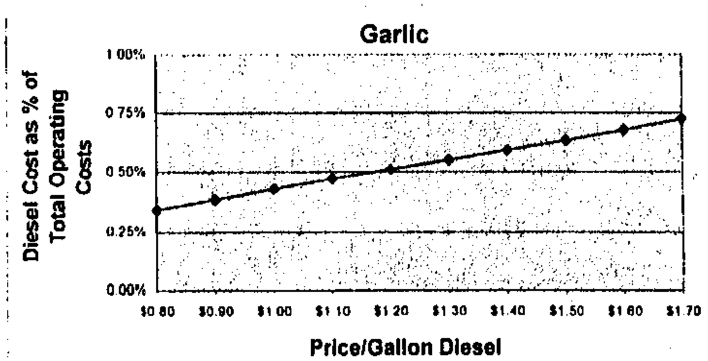
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic Garlic	$8,398	24.9	$1.06	$26	0.31%	36.1	$0.83	$30	0.35%	$8,454
	Average	$8,398	24.9	$1.06	$26.4	0.31%	36.1	$0.83	$30.0	0.35%	$8,454

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	26,000	$219,784,758	$0.80	$750,880	0.34%
	26,000	$219,878,618	$0.90	$844,740	0.38%
	26,000	$219,972,478	$1.00	$938,600	0.43%
	26,000	$220,066,338	$1.10	$1,032,460	0.47%
	26,000	$220,160,198	$1.20	$1,126,320	0.51%
	26,000	$220,254,058	$1.30	$1,220,180	0.55%
	26,000	$220,347,918	$1.40	$1,314,040	0.60%
	26,000	$220,441,778	$1.50	$1,407,900	0.64%
	26,000	$220,535,638	$1.60	$1,501,760	0.68%
	26,000	$220,629,498	$1.70	$1,595,620	0.72%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing garlic.



Costs for Producing Raisin Grapes* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1997 : SJV	Thompson Seedless Raisins	$1,251	4.5	$1.30	$6	0.45%	29.7	$0.97	$29	2.24%	$1,286
1997 : SJV South	Organic Raisin Grapes	$987	4.5	$1.30	$6	0.57%	25.1	$0.97	$24	2.39%	$1,017
1998 : Fresno	40 Acre Raisin Vineyard	$977	2.8	$1.22	$3	0.34%	25.7	$0.78	$20	2.00%	$1,001
1998 : Fresno	120 Acre Raisin Vineyard	$1,034	3.6	$1.22	$4	0.41%	23.9	$0.78	$19	1.76%	$1,057
	Average	$1,062	3.8	$1.26	$4.8	0.44%	26.1	$0.88	$22.8	2.09%	$1,090

* Based on data from the UC Cooperative Extension on the costs to produce raisin grapes in selected counties.

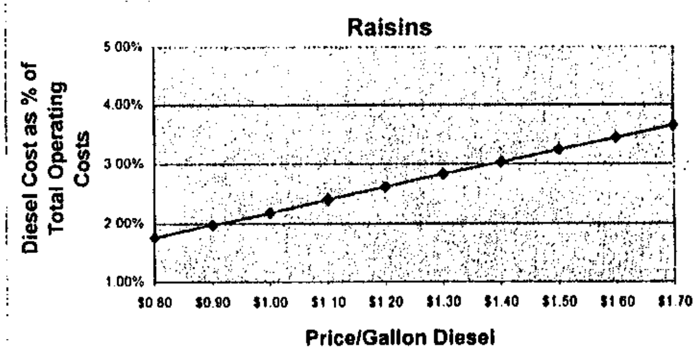
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1997 : SJV	Thompson Seedless Raisins	$1,381	4.5	$1.06	$5	0.34%	29.7	$0.83	$25	1.75%	$1,410
1997 : SJV South	Organic Raisin Grapes	$1,089	4.5	$1.06	$5	0.42%	25.1	$0.83	$21	1.87%	$1,115
1998 : Fresno	40 Acre Raisin Vineyard	$1,062	2.8	$1.06	$3	0.28%	25.7	$0.83	$21	1.97%	$1,086
1998 : Fresno	120 Acre Raisin Vineyard	$1,123	3.6	$1.06	$4	0.33%	23.9	$0.83	$20	1.73%	$1,147
	Average	$1,164	3.8	$1.06	$4.1	0.34%	26.1	$0.83	$21.7	1.82%	$1,190

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	235,000	$279,365,145	$0.80	$4,904,450	1.76%
	235,000	$279,978,201	$0.90	$5,517,506	1.97%
	235,000	$280,591,257	$1.00	$6,130,563	2.18%
	235,000	$281,204,314	$1.10	$6,743,619	2.40%
	235,000	$281,817,370	$1.20	$7,356,675	2.61%
	235,000	$282,430,426	$1.30	$7,969,731	2.82%
	235,000	$283,043,482	$1.40	$8,582,788	3.03%
	235,000	$283,656,539	$1.50	$9,195,844	3.24%
	235,000	$284,269,595	$1.60	$9,808,900	3.45%
	235,000	$284,882,651	$1.70	$10,421,956	3.66%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing raisin grapes.



Costs for Producing Table Grapes* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1998 : SJV	Thompson Seedless Raisins	$5,533	4.6	$1.22	$6	0.10%	26.8	$0.78	$21	0.38%	$5,559
	Average	$5,533	4.6	$1.22	$5.6	0.10%	26.8	$0.78	$20.9	0.38%	$5,559

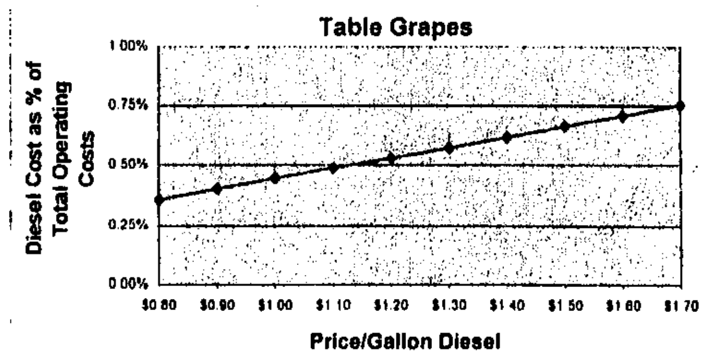
* Based on data from the UC Cooperative Extension on the costs to produce table grapes in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1998 : SJV	Thompson Seedless Raisins	$6,011	4.6	$1.06	$5	0.08%	26.8	$0.83	$22	0.37%	$6,038
	Average	$6,011	4.6	$1.06	$4.8	0.08%	26.8	$0.83	$22.2	0.37%	$6,038

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	88,000	$531,289,863	$0.80	$1,886,720	0.36%
	88,000	$531,525,703	$0.90	$2,122,560	0.40%
	88,000	$531,761,543	$1.00	$2,358,400	0.44%
	88,000	$531,997,383	$1.10	$2,594,240	0.49%
	88,000	$532,233,223	$1.20	$2,830,080	0.53%
	88,000	$532,469,063	$1.30	$3,065,920	0.58%
	88,000	$532,704,903	$1.40	$3,301,760	0.62%
	88,000	$532,940,743	$1.50	$3,537,600	0.66%
	88,000	$533,176,583	$1.60	$3,773,440	0.71%
	88,000	$533,412,423	$1.70	$4,009,280	0.75%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing table grapes.

Costs for Producing Wine Grapes* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : North Coast	Organic, annual sown cover crop	$2,134		$0.98	$0	0.00%	40.0	$0.71	$28	1.31%	$2,162
1992 : North Coast	Organic, resident vegetation	$2,075		$0.98	$0	0.00%	34.5	$0.71	$25	1.17%	$2,100
1996 : Sierra Nevada	Zinfandel Variety 28 Acre	$1,507	17.8	$1.47	$26	1.70%	9.2	$1.09	$10	0.65%	$1,543
1996 : Santa Maria Valley	Drip Irrigated Chardonnay	$2,152	3.2	$1.20	$4	0.18%	24.3	$1.15	$28	1.28%	$2,184
1996 : San Luis Obispo	Drip Irrigated Cabernet Sauvignon	$2,525	3.2	$1.40	$4	0.18%	14.6	$1.15	$17	0.66%	$2,546
1997 : SJV	Wine Grapes	$1,142	4.5	$1.30	$6	0.50%	18.6	$0.97	$18	1.55%	$1,166
1998 : Lake County	Sauvignon Blanc	$1,919	5.1	$1.22	$6	0.32%	16.3	$0.78	$13	0.66%	$1,938
1999 : Sonoma County	Chardonnay	$2,861	17.8	$1.02	$18	0.63%	31.6	$0.62	$20	0.68%	$2,899
2000 : Sierra Nevada	Zinfandel Variety 5 Acre	$1,632	37.5	$1.49	$56	3.26%	20.1	$1.09	$22	1.28%	$1,710
2001 : SJV North	Cabernet Sauvignon	$1,651	2.7	$1.51	$4	0.25%	14.6	$1.26	$18	1.10%	$1,673
2002 : Sacramento	Chardonnay	$1,910	5.7	$1.51	$9	0.44%	22.7	$1.26	$29	1.47%	$1,947
	Average	$1,955	10.8	$1.28	$13.9	0.70%	22.4	$0.98	$22.0	1.11%	$1,988

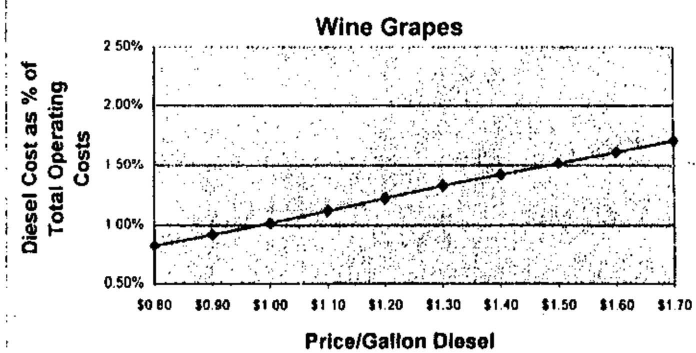
* Based on data from the UC Cooperative Extension on the costs to produce wine grapes in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : North Coast	Organic, annual sown cover crop	$2,693		$1.06	$0	0.00%	40.0	$0.83	$33	1.22%	$2,726
1992 : North Coast	Organic, resident vegetation	$2,619		$1.06	$0	0.00%	34.5	$0.83	$29	1.08%	$2,648
1996 : Sierra Nevada	Zinfandel Variety 28 Acre	$1,701	17.8	$1.06	$19	1.09%	9.2	$0.83	$8	0.44%	$1,727
1996 : Santa Maria Valley	Drip Irrigated Chardonnay	$2,429	3.2	$1.06	$3	0.14%	24.3	$0.83	$20	0.82%	$2,453
1996 : San Luis Obispo	Drip Irrigated Cabernet Sauvignon	$2,850	3.2	$1.06	$3	0.12%	14.6	$0.83	$12	0.42%	$2,865
1997 : SJV	Wine Grapes	$1,260	4.5	$1.06	$5	0.37%	18.6	$0.83	$15	1.21%	$1,280
1998 : Lake County	Sauvignon Blanc	$2,085	5.1	$1.06	$5	0.26%	16.3	$0.83	$14	0.64%	$2,104
1999 : Sonoma County	Chardonnay	$3,042	17.8	$1.06	$19	0.61%	31.6	$0.83	$26	0.85%	$3,087
2000 : Sierra Nevada	Zinfandel Variety 5 Acre	$1,679	37.5	$1.06	$40	2.29%	20.1	$0.83	$17	0.98%	$1,735
2001 : SJV North	Cabernet Sauvignon	$1,651	2.7	$1.06	$3	0.17%	14.6	$0.83	$12	0.73%	$1,666
2002 : Sacramento	Chardonnay	$1,880	5.7	$1.06	$6	0.32%	22.7	$0.83	$19	0.99%	$1,905
	Average	$2,172	10.8	$1.06	$11.5	0.52%	22.4	$0.83	$18.6	0.85%	$2,200

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	480,000	$1,055,532,597	$0.80	$8,604,393	0.82%
	480,000	$1,056,608,146	$0.90	$9,679,942	0.92%
	480,000	$1,057,683,695	$1.00	$10,755,491	1.02%
	480,000	$1,058,759,244	$1.10	$11,831,040	1.12%
	480,000	$1,059,834,793	$1.20	$12,906,589	1.22%
	480,000	$1,060,910,342	$1.30	$13,982,138	1.32%
	480,000	$1,061,985,891	$1.40	$15,057,687	1.42%
	480,000	$1,063,061,440	$1.50	$16,133,236	1.52%
	480,000	$1,064,136,989	$1.60	$17,208,785	1.62%
	480,000	$1,065,212,538	$1.70	$18,284,335	1.72%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing wine grapes.

Costs for Producing Hay Alfalfa* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1998 : San Luis Obispo	Alfalfa	$401	3.6	$0.99	$4	0.84%	27.1	$0.75	$20	4.77%	$425
1998 : SJV	Alfalfa Hay, 300 Acre Planting	$771	1.9	$1.22	$2	0.29%	35.1	$0.78	$27	3.42%	$801
1998 : Sacramento Valley	Alfalfa Hay, Flood Irrigated	$900	2.6	$1.22	$3	0.35%	29.5	$0.78	$23	2.48%	$926
2001 : Siskiyou County	lfalfa Hay, Center Pivot Irrigatio	$356	1.9	$1.51	$3	0.76%	9.3	$1.26	$12	3.15%	$370
2001 : Siskiyou County	Alfalfa Hay, Wheel Line Irrigatio	$395	1.9	$1.51	$3	0.68%	9.3	$1.26	$12	2.85%	$409
	Average	$564	2.4	$1.29	$3.1	0.52%	22.0	$0.97	$21.3	3.63%	$586

* Based on data from the UC Cooperative Extension on the costs to produce alfalfa hay in selected counties.

Note: Operating costs include costs to establish an alfalfa stand and costs to produce alfalfa hay. Assumes costs to produce alfalfa and hay are similar.

Adjusted to 2001 to Reflect Inflation*

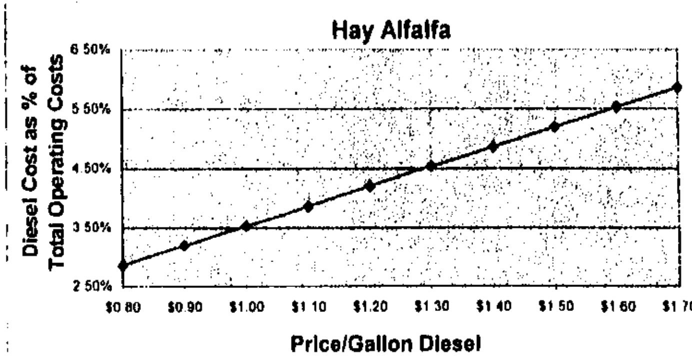
Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1998 : San Luis Obispo	Alfalfa	436	3.6	$1.06	$4	0.83%	27.1	$0.83	$22	4.86%	$462
1998 : SJV	Alfalfa Hay, 300 Acre Planting	838	1.9	$1.06	$2	0.23%	35.1	$0.83	$29	3.35%	$869
1998 : Sacramento Valley	Alfalfa Hay, Flood Irrigated	978	2.6	$1.06	$3	0.28%	29.5	$0.83	$24	2.44%	$1,005
2001 : Siskiyou County	lfalfa Hay, Center Pivot Irrigatio	356	1.9	$1.06	$2	0.54%	9.3	$0.83	$8	2.10%	$365
2001 : Siskiyou County	Alfalfa Hay, Wheel Line Irrigatio	395	1.9	$1.06	$2	0.49%	9.3	$0.83	$8	1.90%	$404
	Average	$600	2.4	$1.06	$2.5	0.40%	22.0	$0.83	$18.3	2.95%	$621

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	1,540,000	$955,552,989	$0.80	$27,153,280	2.84%
	1,540,000	$958,947,149	$0.90	$30,547,440	3.19%
	1,540,000	$962,341,309	$1.00	$33,941,600	3.53%
	1,540,000	$965,735,469	$1.10	$37,335,760	3.87%
	1,540,000	$969,129,629	$1.20	$40,729,920	4.20%
	1,540,000	$972,523,789	$1.30	$44,124,080	4.54%
	1,540,000	$975,917,949	$1.40	$47,518,240	4.87%
	1,540,000	$979,312,109	$1.50	$50,912,400	5.20%
	1,540,000	$982,706,269	$1.60	$54,306,560	5.53%
	1,540,000	$986,100,429	$1.70	$57,700,720	5.85%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.

** Assumes that increases in diesel fuel price does not increase other direct costs for producing alfalfa hay.



Costs for Producing Lemons* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline				Diesel				Total Operating Costs per Acre
			Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	
1997 : Ventura County	Lemons	$4,436	18.5	$1.20	$22	0.50%	12.6	$1.15	$14	0.32%	$4,473
1997 : South Coast	Organic, Fresh Market	$3,131	4.7	$1.30	$6	0.19%	8.1	$0.97	$8	0.25%	$3,145
1998 : San Diego County	Lemons	$9,756	50.1	$1.20	$60	0.61%	25.3	$0.85	$21	0.22%	$9,838
1998 : Coachella Valley	Lemons	$5,661	23.7	$1.16	$28	0.48%	11.8	$0.76	$9	0.16%	$5,697
	Average	$5,746	24.3	$1.22	$29.5	0.51%	14.4	$0.93	$13.4	0.23%	$5,788

* Based on data from the UC Cooperative Extension on the costs to produce lemons in selected counties.

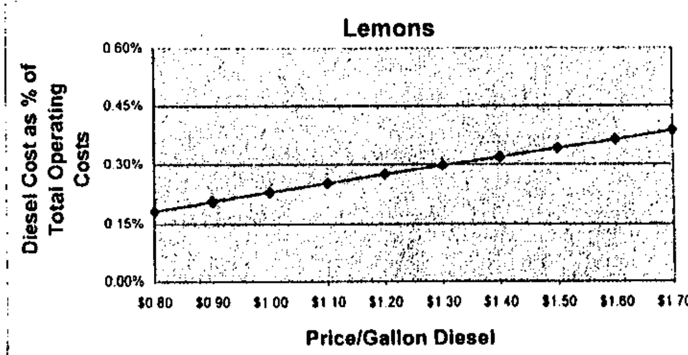
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline				Diesel				Total Operating Costs per Acre
			Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	
1997 : Ventura County	Lemons	$4,895	18.5	$1.06	$20	0.40%	12.6	$0.83	$10	0.21%	$4,925
1997 : South Coast	Organic, Fresh Market	$3,455	4.7	$1.06	$5	0.14%	8.1	$0.83	$7	0.19%	$3,467
1998 : San Diego County	Lemons	$10,600	50.1	$1.06	$53	0.50%	25.3	$0.83	$21	0.20%	$10,674
1998 : Coachella Valley	Lemons	$6,150	23.7	$1.06	$25	0.41%	11.8	$0.83	$10	0.16%	$6,185
	Average	$6,275	24.3	$1.06	$25.7	0.41%	14.4	$0.83	$12.0	0.19%	$6,313

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	49,500	$312,463,921	$0.80	$570,933	0.18%
	49,500	$312,535,288	$0.90	$642,300	0.21%
	49,500	$312,606,654	$1.00	$713,666	0.23%
	49,500	$312,678,021	$1.10	$785,033	0.25%
	49,500	$312,749,388	$1.20	$856,400	0.27%
	49,500	$312,820,754	$1.30	$927,766	0.30%
	49,500	$312,892,121	$1.40	$999,133	0.32%
	49,500	$312,963,488	$1.50	$1,070,499	0.34%
	49,500	$313,034,854	$1.60	$1,141,866	0.36%
	49,500	$313,106,221	$1.70	$1,213,233	0.39%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing lemons.



Costs for Producing Lettuce* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Leaf Lettuce	$2,335	11.7	$0.98	$11	0.48%	22.1	$0.71	$16	0.66%	$2,362
1993 : Central Coast	Organic, Romaine Lettuce	$2,400	11.7	$0.98	$11	0.47%	22.1	$0.71	$16	0.65%	$2,427
1999 : Ventura County	Loose-leaf Lettuce	$3,339	4.0	$1.20	$5	0.14%	36.9	$0.72	$27	0.79%	$3,370
	Average	$2,691	9.1	$1.05	$9.6	0.35%	27.0	$0.71	$19.3	0.71%	$2,720

* Based on data from the UC Cooperative Extension on the costs to produce lettuce in selected counties.

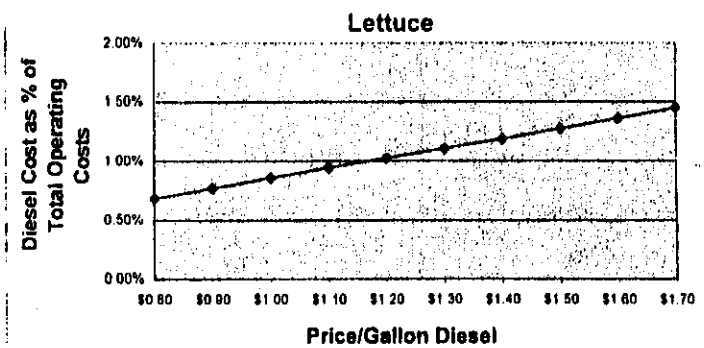
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Leaf Lettuce	$2,862	11.7	$1.06	$12	0.43%	22.1	$0.83	$18	0.63%	$2,893
1993 : Central Coast	Organic, Romaine Lettuce	$2,942	11.7	$1.06	$12	0.42%	22.1	$0.83	$18	0.62%	$2,972
1999 : Ventura County	Loose-leaf Lettuce	$3,549	4.0	$1.06	$4	0.12%	36.9	$0.83	$31	0.85%	$3,584
	Average	$3,118	9.1	$1.06	$9.6	0.31%	27.0	$0.83	$22.4	0.71%	$3,150

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	228,000	$717,956,354	$0.80	$4,926,016	0.69%
	228,000	$718,572,106	$0.90	$5,541,768	0.77%
	228,000	$719,187,858	$1.00	$6,157,520	0.86%
	228,000	$719,803,610	$1.10	$6,773,272	0.94%
	228,000	$720,419,362	$1.20	$7,389,024	1.03%
	228,000	$721,035,114	$1.30	$8,004,776	1.11%
	228,000	$721,650,866	$1.40	$8,620,528	1.19%
	228,000	$722,266,618	$1.50	$9,236,280	1.28%
	228,000	$722,882,370	$1.60	$9,852,032	1.36%
	228,000	$723,498,122	$1.70	$10,467,784	1.45%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing lettuce.



Costs for Producing Nectarines* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
2000 : SJV South	July/August Harvest Varieties	$9,394	11.4	$1.49	$17	0.18%	77.4	$1.09	$84	0.89%	$9,495
	Average	$9,394	11.4	$1.49	$17.0	0.18%	77.4	$1.09	$84.3	0.89%	$9,495

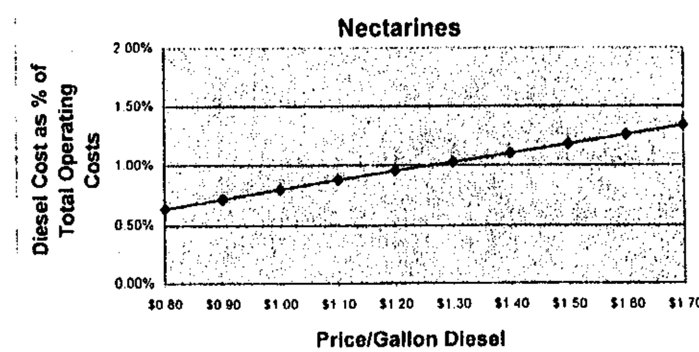
* Based on data from the UC Cooperative Extension on the costs to produce nectarines in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
2000 : SJV South	July/August Harvest Varieties	$9,661	11.4	$1.06	$12	0.12%	77.4	$0.83	$64	0.66%	$9,737
	Average	$9,661	11.4	$1.06	$12.1	0.12%	77.4	$0.83	$64.2	0.66%	$9,737

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	36,500	$355,326,295	$0.80	$2,258,620	0.64%
	36,500	$355,608,622	$0.90	$2,540,948	0.71%
	36,500	$355,890,950	$1.00	$2,823,275	0.79%
	36,500	$356,173,277	$1.10	$3,105,603	0.87%
	36,500	$356,455,605	$1.20	$3,387,930	0.95%
	36,500	$356,737,932	$1.30	$3,670,258	1.03%
	36,500	$357,020,260	$1.40	$3,952,585	1.11%
	36,500	$357,302,587	$1.50	$4,234,913	1.19%
	36,500	$357,584,915	$1.60	$4,517,240	1.26%
	36,500	$357,867,242	$1.70	$4,799,568	1.34%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing nectarines.

Costs for Producing Onions* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Diesel: Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operatiing Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Red Onions	$3,707	18.3	$0.98	$18	0.48%	46.4	$0.71	$33	0.88%	$3,758
1993 : Central Coast	Organic, Yellow Onions	$3,536	18.3	$0.98	$18	0.50%	46.4	$0.71	$33	0.92%	$3,587
2002 : Shasta & Lassen	Onion Seed	$1,412		$1.51	$0	0.00%	52.4	$1.26	$66	4.46%	$1,478
	Average	$2,885	18.3	$1.16	$21.1	0.72%	48.4	$0.89	$43.2	1.47%	$2,941

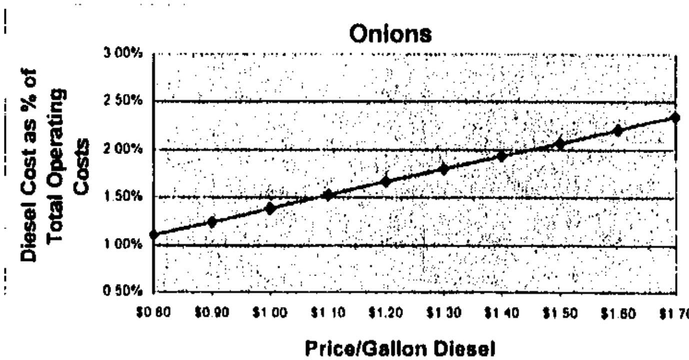
* Based on data from the UC Cooperative Extension on the costs to produce onions in selected counties

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Diesel: Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operatiing Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Red Onions	$4,543	18.3	$1.06	$19	0.42%	46.4	$0.83	$39	0.84%	$4,601
1993 : Central Coast	Organic, Yellow Onions	$4,334	18.3	$1.06	$19	0.44%	46.4	$0.83	$39	0.88%	$4,391
2002 . Shasta & Lassen	Onion Seed	$1,390		$1.06	$0	0.00%	52.4	$0.83	$43	3.03%	$1,434
	Average	$3,422	18.3	$1.06	$19.4	0.56%	48.4	$0.83	$40.2	1.16%	$3,475

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	40,400	$140,344,297	$0.80	$1,563,749	1.11%
	40,400	$140,539,766	$0.90	$1,759,218	1.25%
	40,400	$140,735,234	$1.00	$1,954,687	1.39%
	40,400	$140,930,703	$1.10	$2,150,155	1.53%
	40,400	$141,126,172	$1.20	$2,345,624	1.66%
	40,400	$141,321,640	$1.30	$2,541,093	1.80%
	40,400	$141,517,109	$1.40	$2,736,561	1.93%
	40,400	$141,712,578	$1.50	$2,932,030	2.07%
	40,400	$141,908,046	$1.60	$3,127,499	2.20%
	40,400	$142,103,515	$1.70	$3,322,967	2.34%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing onions.

Costs for Producing Oranges* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1997 : South Coast	Organic, Fresh Market Oranges	$1,828	4.7	$1.30	$6	0.33%	8.7	$0.97	$8	0.46%	$1,843
1997 : Ventura County	Valencia Oranges	$2,279	18.5	$1.20	$22	0.96%	7.2	$1.15	$8	0.36%	$2,310
1998 : San Diego County	Valencia Oranges	$5,883	50.1	$1.20	$60	1.01%	20.8	$0.85	$18	0.30%	$5,961
1998 : Coachella Valley	Valencia Oranges	$3,494	23.7	$1.16	$28	0.78%	10.3	$0.76	$8	0.22%	$3,529
1998 : Western Riverside	Navel Oranges	$3,700	23.7	$1.16	$28	0.74%	11.0	$0.76	$8	0.22%	$3,736
	Average	$3,437	24.2	$1.20	$29.1	0.84%	11.6	$0.90	$10.4	0.30%	$3,476

* Based on data from the UC Cooperative Extension on the costs to produce oranges in selected counties.

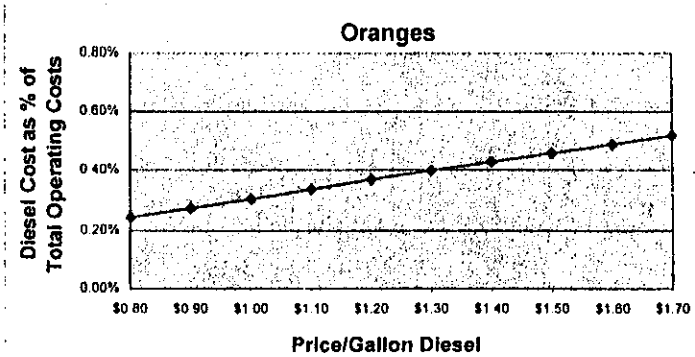
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1997 : South Coast	Organic, Fresh Market Oranges	$2,018	4.7	$1.06	$5	0.24%	8.7	$0.83	$7	0.36%	$2,030
1997 : Ventura County	Valencia Oranges	$2,515	18.5	$1.06	$20	0.77%	7.2	$0.83	$6	0.23%	$2,541
1998 : San Diego County	Valencia Oranges	$6,392	50.1	$1.06	$53	0.82%	20.8	$0.83	$17	0.27%	$6,462
1998 : Coachella Valley	Valencia Oranges	$3,796	23.7	$1.06	$25	0.66%	10.3	$0.83	$9	0.22%	$3,830
1998 : Western Riverside	Navel Oranges	$4,020	23.7	$1.06	$25	0.62%	11.0	$0.83	$9	0.23%	$4,054
	Average	$3,748	24.2	$1.06	$25.6	0.68%	11.6	$0.83	$9.6	0.25%	$3,783

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	194,500	$735,808,885	$0.80	$1,805,894	0.25%
	194,500	$736,034,622	$0.90	$2,031,630	0.28%
	194,500	$736,260,359	$1.00	$2,257,367	0.31%
	194,500	$736,486,096	$1.10	$2,483,104	0.34%
	194,500	$736,711,832	$1.20	$2,708,840	0.37%
	194,500	$736,937,569	$1.30	$2,934,577	0.40%
	194,500	$737,163,306	$1.40	$3,160,314	0.43%
	194,500	$737,389,042	$1.50	$3,386,051	0.46%
	194,500	$737,614,779	$1.60	$3,611,787	0.49%
	194,500	$737,840,516	$1.70	$3,837,524	0.52%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing oranges.



301

Costs for Producing Peaches* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1998 : Sacramento & SJV	Cling Peaches, Flood Irrigation	$2,550	6.8	$1.22	$8	0.32%	24.3	$0.78	$19	0.74%	$2,577
2000 : Sierra Nevada	Fresh Market	$3,996	5.7	$1.49	$8	0.21%	27.1	$1.09	$30	0.73%	$4,034
2000 : SJV South	July/August Harvest Varieties	$9,394	11.4	$1.49	$17	0.18%	77.4	$1.09	$84	0.89%	$9,495
	Average	$5,313	8.0	$1.40	$11.1	0.21%	42.9	$0.99	$42.4	0.79%	$5,369

* Based on data from the UC Cooperative Extension on the costs to produce peaches in selected counties.

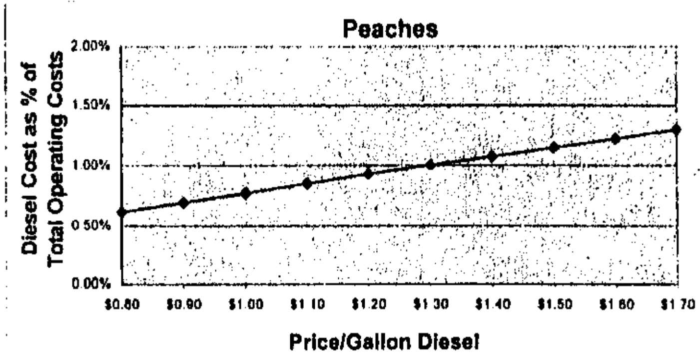
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1998 : Sacramento & SJV	Cling Peaches, Flood Irrigation	$2,770	6.8	$1.06	$7	0.26%	24.3	$0.83	$20	0.72%	$2,798
2000 : Sierra Nevada	Fresh Market	$4,110	5.7	$1.06	$6	0.15%	27.1	$0.83	$22	0.54%	$4,138
2000 : SJV South	July/August Harvest Varieties	$9,661	11.4	$1.06	$12	0.12%	77.4	$0.83	$64	0.66%	$9,737
	Average	$5,514	8.0	$1.06	$8.4	0.15%	42.9	$0.83	$35.6	0.64%	$5,558

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	67,800	$376,726,887	$0.80	$2,328,523	0.62%
	67,800	$377,017,953	$0.90	$2,619,589	0.69%
	67,800	$377,309,018	$1.00	$2,910,654	0.77%
	67,800	$377,600,084	$1.10	$3,201,719	0.85%
	67,800	$377,891,149	$1.20	$3,492,785	0.92%
	67,800	$378,182,214	$1.30	$3,783,850	1.00%
	67,800	$378,473,280	$1.40	$4,074,916	1.08%
	67,800	$378,764,345	$1.50	$4,365,981	1.15%
	67,800	$379,055,411	$1.60	$4,657,046	1.23%
	67,800	$379,346,476	$1.70	$4,948,112	1.30%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing peaches.



Costs for Producing Peppers* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Green Bell Peppers	$5,301	11.7	$0.98	$11	0.21%	32.8	$0.71	$23	0.44%	$5,336
1993 : Central Coast	Organic, Red Bell Peppers	$4,170	11.7	$0.98	$11	0.27%	32.8	$0.71	$23	0.55%	$4,205
1997 : Santa Clara	Bell Peppers	$5,151	1.0	$1.30	$1	0.02%	40.0	$0.97	$39	0.75%	$5,191
1999 : Ventura County	Bell Peppers	$4,678	4.0	$1.20	$5	0.10%	42.9	$0.72	$31	0.66%	$4,714
	Average	$4,825	7.1	$1.12	$7.9	0.16%	37.1	$0.78	$28.9	0.59%	$4,861

* Based on data from the UC Cooperative Extension on the costs to produce peppers in selected counties.

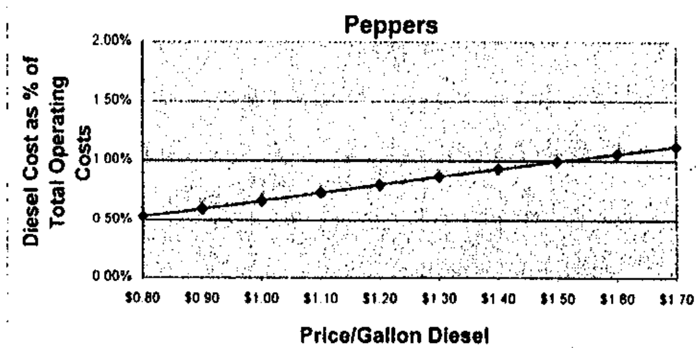
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1993 : Central Coast	Organic, Green Bell Peppers	$6,497	11.7	$1.06	$12	0.19%	32.8	$0.83	$27	0.42%	$6,537
1993 : Central Coast	Organic, Red Bell Peppers	$5,111	11.7	$1.06	$12	0.24%	32.8	$0.83	$27	0.53%	$5,150
1997 : Santa Clara	Bell Peppers	$5,684	1.0	$1.06	$1	0.02%	40.0	$0.83	$33	0.58%	$5,718
1999 : Ventura County	Bell Peppers	$4,973	4.0	$1.06	$4	0.08%	42.9	$0.83	$36	0.71%	$5,013
	Average	$5,566	7.1	$1.06	$7.5	0.13%	37.1	$0.83	$30.8	0.55%	$5,604

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	22,000	$123,272,243	$0.80	$653,620	0.53%
	22,000	$123,353,946	$0.90	$735,323	0.60%
	22,000	$123,435,648	$1.00	$817,025	0.66%
	22,000	$123,517,351	$1.10	$898,728	0.73%
	22,000	$123,599,053	$1.20	$980,430	0.79%
	22,000	$123,680,756	$1.30	$1,062,133	0.86%
	22,000	$123,762,458	$1.40	$1,143,835	0.92%
	22,000	$123,844,161	$1.50	$1,225,538	0.99%
	22,000	$123,925,863	$1.60	$1,307,240	1.05%
	22,000	$124,007,566	$1.70	$1,388,943	1.12%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing peppers.



Costs for Producing Pistachios* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
2000 : SJV	Low-Volume Irrigation	$1,213	10.5	$1.49	$16	1.26%	12.2	$1.09	$13	1.07%	$1,242
	Average	$1,213	10.5	$1.49	$15.6	1.26%	12.2	$1.09	$13.3	1.07%	$1,242

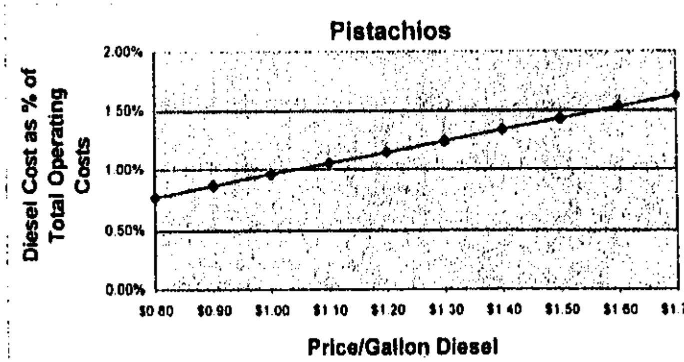
* Based on data from the UC Cooperative Extension on the costs to produce pistachios in selected counties.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
2000 : SJV	Low-Volume Irrigation	$1,248	10.5	$1.06	$11	0.88%	12.2	$0.83	$10	0.80%	$1,269
	Average	$1,248	10.5	$1.06	$11.1	0.88%	12.2	$0.83	$10.1	0.80%	$1,269

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	78,000	$98,940,379	$0.80	$761,904	0.77%
	78,000	$99,035,617	$0.90	$857,142	0.87%
	78,000	$99,130,855	$1.00	$952,380	0.96%
	78,000	$99,226,093	$1.10	$1,047,618	1.06%
	78,000	$99,321,331	$1.20	$1,142,856	1.15%
	78,000	$99,416,569	$1.30	$1,238,094	1.25%
	78,000	$99,511,807	$1.40	$1,333,332	1.34%
	78,000	$99,607,045	$1.50	$1,428,570	1.43%
	78,000	$99,702,283	$1.60	$1,523,808	1.53%
	78,000	$99,797,521	$1.70	$1,619,046	1.62%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increase in diesel fuel price does not increase other direct costs for producing pistachios.

Costs for Producing Prunes* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1997 : SJV South	French Variety Prunes	$2,452	20.4	$1.30	$26	1.06%	10.3	$0.97	$10	0.40%	$2,488
2001 : Sacramento	French Var, Low-Vol. Irrigation	$2,587	8.1	$1.51	$12	0.47%	11.0	$1.26	$14	0.53%	$2,613
	Average	$2,519	14.2	$1.41	$20.0	0.78%	10.7	$1.12	$11.9	0.47%	$2,551

* Based on data from the UC Cooperative Extension on the costs to produce prunes in selected counties.

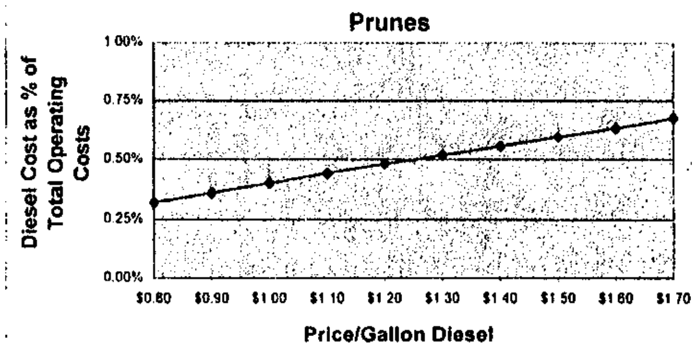
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1997 : SJV South	French Variety Prunes	$2,705	20.4	$1.06	$22	0.79%	10.3	$0.83	$9	0.31%	$2,735
2001 : Sacramento	French Var, Low-Vol. Irrigation	$2,587	8.1	$1.06	$9	0.33%	11.0	$0.83	$9	0.35%	$2,605
	Average	$2,646	14.2	$1.06	$15.1	0.56%	10.7	$0.83	$8.9	0.33%	$2,670

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	86,000	$229,586,067	$0.80	$733,752	0.32%
	86,000	$229,677,786	$0.90	$825,471	0.36%
	86,000	$229,769,505	$1.00	$917,190	0.40%
	86,000	$229,861,224	$1.10	$1,008,909	0.44%
	86,000	$229,952,943	$1.20	$1,100,628	0.48%
	86,000	$230,044,662	$1.30	$1,192,347	0.52%
	86,000	$230,136,381	$1.40	$1,284,066	0.56%
	86,000	$230,228,100	$1.50	$1,375,785	0.60%
	86,000	$230,319,819	$1.60	$1,467,504	0.64%
	86,000	$230,411,538	$1.70	$1,559,223	0.68%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing prunes.



305

Costs for Producing Rice* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : Sacramento	Organic, Water Seeded	$243		$0.98	$0	0.00%	27.6	$0.71	$20	7.47%	$26[illegible]
1992 : Sacramento	No-Till Drill Seeded	$231		$0.98	$0	0.00%	19.2	$0.71	$14	5.59%	$244
1998 : Sacramento	Rice Only Rotation	$493	1.6	$1.22	$2	0.39%	22.2	$0.78	$17	3.38%	$512
1998 : Sacramento	Multiple Crop Rotation	$533	0.6	$1.22	$1	0.13%	20.6	$0.78	$16	2.92%	$550
2000 : Shasta & Lassen	Wild Rice	$683	0.4	$1.49	$1	0.08%	11.1	$1.09	$12	1.73%	$698
2001 : Sacramento	Rice Only Rotation	$561	1.6	$1.51	$2	0.41%	33.3	$1.26	$42	6.93%	$605
	Average	$457	1.1	$1.23	$1.3	0.27%	22.3	$0.89	$19.8	4.14%	$478

* Based on data from the UC Cooperative Extension on the costs to produce rice in selected counties.

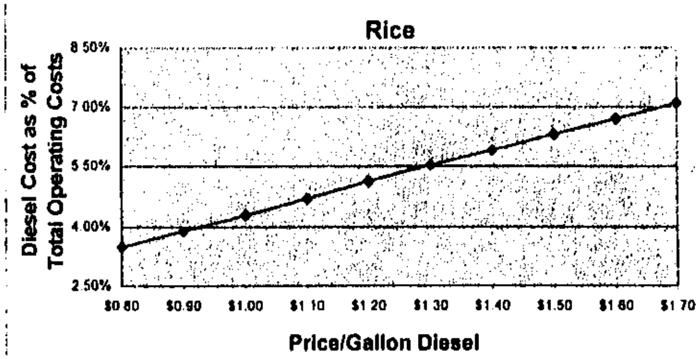
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1992 : Sacramento	Organic, Water Seeded	$306		$1.06	$0	0.00%	27.6	$0.83	$23	6.95%	$329
1992 : Sacramento	No-Till Drill Seeded	$291		$1.06	$0	0.00%	19.2	$0.83	$16	5.19%	$307
1998 : Sacramento	Rice Only Rotation	$535	1.6	$1.06	$2	0.31%	22.2	$0.83	$18	3.31%	$555
1998 : Sacramento	Multiple Crop Rotation	$579	0.6	$1.06	$1	0.10%	20.6	$0.83	$17	2.86%	$597
2000 : Shasta & Lassen	Wild Rice	$703	0.4	$1.06	$0	0.06%	11.1	$0.83	$9	1.29%	$712
2001 : Sacramento	Rice Only Rotation	$561	1.6	$1.06	$2	0.29%	33.3	$0.83	$28	4.68%	$590
	Average	$496	1.1	$1.06	$1.1	0.22%	22.3	$0.83	$18.5	3.59%	$515

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	471,000	$242,321,251	$0.80	$8,406,408	3.47%
	471,000	$243,372,052	$0.90	$9,457,209	3.89%
	471,000	$244,422,853	$1.00	$10,508,010	4.30%
	471,000	$245,473,654	$1.10	$11,558,811	4.71%
	471,000	$246,524,455	$1.20	$12,609,612	5.11%
	471,000	$247,575,256	$1.30	$13,660,413	5.52%
	471,000	$248,626,057	$1.40	$14,711,214	5.92%
	471,000	$249,676,858	$1.50	$15,762,015	6.31%
	471,000	$250,727,659	$1.60	$16,812,816	6.71%
	471,000	$251,778,460	$1.70	$17,863,617	7.09%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing rice.



Costs for Producing Strawberries* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
2001 : Ventura County	Strawberries	$26,090	26.9	$1.51	$41	0.15%	55.6	$1.26	$70	0.27%	$26,201
2001 : Santa Maria Valley	Strawberries	$21,225	25.2	$1.51	$38	0.18%	100.9	$1.26	$127	0.59%	$21,390
2001 : Central Coast	Strawberries	$26,873	23.0	$1.51	$35	0.13%	86.7	$1.26	$109	0.40%	$27,017
	Average	$24,729	25.0	$1.51	$37.8	0.15%	81.1	$1.26	$102.1	0.41%	$24,869

* Based on data from the UC Cooperative Extension on the costs to produce strawberries in selected counties.

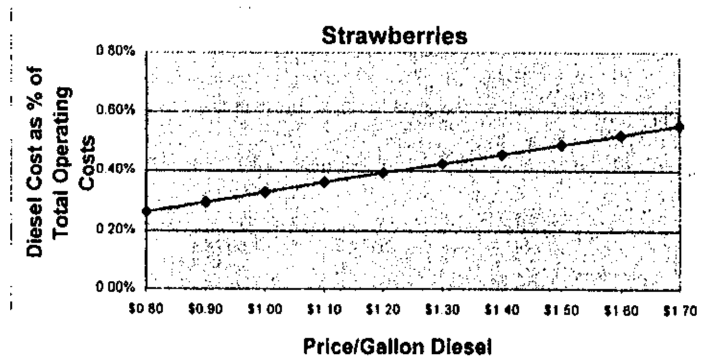
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
2001 : Ventura County	Strawberries	$26,090	26.9	$1.06	$29	0.11%	55.6	$0.83	$46	0.18%	$26,165
2001 : Santa Maria Valley	Strawberries	$21,225	25.2	$1.06	$27	0.13%	100.9	$0.83	$84	0.39%	$21,335
2001 : Central Coast	Strawberries	$26,873	23.0	$1.06	$24	0.09%	86.7	$0.83	$72	0.27%	$26,969
	Average	$24,729	25.0	$1.06	$26.5	0.11%	81.1	$0.83	$67.3	0.27%	$24,823

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	26,400	$655,268,851	$0.80	$1,711,846	0.26%
	26,400	$655,482,832	$0.90	$1,925,827	0.29%
	26,400	$655,696,812	$1.00	$2,139,808	0.33%
	26,400	$655,910,793	$1.10	$2,353,789	0.36%
	26,400	$656,124,774	$1.20	$2,567,770	0.39%
	26,400	$656,338,755	$1.30	$2,781,750	0.42%
	26,400	$656,552,736	$1.40	$2,995,731	0.46%
	26,400	$656,766,716	$1.50	$3,209,712	0.49%
	26,400	$656,980,697	$1.60	$3,423,693	0.52%
	26,400	$657,194,678	$1.70	$3,637,674	0.55%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing strawberries.



Costs for Producing Fresh Tomatoes* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
2000 : SJV	Fresh Maket, Furrow Irrigated	$4,798	2.1	$1.48	$3	0.06%	46.4	$1.09	$51	1.04%	$4,852
	Average	$4,798	2.1	$1.48	$3.1	0.06%	46.4	$1.09	$50.5	1.04%	$4,852

* Based on data from the UC Cooperative Extension on the costs to produce fresh market tomatoes in selected counties.

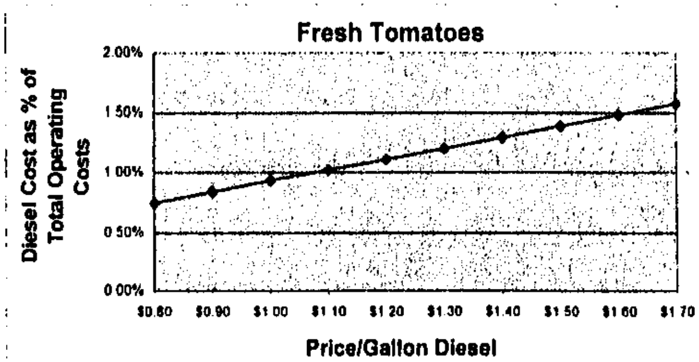
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
2000 : SJV	Fresh Maket, Furrow Irrigated	$4,935	2.1	$1.06	$2	0.04%	46.4	$0.83	$38	0.77%	$4,976
	Average	$4,935	2.1	$1.06	$2.2	0.04%	46.4	$0.83	$38.5	0.77%	$4,976

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	41,000	$203,943,083	$0.80	$1,520,608	0.75%
	41,000	$204,133,159	$0.90	$1,710,684	0.84%
	41,000	$204,323,235	$1.00	$1,900,760	0.93%
	41,000	$204,513,311	$1.10	$2,090,836	1.02%
	41,000	$204,703,387	$1.20	$2,280,912	1.11%
	41,000	$204,893,463	$1.30	$2,470,988	1.21%
	41,000	$205,083,539	$1.40	$2,661,064	1.30%
	41,000	$205,273,615	$1.50	$2,851,140	1.39%
	41,000	$205,463,691	$1.60	$3,041,216	1.48%
	41,000	$205,653,767	$1.70	$3,231,292	1.57%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing fresh market tomatoes.



Costs for Producing Processing Tomatoes* in California

			Gasoline				Diesel				
Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	Total Operating Costs per Acre
1994 : Sacramento	Organic, Processing Tomatoes	$987	0.7	$1.17	$1	0.08%	71.0	$0.85	$60	5.76%	$1,048
1997 : Yolo County	Processing Tomatoes	$1,114	1.9	$1.30	$2	0.21%	99.4	$0.97	$96	7.95%	$1,213
2000 : SJV	Processing Tomatoes	$1,028	1.3	$1.48	$2	0.17%	86.9	$1.09	$95	8.42%	$1,125
2001 : SJV	Processing, Double Row Seeded	$1,073	1.3	$1.51	$2	0.17%	66.5	$1.26	$84	7.23%	$1,159
2001 : Sacramento	Processing Tomatoes	$1,109	1.3	$1.51	$2	0.17%	84.3	$1.26	$106	8.73%	$1,217
2002 : SJV South	Processing, Transplaned	$1,582	0.3	$1.51	$0	0.03%	43.0	$1.26	$54	3.31%	$1,637
2002 : SJV South	Processing Tomatoes	$1,407	1.3	$1.51	$2	0.13%	48.3	$1.26	$61	4.14%	$1,470
	Average	$1,186	1.2	$1.43	$1.7	0.13%	71.3	$1.14	$81.0	6.39%	$1,267

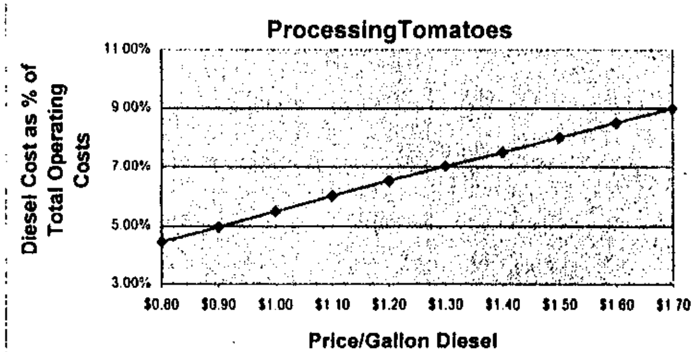
* Based on data from the UC Cooperative Extension on the costs to produce processing tomatoes in selected counties.

Adjusted to 2001 to Reflect Inflation*

			Gasoline				Diesel				
Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gallons used per Acre	Cost per Gallon	Total Gasoline Cost	% of Total Operating Costs	Gallons used per Acre	Cost per Gallon	Total Diesel Cost	% of Total Operating Costs	Total Operating Costs per Acre
1994 : Sacramento	Organic, Processing Tomatoes	$1,179	0.7	$1.06	$1	0.06%	71.0	$0.83	$59	4.76%	$1,239
1997 : Yolo County	Processing Tomatoes	$1,229	1.9	$1.06	$2	0.15%	99.4	$0.83	$82	6.28%	$1,314
2000 : SJV	Processing Tomatoes	$1,057	1.3	$1.06	$1	0.12%	86.9	$0.83	$72	6.38%	$1,131
2001 : SJV	Processing, Double Row Seeded	$1,073	1.3	$1.06	$1	0.12%	66.5	$0.83	$55	4.89%	$1,130
2001 : Sacramento	Processing Tomatoes	$1,109	1.3	$1.06	$1	0.12%	84.3	$0.83	$70	5.93%	$1,180
2002 : SJV South	Processing, Transplaned	$1,558	0.3	$1.06	$0	0.02%	43.0	$0.83	$36	2.24%	$1,594
2002 : SJV South	Processing Tomatoes	$1,385	1.3	$1.06	$1	0.10%	48.3	$0.83	$40	2.81%	$1,427
	Average	$1,227	1.2	$1.06	$1.2	0.10%	71.3	$0.83	$59.2	4.60%	$1,288

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	254,000	$326,522,395	$0.80	$14,495,417	4.44%
	254,000	$328,334,322	$0.90	$16,307,344	4.97%
	254,000	$330,146,249	$1.00	$18,119,271	5.49%
	254,000	$331,958,177	$1.10	$19,931,199	6.00%
	254,000	$333,770,104	$1.20	$21,743,126	6.51%
	254,000	$335,582,031	$1.30	$23,555,053	7.02%
	254,000	$337,393,958	$1.40	$25,366,980	7.52%
	254,000	$339,205,885	$1.50	$27,178,907	8.01%
	254,000	$341,017,812	$1.60	$28,990,834	8.50%
	254,000	$342,829,739	$1.70	$30,802,761	8.98%



* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing processing tomatoes.

309

Costs for Producing Processing Walnuts* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1994 : Sacramento	Organic, Sprinkler Irrigated	$2,367	17.8	$1.17	$21	0.87%	26.2	$0.85	$22	0.92%	$2,410
1998 : SJV South	Walnuts	$1,322	13.0	$1.22	$16	1.17%	13.7	$0.78	$11	0.79%	$1,348
2001 : SJV North	prinkler Irrigation, lateral bearing	$1,365	10.5	$1.51	$16	1.13%	20.6	$1.26	$26	1.85%	$1,407
2002 : Sacramento	Sprinkler Irrigation	$1,191	13.5	$1.51	$20	1.65%	15.2	$1.26	$19	1.55%	$1,230
	Average	$1,561	13.7	$1.35	$18.5	1.16%	18.9	$1.04	$19.6	1.23%	$1,599

* Based on data from the UC Cooperative Extension on the costs to produce walnuts in selected counties.

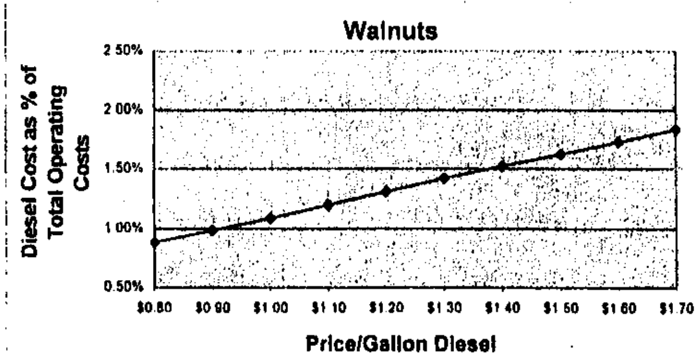
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operating Costs	Total Operating Costs per Acre
1994 : Sacramento	Organic, Sprinkler Irrigated	$2,829	17.8	$1.06	$19	0.66%	26.2	$0.83	$22	0.76%	$2,869
1998 : SJV South	Walnuts	$1,436	13.0	$1 06	$14	0.94%	13.7	$0.83	$11	0.78%	$1,461
2001 : SJV North	prinkler Irrigation, lateral bearing	$1,365	10 5	$1.06	$11	0.80%	20.6	$0.83	$17	1.23%	$1,393
2002 : Sacramento	Sprinkler Irrigation	$1,172	13.5	$1.06	$14	1.19%	15.2	$0.83	$13	1.05%	$1,199
	Average	$1,700	13.7	$1.06	$14.5	0.84%	18.9	$0.83	$15.7	0.91%	$1,731

* According to "Economic Indicators" prepared for the Joint Economic Committee (106th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	196,000	$339,086,884	$0.80	$2,966,264	0.87%
	196,000	$339,457,667	$0.90	$3,337,047	0.98%
	196,000	$339,828,450	$1.00	$3,707,830	1.09%
	196,000	$340,199,233	$1.10	$4,078,613	1.20%
	196,000	$340,570,016	$1.20	$4,449,396	1.31%
	196,000	$340,940,799	$1.30	$4,820,179	1.41%
	196,000	$341,311,582	$1.40	$5,190,962	1.52%
	196,000	$341,682,365	$1.50	$5,561,745	1.63%
	196,000	$342,053,148	$1.60	$5,932,528	1.73%
	196,000	$342,423,931	$1.70	$6,303,311	1.84%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing walnuts.



Costs for Producing Processing Wheat* in California

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operatiing Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1994 : Yolo County	Dryland & Conventional Tillage	$121	0.6	$1.17	$1	0.54%	13.3	$0.85	$11	8.46%	$133
1994 : Yolo County	Dryland & Non Tillage Conditions	$108	0.6	$1.17	$1	0.58%	3.2	$0.85	$3	2.47%	$112
1996 : San Luis Obispo	Dryland & Conventional Tillage	$67	0.4	$1.20	$0	0.58%	13.3	$1.15	$15	18.55%	$82
1999 : SJV	Wheat Silage	$153	0.6	$1.02	$1	0.37%	16.2	$0.62	$10	6.14%	$164
1999 : SJV	Double Cropped	$243	0.6	$1.02	$1	0.24%	16.2	$0.62	$10	3.96%	$254
2000 : Sacramento	Irrigated	$119	0.6	$1.49	$1	0.68%	16.9	$1.26	$21	15.13%	$141
	Average	$135	0.6	$1.18	$0.7	0.45%	13.2	$0.89	$11.8	7.97%	$148

* Based on data from the UC Cooperative Extension on the costs to produce wheat in selected counties.

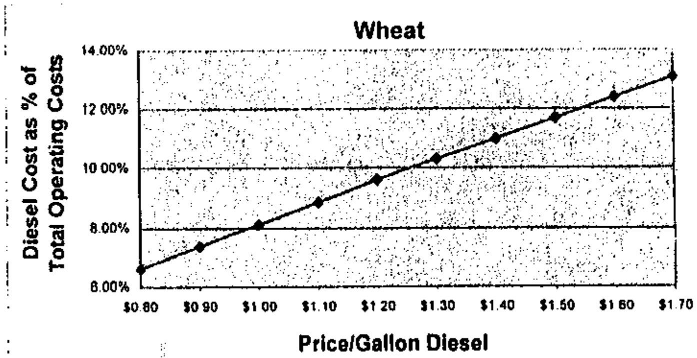
Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Total Operating Costs/Acre (w/o fuel)	Gasoline: Gallons used per Acre	Gasoline: Cost per Gallon	Gasoline: Total Gasoline Cost	Gasoline: % of Total Operating Costs	Diesel: Gallons used per Acre	Diesel: Cost per Gallon	Diesel: Total Diesel Cost	Diesel: % of Total Operatiing Costs	Total Operating Costs per Acre
1994 : Yolo County	Dryland & Conventional Tillage	$145	0.6	$1.06	$1	0.42%	13.3	$0.83	$11	7.03%	$157
1994 : Yolo County	Dryland & Non Tillage Conditions	$129	0.6	$1.06	$1	0.44%	3.2	$0.83	$3	2.03%	$132
1996 : San Luis Obispo	Dryland & Conventional Tillage	$75	0.4	$1.06	$0	0.49%	13.3	$0.83	$11	12.73%	$87
1999 : SJV	Wheat Silage	$163	0.6	$1.06	$1	0.36%	16.2	$0.83	$13	7.61%	$177
1999 : SJV	Double Cropped	$259	0.6	$1.06	$1	0.23%	16.2	$0.83	$13	4.94%	$273
2000 : Sacramento	Irrigated	$122	0.6	$1.06	$1	0.50%	16.9	$0.83	$14	10.27%	$137
	Average	$149	0.6	$1.06	$0.6	0.38%	13.2	$0.83	$11.0	6.83%	$160

* According to "Economic Indicators" prepared for the Joint Economic Committee (108th US Congress)

Scenarios	Acres Harvested*	Total Operating Costs**	Cost of Diesel per Galon	Total Diesel Fuel Costs	Diesel Fuel Costs as % of Total Operating Costs
Base	461,000	$73,770,639	$0.80	$4,868,160	6.60%
	461,000	$74,379,159	$0.90	$5,476,680	7.36%
	461,000	$74,987,679	$1.00	$6,085,200	8.11%
	461,000	$75,596,199	$1.10	$6,693,720	8.85%
	461,000	$76,204,719	$1.20	$7,302,240	9.58%
	461,000	$76,813,239	$1.30	$7,910,760	10.30%
	461,000	$77,421,759	$1.40	$8,519,280	11.00%
	461,000	$78,030,279	$1.50	$9,127,800	11.70%
	461,000	$78,638,799	$1.60	$9,736,320	12.38%
	461,000	$79,247,319	$1.70	$10,344,840	13.05%

* Total acres harvested of commodity in California 2001. From CDFA Resource Directory.
** Assumes that increases in diesel fuel price does not increase other direct costs for producing wheat.



CATTLE:

MILK & BEEF PRODUCTION

Costs for Producing Cow Dairy - Milk

Year / Location	Variety	Tractors, Trucks, Fuel & Oil Costs	Total Operating Costs (w/o fuel)	Total Operating Costs	Total Annual Operating Costs	Fuel as % of Total Operating Costs
2001 : Humboldt	Dairy Milk*	$3.19	$38.83	$42.02	$504.24	7.59%
2001 : North Bay	Dairy Milk*	$3.07	$49.99	$53.06	$636.72	5.79%
2001 : North Valley	Dairy Milk*	$3.36	$45.79	$49.15	$589.80	6.84%
2001 : South Valley	Dairy Milk*	$3.75	$47.15	$50.90	$610.80	7.37%
2001 : So. California	Dairy Milk*	$1.03	$47.21	$48.24	$578.88	2.14%
	Average	$2.88	$45.79	$48.67	$584.09	5.94%

* All costs are per cow per month. Data from USDA NASS California Cost of Production for Dairy Milk.

Year / Location	Variety	Gallons Diesel Used Per Cow*	Total Fuel Costs with a 3 ¢ / gal increase	Total Operating Costs w/ price increase	Total Annual Operating Costs	% Change due to 3 ¢ increase
2001 : Humboldt	Dairy Milk	3.8	$3.31	$42.14	$505.62	0.27%
2001 : North Bay	Dairy Milk	3.7	$3.18	$53.17	$638.05	0.21%
2001 : North Valley	Dairy Milk	4.0	$3.48	$49.27	$591.26	0.25%
2001 : South Valley	Dairy Milk	4.5	$3.89	$51.04	$612.43	0.27%
2001 : So. California	Dairy Milk	1.2	$1.07	$48.28	$579.33	0.08%
	Average	$3.47	$2.98	$48.78	$585.34	0.21%

* Assuming California average wholesale diesel price in 2001 of 83 ¢ per gallon and conservative assumption that all fuel costs are attributable to diesel fuel.

Costs for Producing Cattle / Calf - Beef

In State of Oregon*

Year / Location	Variety	Fuel & Lube, Machinery / Equip.	Gallons Diesel Used Per Cow**	Total Operating Costs (w/o fuel)	Total Operating Costs	Fuel as % of Total Operating Costs
1997 : High Desert Area	50 cow / calf	$24.18	35.6	$499.30	$523.48	4.62%
1998 : Mountain Region	50 cow / calf	$32.30	64.6	$534.82	$567.12	5.70%
1998 : North Central Plateau	50 cow / calf	$36.98	74.0	$493.16	$530.14	6.98%
1997 : High Desert Area	100 cow / calf	$17.88	26.3	$332.16	$350.04	5.11%
1998 : Mountain Region	100 cow / calf	$24.90	49.8	$387.42	$412.32	6.04%
1996 : Klamath Basin, California Winter Range	210 cow / calf	$5.75	8.0	$321.94	$327.69	1.75%
1996 : Klamath Basin, Irrigated Pasture	210 cow / calf	$3.94	5.5	$360.96	$364.90	1.08%
1998 : North Central Plateau	300 cow / calf	$10.31	20.6	$300.67	$310.98	3.32%
1998 : Mountain Region	300 cow / calf	$9.49	19.0	$316.35	$325.84	2.91%
1997 : High Desert Area	350 cow / calf	$9.61	14.1	$296.08	$305.69	3.14%
1997 : High Desert Area	500 cow / calf	$7.79	11.5	$283.26	$291.05	2.68%
1998 : Mountain Region	500 cow / calf	$9.64	19.3	$295.90	$305.54	3.16%
1998 : North Central Plateau	750 cow / calf	$6.96	13.9	$265.05	$272.01	2.56%

* All costs are per cow. Data from Oregon State University Extension Agricultural and Resource Economics Department.
** Assuming average wholesale diesel price in 1996 of 72 ¢ /gal, 1997 of 68 ¢ /gal, 1998 of 50 ¢ /gal and conservative assumption that all fuel costs are attributable to diesel fuel. Price info from EIA values for PADD V.

Adjusted to 2001 to Reflect Inflation*

Year / Location	Variety	Operation Costs (w/o) fuel	Fuel Costs in 2001***	Total Operating Costs	Fuel Costs with a 3¢ / gal increase	Total Operating Costs w/ price increase	% Change due to 3 ¢ increase
1997 : High Desert Area	50 cow / calf	$550.94	$29.51	$580.45	$30.58	$581.52	0.18%
1998 : Mountain Region	50 cow / calf	$581.08	$53.62	$634.70	$55.56	$636.64	0.30%
1998 : North Central Plateau	50 cow / calf	$535.82	$61.39	$597.21	$63.61	$599.43	0.37%
1997 : High Desert Area	100 cow / calf	$366.51	$21.82	$388.34	$22.61	$389.13	0.20%
1998 : Mountain Region	100 cow / calf	$420.93	$41.33	$462.27	$42.83	$463.76	0.32%
1996 : Klamath Basin, California Winter Range	210 cow / calf	$363.39	$6.63	$370.02	$6.87	$370.26	0.06%
1996 : Klamath Basin, Irrigated Pasture	210 cow / calf	$407.43	$4.54	$411.97	$4.71	$412.14	0.04%
1998 : North Central Plateau	300 cow / calf	$326.68	$17.11	$343.79	$17.73	$344.41	0.18%
1998 : Mountain Region	300 cow / calf	$343.72	$15.75	$359.47	$16.32	$360.04	0.16%
1997 : High Desert Area	350 cow / calf	$326.70	$11.73	$338.43	$12.15	$338.86	0.13%
1997 : High Desert Area	500 cow / calf	$312.56	$9.51	$322.07	$9.85	$322.41	0.11%
1998 : Mountain Region	500 cow / calf	$321.50	$16.00	$337.50	$16.58	$338.08	0.17%
1998 : North Central Plateau	750 cow / calf	$287.98	$11.55	$299.53	$11.97	$299.95	0.14%

* According to "Economic Indicators" prepared for the Joint Economic Committee (106th US Congress)
** Average California wholesale diesel cost in 2001 83 ¢ / gallon.

APPENDIX N

Impact of Fuel Taxes on Fuel Purchases of Out-of-State Diesel Fuel

Impact of Fuel Taxes on Fuel Purchases of Out-of-State Diesel Fuel

I. Introduction

In considering the ability of California businesses to compete with out-of-state diesel end users, it is important to consider how diesel fuel taxes (especially state excise taxes), can play a role in a transportation company's decisions on where to purchase fuel, even if retail prices between California and surrounding states are the same.

In general, up to four different taxes may be levied on a gallon of diesel fuel[1]. These taxes, and their on-road rates for California and neighboring states, are shown in Appendix O-1. As can be seen, all retail diesel fuel is charged a federal excise tax of 24.4 cents per gallon. In addition, most states also have a state excise tax, which can vary from 18 to 27 cents per gallon. In California, a sales tax (from 7.25 - 8.75 percent) is levied on the total price (including the excise taxes) of the gallon of fuel[2]. Additional taxes to pay for environmental spills and underground storage tank monitoring may also be charged. These taxes are known as pump taxes, and are the taxes that are reflected in the retail price of diesel fuel paid at the pump. In Oregon, however, instead of a state excise tax, Oregon uses a weight mileage tax[3], based on vehicle weight and the number of miles the operator drives within the state of Oregon (estimated in this example to be about 55 cents). This tax is not reflected in the pump price of diesel fuel, but is remitted to the state of Oregon separately.

Appendix O-1:
State & Federal Diesel Taxes in California and Nearby States
(Cents per Gallon)

	California	Arizona	Idaho	Nevada	Oregon	Utah
Federal Excise Tax	24.4	24.4	24.4	24.4	24.4	24.4
State Excise Tax	18	26	25	27	0	24.5
Sales Tax[1]	12	--	--	--	--	--
Other[2,3]	1.2	1	--	0.75	--	--
Total Pump Taxes	55.6	51.4	49.4	52.2	24.4	48.9
Mileage Tax[4]	--	--**	--**	--	55*	--
Total State Taxes	55.6	51.4	49.4	52.2	79.4	48.9

1. California local sales tax variable throughout state from 7.25% - 8.75%
2. Arizona UST tax of 1 ¢/gallon
3. Nevada tax includes .75 ¢/gallon Clean Up Fee (non-refundable)
4. Tax based on weight-mile tiered tax.

* Oregon tax of 12 ¢/mile based on 80,000-lb load. Actual tax levied varies with weight. Estimated to be equivalent to about 55 cents per gallon.

** Arizona and Idaho have repealed the mileage-based tax in their states.

Using the scenario whereby retail prices are the same between California and neighboring states, it is to a transportation company's economic benefit to purchase diesel fuel outside of California and consume that same fuel in California. This is due to differences in the excise taxes between neighboring states and California, and the way excise taxes are prorated to account for travel within the individual states.

For example, if a diesel truck operator purchases fuel in Nevada, the state excise tax of 27 cents per gallon would be collected at the time of fueling. If that truck is then driven into California and the remaining fuel is consumed there, the truck operator would receive an excise tax credit of 27 cents per gallon from the state of Nevada for the fuel not consumed in Nevada. The truck operator would then pay the state of California 18 cents per gallon for the fuel consumed within California. Assuming the retail prices between California and Nevada are the same, the truck operator would save 9 cents per gallon on the fuel purchase, which could amount to thousands of dollars annually per truck in fuel cost savings. As can be seen in Appendix O-1, this same situation exists between California and Arizona as well. Because of this difference in excise taxes, diesel vehicle operators have an incentive to purchase fuel out-of-state and take advantage of these tax differences.

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[1] Oil Price Information Service, Fuel Regs & Specs, 2002 Edition

[2] California State Board of Equalization, California Diesel Fuel Tax Law, Fuel Tax Agreements

[3] Oregon Department of Transportation, Motor Carrier Transportation Division, Mileage Tax Rates

APPENDIX O

References

REFERENCES

1 Final Report, 1996 American Petroleum Institute/National Petroleum Refiners Association, Survey of Refining Operations and Product Quality, July 1997.

2 California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, Appendix IV

3 California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, Appendix III.

4 California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, Appendix II.

5 California Environmental Protection Agency, Air Resources Board,. *Draft State and Federal Element of South Coast State Implementation Plan.* January 2003.

6 San Joaquin Valley Air Pollution Control District. *Amended 2002 and 2005 Ozone Rate of Progress Plan.* December 31, 2002.

7 United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, December 2000, Chapter II.

8 Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Part A. Exposure Assessment. As approved by the Scientific Review Panel on April 22, 1998, pp. A-5–A-7

9 Arey J., Zeilinska, B., Atkinson, R. and A.M. Winer, 1988. Formation of Nitroarenes During Ambient High-Volume Sampling. *Environ. Sci. Technol.*, 22:457-462.

10 Atkinson, R., Arey, J., Winer, A.M., Zielinska, B., Harger, W.P., and McElroy, P.A. 1988. A Survey of Ambient Concentrations of Selected Polycyclic Aromatic Hydrocarbons (PAH) at Various Locations in California. Final Report. California Air Resources Board, Sacramento, CA.

11 California Environmental Protection Agency, Air Resources Board. *Findings of the Scientific Review Panel on The Report on Diesel Exhaust as Adopted at the Panel's April 22, 1998 Meeting.* Appendix II of Staff Report, Initial Statement of Reasons - Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant.

[12] Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Part A. Exposure Assessment. As approved by the Scientific Review Panel on April 22, 1998, p. A-50.

[13] California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, Appendix VI.

[14] California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, p. 15

[15] Kittelson, D.B., Arnold, M., Watts, W.F. (1999) Review of Diesel Particulate Matter Sampling Methods. Final Report. University of Minnesota www.me.umn.edu/centers/cdr/Proj_EPA.html.

[16] Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Part A. Exposure Assessment. As Approved by the Scientific Review Panel on April 22, 1998.

[17] United States Environmental Protection Agency,. Assessment and Standards Division, Office of Transportation and Air Quality, *Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel.* EPA420-R-03-008, April 2003, Chapter II.

[18] California Environmental Protection Agency. *Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant: Health Risk Assessment for Diesel Exhaust; Appendix III, Part B*; Office of Environmental Health Hazard Assessment: Sacramento, CA, 1998

[19] California Air Resources Board. *Resolution 98–35: Identification of Particulate Emissions from Diesel-Fueled Engines as a Toxic Air Contaminant*; California Air Resources Board: Sacramento, CA, 1998, http://www.arb.ca.gov/regact/diesltac/res98-35.pdf

[20] Diaz-Sanchez, D.; Tsien, A.; Casillas, A.; Dotson, A.R.; Saxon, A. Enhanced Nasal Cytokine Production in Human Beings after in vivo Challenge with Diesel Exhaust Particles; *J. Allergy Clin. Immunol.* 1996, *98*, 114-123.

[21] Diaz-Sanchez, D.; Garcia, M.P.; Wang, M.; Jyrala, M.; Saxon, A. Nasal Challenge with Diesel Exhaust Particles Can Induce Sensitization to a Neoallergen in the Human Mucosa; *J. Allergy Clin. Immunol.* 1999, *104*, 1183-1188.

[22] Takano, H.; Ichinose, T.; Miyabara, Y.; Shibuya, T.; Lim, H.B.; Yoshikawa, T.; Sagai, M. Inhalation of Diesel Exhaust Enhances Allergen-related Eosinophil Recruitment and Airway Hyperresponsiveness in Mice; *Toxicol. Appl. Pharmacol.* **1998**, *150*, 328-337.

[23] Lloyd, A.C.; Cackette, T.A. Diesel Engines: Environmental Impact and Control; *J Air Waste Manage. Assoc.* 2001, 51: 809-847

[24] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, December 2000, Chapter II.

[25] Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Federal Register: January 18, 2001 (Volume 66, Number 12) Pages 5001-5134

[26] Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel. Proposed Rules. Federal Register: May 23, 2003 (Volume 68, Number 100) Pages 28328-28603.

[27] Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Part A. Exposure Assessment. As approved by the Scientific Review Panel on April 22, 1998.

[28] California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000.

[29] Documents developed by the Portable Equipment Workgroup are available for viewing or downloading at http://www.arb.ca.gov/diesel/portdiesel.htm

[30] The Proposed and Draft ATCMs and other relevant documents are available for viewing or downloading at http://www.arb.ca.gov/diesel/documents.htm

[31] Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Federal Register: January 18, 2001 (Volume 66, Number 12) Page 5090.

[32] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, December 2000, Chapter III.

[33] U.S. Department of Energy, Engine Manufaturers Association, and Manufacturers of Emissions Controls Association, *Diesel Emissions Control – Sulfur Effects (DECSE) Program Phase II Summary Report: NOx Adsorber Catalysts.* October 2000

[34] Clark, W., Sverdrup, G.M., Goguen, S.J., Keller, G., McKinnon, D., Quinn, M.J., and Graves, R.L. *Overview of diesel emission control - Sulfur effects program*; SAE #2000-01-1879; Society of Automotive Engineers, Inc.: Warrendale, PA, 2000.

[35] Manufacturers of Emission Controls Association. Catalyst-based diesel particulate filters and NO_X adsorbers: A summary of the technologies and the effects of fuel sulfur; 2000. http://www.meca.org.

[36] Diesel Emissions Control – Sulfur Effects (DECSE) Program Phase 1 Interim Data Report No. 4: Diesel Particulate Filters – Final Report. U.S. Department of Energy, Engine Manufaturers Association, and Manufacturers of Emissions Controls Association. January 2000.

[37] Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements", Federal Register: January 18, 2001 (Volume 66, Number 12) (Rules and Regulations). p. 12.

[38] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Strategies and Issues in Correlating Diesel Fuel Properties with Emissions*, "Staff Discussion Document," EPA420-P-01-001, , July 2001, pp. 41-42.

[39] Lee, R; Pedley, J; and Hobbs, C; 1998. "Fuel Quality Impact on Heavy-Duty Diesel Emissions – A Literature Review;" SAE 982649; Society of Automotive Engineers, Inc; Warrendale, Pennsylvania.

[40] Barbour, R.H., Rickeard, D.J., Elliot, N.G., "Understanding Diesel Lubricity", SAE #2000-01-1918; Society of Automotive Engineers, Inc.: Warrendale, PA, 2000

[41] United States Environmental Protection Agency,. Assessment and Standards Division, Office of Transportation and Air Quality, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements..* EPA420-R-00-026. December 2000, Chapter IV. pp 64 – 78.

[42] ASTM Standard D 975-98a, "Standard Specification for Diesel Fuel Oils", ASTM Standards, Section 5, Vol. 05.01 (1998).

[43] "Demand for Diesels: The European Experience", Diesel Technology Forum, July 2001, www.dieselforum.org/whitepaper/downloads/europeanexperience.pdf

[44] Lacey, P.I., Howell, S.A., "Fuel Lubricity Reviewed", SAE Technical Paper 982567, 1998.

[45] Nikanjam, Manuch, Henderson, Paul, Lacey, Paul, Caprotti, Rinaldo, Simeroth, Dean, Mithchell, Ken,, "Diesel Fuel Lubricity". Presented at the 8th Annual Fuels & Lubes. Asia Conferenc and Exhibition, F&L Asia , Inc, January 29 – February 1, 2002.

[46] Nikanjam, M., Crosby, T., Henderson, P., Cray, C., Meyer, K., Davenport, N., "ISO Diesel Fuel Lubricity Round Robin Program", SAE Technical Paper 952372, 1995.

[47] D6078-99 Standard Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluato (SLBOCLE).

[48] D6079-02 Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR).

[49] Nikanjam, Manuch, Chevron Products Company; "Diesel Fuel Lubricity: On the Path to Specifications", SAE Technical Paper 1999-01-1479, 1999.

[50] U.S. Ultra Low Sulfur Diesel Fuel Properties, EMA Engine Manufacturer's Association, September 20, 2002.

[51] The Diesel Fuel Task Force; "Report of the Diesel Fuel Task Force", DCN 93-674-062-01, February 18,1994. p.4-4.

[52] Meyer, Klaus, Livingston, Thomas C., Presentation "Diesel Fuel Lubricity Requirements for Light Duty Fuel Injection Equipment", CARB Fuels Workshop, Sacramento, CA, February 20, 2003.

[53] Westbrook, S.R., Lacey, P.I., McInnis, L.A., Lestz, S.J.,LePera, M.E.; "Survey of Low Sulfur Diesel Fuel and Aviation Kerosenes from U.S. Military Installations", SAE Technical Paper 952369, 1995.

[54] Nikanjam, Manuch, Chevron Products Company, California Air Resource Board Public Meeting Presentation, "Diesel Fuel Lubricity The Need For Specification", Sacramento, CA, Feb. 20 2003.

[55] Tucker, R.F., Stradling, R.J., Wolveridge, P.E., Rivers, K.J., Ubbens, A., "The Lubricity of Deeply Hydrogenated Diesel Fuels – The Swedish Experience", SAE Technical Paper 942016, 1994.

[56] "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements", Federal Register: January 18, 2001 (Volume 66, Number 12) (Rules and Regulations Pages 5083-5084).

[57] Dimitrakis, William J., "The importance of lubricity", The Lubrizol Corporation, USA, Hydrocarbon Engineering, March 2003, pp.37-39.

[58] Nancy Strete, David Forrester, Lubrizol Corporation, Teleconference with ARB personnel Gary Yee, Robert Okamoto, and Cherie Cotter, April 21, 2003.

[59] Alan Melard, Infineum Corporation, Teleconference with ARB personnel Gary Yee, Robert Okamoto, and Cherie Cotter, April 22, 2003.

[60] Barbara Goodrich, BP, Teleconference with ARB personnel Gary Yee and Cherie Cotter, March 20, 2003.

[61] Mozdzen, Edward C., Wall, Stephen W., and Byfleet, William D., "The No-Harm Performance of Lubricity Additives for Low Sulphur Diesel Fuels", SAE Technical Paper 982571, 1998.

[62] Kenneth Mitchell, Shell Canada, Teleconference with ARB personnel Gary Yee and Cherie Cotter, April 25, 2003.

[63] Cameron, Frances, California Air Resources Board; "Lubricity of California Diesel Fuel", SAE Technical Paper 981362, 1998.

[64] Lacey, P.I., Mason, R.L., "Fuel Lubricity: Statistical Analysis of Literature Data", SAE Technical Paper 2000-01-1917, June 2000.

[65] American Society for Testing and Materials, ASTM D 2622-94. Standard Method for Sulfur in Petroleum Products by X-Ray Spectrometry, 1994

[66] American Society for Testing and Materials, ASTM D 5453-93. Standard Method for Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence, 1993.

[67] Nadkarni, R.A. Determination of Sulfur in Petroleum Products and Lubricants: A Critical Review of Test Performance, American Laboratory, 2000,16.

[68] South Coast Air Quality Management District, September 6, 2000. Staff Report, Proposed Amended Rule 431.2 – Sulfur Content of Liquid Fuels.

[69] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, December 2000 .

[70] Charles River Associates, Inc. *An Assessment of the Potential Impacts of Proposed Environmental Regulations on U.S .Refinery Supply of Diesel Fuel*, CRA No. D02316-00, August 2000. http://www.crai.com/asst_diesel.pdf

[71] United States Department of Energy, Energy Information Administration. *The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply,* May 2001.

[72] United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, Chapter IV. December 2000, pp 30 – 32.

73 United States Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* EPA420-R-00-026, Chapter III. December 2000, pp 96 – 98.

74 "Lubrication Theory and Practice.", accessed May 1, 2003, www.lubrizol.com/lubetheory/theory.htm

75 Whitacre, Shawn. "Catalyst Compatible" Diesel Engine Oils, DECSE Phase II, Presentation at DOE/NREL Workshop "Exploring Low Emission Diesel Engine Oils." January 31, 2000.

76 "SwRI forms research consortium on diesel aftertreatment sensitivity to lubricants", January 31, 2001,www.dieselnet.com/news/0101swri.html

77 United States Environmental Protection Agency; Office of transportation and Air Quality, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions: Draft Technical Report*, EPA 420-P-02-001, October 2000, www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

78 Lovelace Respiratory Research Institute, Tier 2 Testing of Biodiesel Exhaust Emissions: Final Report. Study Report Number FY98-056 submitted to National Biodiesel Board, May 22, 2000, pp. 1-59.

79 Economides. N. and Higgins, T. International diesel fuel policies will shape markets for years. World Diesel 2003. Pp. 25-28.

80 Klavers, Kristine, Global Trends for Automotive Diesel Qualities. World Diesel 2003. Pp 29-34.

81 European Conference of Ministers of Transport. Report to the Committee of Deputies: *Sulphur-Free Auto Fuels*. March 2001.

82 World-Wide Fuel Charter, December 2002, Page 5.

83 Cooper, B. H., and Knudsen, K.G. "What does it take to produce ultra-low sulfur diesel?" World Refining, November 2000.

84 Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999. California Energy Commission Publication #600-02-001F-ES, November 2002.

85 State of California, Air Resources Board, Public Hearing to Consider Amendments Adopting More Stringent Emission Standards for 2007 and Subsequent Model Year Heavy-Duty Diesel Engines. Staff Report: Initial Statement of Reasons, September 7, 2001.

86 California Environmental Protection Agency. Air Resources Board. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000, Chapter VIII.

[87] Final Program Environmental Assessment for: Proposed Fleet Rules and Related Rule Amendments. South Coast Air Quality Management District. SCAQMD No. 000307DWS. June 5, 2000.

[88] United States Environmental Protection Agency,. Assessment and Standards Division, Office of Transportation and Air Quality, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements..* EPA420-R-00-026. December 2000, Chapter 5.

[89] California Energy Commission – Weekly Fuels Watch Report, 2002, www.energy.ca.gov/database/fore/index.html

[90] Energy Information Adminstration, U.S. Department of Energy: The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply, www.eia.doe.gov/oiaf/servicerpt/ulsd/pdf/ulsd.pdf, Chapter 6.

[91] MathPro Inc., Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap, October 1999, updated August 2000.

[92] National Petroleum Council, U.S. Petroleum Refining, Assuring the Adequacy and Affordability of Cleaner Fuels, June 2000, Chapter 3.

[93] EnSys Energy & Systems, Inc., Modeling Impacts of Reformulated Diesel Fuel, August 2000.

[94] MathPro Inc., Prospects for Adequate Supply of Ultra Low Sulfur Diesel Fuel in the Transition Period (2006-2007): An Analysis of Technical and Economic Driving Forces for Investment in ULSD Capacity in the U.S. Refining Sector, February 2002.

[95] Oil Price Information Service, Copyrighted data for AZ, CA, NV, OR from year 1996–2002, http://www.opisnet.com .

[96] Energy Information Administration - Department of Energy, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/pmm_historical.html .

[97] California Department of Food and Agriculture, 2002 Resource Directory, www.plant.cdfa.ca.gov/card/

[98] Studies from University California, Davis, Cooperative Extension, Department of Agricultural and Resource Economics, www.agecon.ucdavis.edu/outreach/crop/cost.htm

[99] Council of Economic Advisors, 108th Congress, 1st Session, Economic Indicators: January 2003, www.access.gpo.gov/congress/eibrowse/broecind.html

[100] California Agricultural Statistics Service - United States Dairy Association, California Cost of Production Annual 2001.

[101] Studies from Oregon Agricultural Enterprise Budgets, Extension Service, Oregon State University (http://oregonstate.edu/Dept/EconInfo/ent_budget/)

[102] State of California, Air Resources Board, Spreadsheet Calculations to Estimate the Average Gallons of Diesel Consumed, Vehicle Miles Traveled, and Cost Impacts, for HDDT based on data from EMFAC2002, Version 2.2.

[103] American Trucking Association, Information Center, Government's Cash Cow: The Trucking Industry (http://www.truckline.com/infocenter/position_papers/cashcow.html)

[104] US Department of Transportation, Federal Highway Administration, Motor Fuel Use – Special Fuel (Diesel) – Private and Commercial Highway Use

[105] US Census Bureau, Census 2000 PHC-T-2, Table 2, States Ranked by Numeric Population Change: 1990 to 2000

[106] ARB, October 2000. *Risk Reduction Plan to Reduce PM Emissions from Diesel-Fueled Engines and Vehicles*, including Appendices II and III, California Air Resources Board, Sacramento, California.