SESSION I

Agency/Organization Concerns on Engine Emissions

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CRITERIA POLLUTANTS: IS THE PROBLEM THE DIESEL OR THE GASOLINE ENGINE? CAN WE MEET FUTURE EMISSIONS STANDARDS?

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BACKGROUND

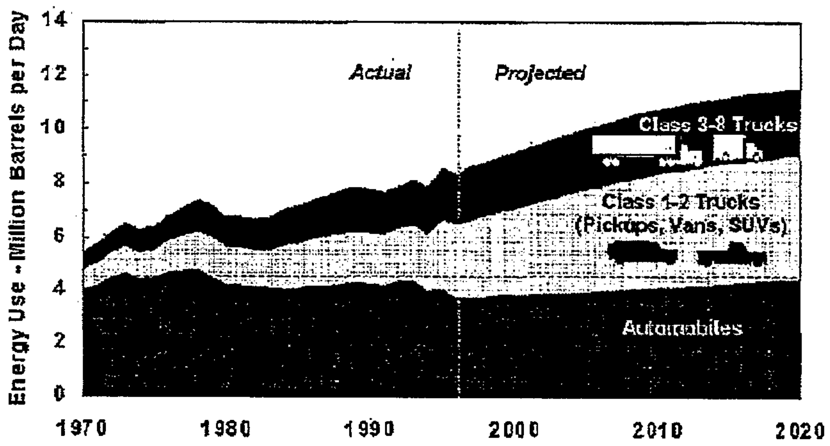
Essentially all of the increase in highway transportation energy use since the oil embargo in 1973 has been due to trucks (see Figure 1) for two reasons. First, freight transport provided by heavy- and medium-duty trucks has continued to grow concomitant with the expansion in economic activity. Second, there has been an explosive growth in popularity for personal transport of low-mpg (miles per gallon) sport utility vehicles, vans, and pickup trucks (also used for commercial transport by business enterprises). Energy Information Administration (EIA) data [1] show that in 1996 trucks of all classes consumed more fuel than automobiles for the first time.

Since it is necessary to continue to produce and transport goods, and provide services important for economic growth, commercial trucks must continue to ply the highways amidst the growing concern about vehicle emissions of criteria pollutants, global climate change from greenhouse gases such as carbon dioxide, and another looming energy crisis. Two issues have to be faced, namely: a) how to meet the demand for commercial transport to sustain continuing expansion of economic activity in an energy efficient and environmentally sound manner and b) how to increase the efficiency (without compromising the functionality of pickup trucks, vans, and sport utility vehicles while reducing criteria pollutant emissions to very low levels.

A real and viable strategy that addresses both issues is to increase the use of the most efficient engine in production today, the diesel (compression-ignition cycle) engine, utilizing the most cost-effective emissions control technologies.

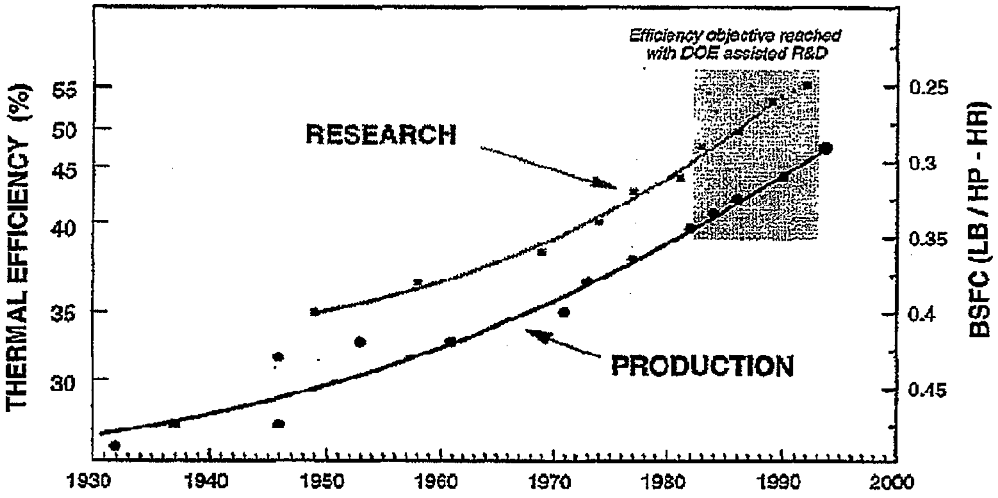
THE CASE FOR THE DIESEL ENGINE

The diesel engine is the engine-of-choice for heavy-duty freight transport where efficiency, low speed power requirements, durability, and reliability are important. It is much more efficient than the gasoline engine, which accounts for its dominance in commercial transport where cost competitiveness is key to staying in business. The trend in heavy-duty Diesel engine thermal efficiency is shown in Figure 2. Truck, rail, and



source: *EIA Annual Energy Outlook 1998*
Federal Highway Administration, Highway Statistics

Figure 1. Highway Transportation Energy Use



Source: Caterpillar

Figure 2. Increasing Diesel Engine Thermal Efficiency

inland marine transport are almost completely diesel powered, and by widespread industry consensus, are expected to remain so in the foreseeable future.

Other than the diesel engine, there are currently no available technologies that can directly compete with the gasoline engine and radically improve the fuel efficiency of pickup trucks, vans, and sport utility vehicles. These vehicles are popular because of their towing and hauling capacity, four-wheel drive traction, and off-road capabilities. Direct injection diesel engines in the power range of 200 horsepower and greater are suitable for these trucks and efficiencies at peak power are from 38 to 42 percent compared to gasoline engines at 34 percent. Recent experiments utilizing direct injection diesel engines in these vehicles indicate that fuel economy can be improved by 35 percent or more.

Because of this higher efficiency, diesel engines produce lower greenhouse gas emissions than comparable gasoline engines (20 percent less in the 1970s and now over 30 percent due to a widening efficiency gap). With mounting international pressures to reduce greenhouse gas emissions from the U.S. transportation sector, the diesel engine appears to be a technology for doing so rather quickly without adverse economic impacts. The infrastructure for manufacturing and servicing the engine is already in place. In Europe where fuel prices have always been much higher than the U.S., the diesel engine has achieved a substantial measure of acceptance even for personal transportation.

Despite its technical advantages over gasoline engines, concern about increasing "dieselization" of these vehicles has been expressed by some environmental groups; these include the Union for Concerned Scientists, American Lung Association, American Council for an Energy-Efficient Economy, Environmental and Energy Study Institute, Natural Resources Defense Council, Sierra Club, Environmental Protection Agency, California Air Resources Board, South Coast Air Quality Management District, and the Council on Environmental Quality. They have expressed concern that widespread deployment of diesel engines in transportation will be detrimental both to the environment and to human health.

THE EMISSIONS ISSUE: IS THE PROBLEM THE DIESEL OR THE GASOLINE ENGINE?

The anti-diesel campaign has intensified as it has become apparent that the diesel engine is the only currently available alternative to the gasoline engine. Citing studies (albeit based on pre-1990 engines) on potential health effects of diesel particulate emissions, there has been an attempt in California to declare diesel exhaust as a toxic air contaminant and, therefore, effectively ban the diesel.

A shift to the less efficient (more carbon dioxide producing) gasoline engines for freight transport vehicles would be costly to implement and would reduce further the already low profitability of trucking companies. Such as shift assumes that gasoline exhaust is much less harmful than diesel exhaust. This assumption is by no means certain. Is there sufficient information on the health effects of gasoline exhaust particulates to determine if they are less deleterious than those from diesel fuel? Perhaps an excerpt from an EPA report [2] comparing the cancer risks from gasoline and diesel particulate matter best illustrates this uncertainty. The report states:

> "Although gasoline engine emission particulate matter is similar to diesel exhaust in terms of chemical and most physical properties, the cancer unit risk estimate for gasoline engine exhaust is based on the comparative potency method rather than particles, for a number of reasons. The comparative potency method is believed, at present to be the most logical approach for estimating cancer risk from gasoline engine exhaust because, first, the EPA's particle based unit risk estimate is not an official estimate and is subject to change. Also, while the composition of gasoline exhaust particulate matter may be similar to that of diesel exhaust, the particles are **considerably smaller.** Cancer potency may therefore differ from diesel exhaust because of greater particle surface area per unit volume and because of altered deposition rates. **Finally, since no chronic inhalation bioassays have been carried out on gasoline engine emissions** *(emphasis ours)*, a particle based cancer risk estimate, using the same methodology for diesel would contain a considerable degree of uncertainty."

Certain things stand out from this excerpt:

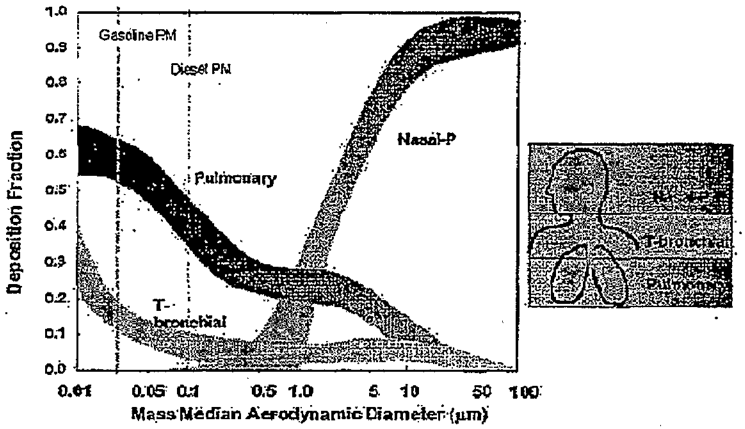
- Toxicity studies have been carried out on diesel particulates but not on gasoline particulates.
- The EPA particle-based unit risk estimate (which is not official and subject to change) is used to estimate the cancer risk from diesel particulates. Using it for gasoline particulates would cortain a considerable degree of uncertainty, and, therefore, not done.
- Because they are considerably smaller than diesel particulates, gasoline particulates have greater surface area per unit volume and different deposition rates, and therefore, different cancer potency than diesel particulates. However, health studies indicate that the smaller particulates maybe more deleterious than the larger particulates.

Health studies indicate that fine particulates may be highly toxic to the human lung at very low mass concentration because of: a) large numbers per unit mass; b) high deposition efficiency in the lower respiratory tract; c) inability of the respiratory tract to clear itself of such particulates; and d) increased surface areas available for interactions with cells [3]. These studies indicate that particulates have a tendency to become deeply deposited in the lungs and bronchial tubes. This tendency increases as the particulates become smaller, indicating that gasoline particulates, compared to diesel particulates, are more readily embedded deeper into the lungs and potentially causing problems. Therefore, gasoline particulates presently could pose an even greater health risk than diesel particulates since the greater number of our vehicles are gasoline fueled.

In September 1997 the EPA issued new standards for fine particulates (or PM 2.5) under the National Ambient Air Quality Standards (NAAQS) of 15 and 65 micrograms per cubic meter annual and daily mass concentrations, respectively. By comparison, when particulates that are 0.02 micrometers in size (the size of the largest number concentration of gasoline particulates) are inhaled, up to 50 percent are deposited in the alveolar region of the human lung (see Figure 3). At a resting ventilation of 8 liters per minute and exposure concentration of 100,000 particles per cubic centimeter, about 80 particles per hour per alveolus would be deposited in a human lung with 300 million alveoli. This large number of particles represents only about 0.5 micrograms per cubic meter.

CAN THE DIESEL MEET FUTURE EMISSIONS STANDARDS?

Contrary to the old perception about diesel engines, high efficiency benefits can be obtained without penalizing the environment. Compared to 1970s diesel engines, technology advances have reduced emissions of particulates by 95 percent and nitrogen oxides (NOx) by 70 percent (see Figure 4). Today's heavy-duty diesel engines emit just under 4 g/bhp-hr of NOx and 0.10 g/bhp-hr of particulates (<0.05 g/bhp-hr for transit buses). In addition, the Environmental Protection Agency (EPA) and major engine manufacturers have issued a "Statement of Principles" that



Source: *Particles in Our Air: Concentrations and Health Effects*, Harvard School of Public Health, 1996

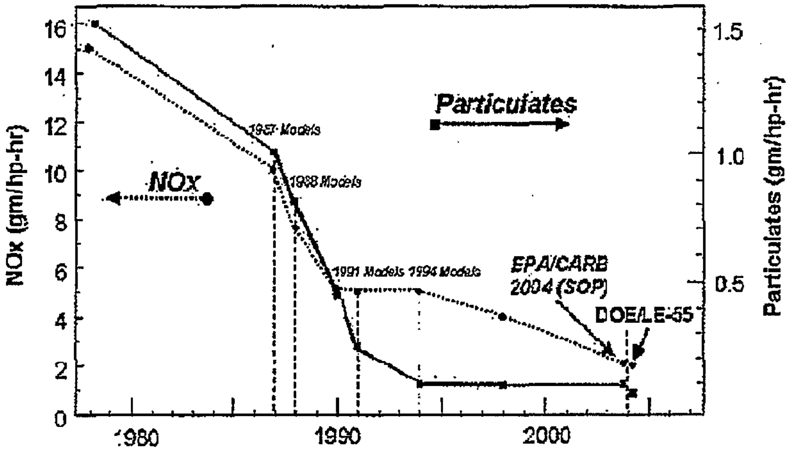
Figure 3. Deposition of Particulates into the Lungs

requires, by 2004, further reduction to 0.05 g/bhp-hr particulates and 2.4 g/bhp-hr of NOx plus non-methane hydrocarbons (NMHC) or 2.5 g/bhp-hr of NOx plus NMHC with a maximum of 0.5 g/bhp-hr of NMHC.

In conjunction with industry partners, the DOE Office of Heavy Vehicle Technologies is funding research and development of advanced low-emissions, 55 percent efficient (LE-55) Diesel engine technologies to enable heavy-duty trucks to continue to operate efficiently and meet EPA emissions standards proposed for 2004. A three-pronged systems approach (Figure 5) that simultaneously addresses fuel formulation, in-cylinder combustion control, and exhaust aftertreatment is being employed to arrive at the most cost-effective emissions control strategy.

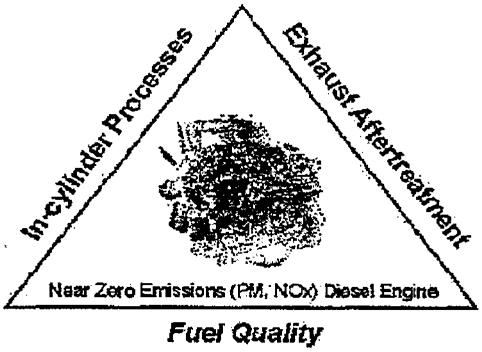
Research progress to date indicates that very low diesel emissions are technically feasible and that the heavy-duty diesel is well on its way to being an environmentally sound engine for continued economic growth. An approach using a combination of low-sulfur fuel, exhaust gas recirculation, and non-thermal plasma exhaust aftertreatment (see Figure 6) is able to lower NOx to 0.4 g/bhp-hr and PM emissions to 0.01 g/bhp-hr.

For pickup trucks, vans, and sport utility vehicles, cooperative agreements are in place to utilize the



Source: Cummins, modified by DOE

Figure 4. Decreasing Diesel Emissions



Three-pronged systems approach appears necessary to meet very low emissions without sacrificing engine efficiency

Figure 5. Diesel Emissions Control Strategy

expertise of the U.S. diesel engine manufacturers to devolve heavy duty diesel technology to these smaller truck classes. The question is not if very low levels of emissions can be achieved but rather, what is cost-effective, and ultimately, what is the cost to the consumer.

CONCLUSION

The diesel engine has already established itself as the engine-of-choice for the heavy-duty transport industry because of its fuel efficiency, durability, and reliability. It appears to be a viable near term solution for reducing transportation energy use and emissions of carbon dioxide, a greenhouse gas. However, many groups are concerned about diesel engines and the likelihood of extensive use of diesels in transportation. Also, there had been a move to classify diesel exhaust as a toxic air contaminant. This may be rather premature because there are studies and scientific evidence that indicate that gasoline particulates (at the low mass concentrations that seem to favor the gasoline over the diesel engine) can potentially be more deleterious to human health. Therefore, judgment on the diesel should not be rushed. Conversion of all commercial freight transport to gasoline engines could turn out to have negative environmental, health, and safety impacts greater than those of the new clean diesel engines.

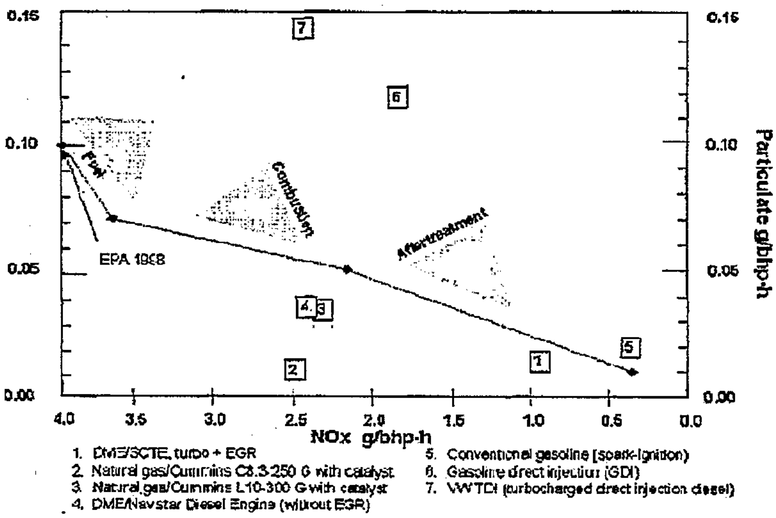


Figure 6. Very Low Diesel Emissions Technically Feasible

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1. *Annual Energy Outlook, 1998.* Energy Information Agency.
2. *Motor Vehicle-Related Air Toxics Study*, Technical Support Branch, Emission Planning and Strategies Division, Office of Mobile Sources, Office of Air and Radiation, U.S. Environmental Protection Agency, April 1993.
3. *Particles in Our Air: Concentrations and Health Effects*, Harvard School of Public Health, 1996.

CALIFORNIA'S REVISED HEAVY-DUTY VEHICLE SMOKE AND TAMPERING INSPECTION PROGRAM

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ABSTRACT

Heavy-duty vehicles account for approximately 30 percent of the oxides of nitrogen (NOx) and 65 percent of the particulate matter (PM) emissions from the entire California on-road fleet, despite the fact that these vehicles comprise only 2 percent of the same. To meet legislative mandates to reduce excess smoke emissions from in-use heavy-duty diesel-powered vehicles, the Air Resources Board (ARB or Board) adopted, in December 1997, amendments to the regulations governing the operation and enforcement of the Heavy-Duty Vehicle Inspection Program (HDVIP or the "roadside" program) and the Periodic Smoke Inspection Program (PSIP or the "fleet" program).

The initial roadside program was adopted in November 1990 in response to Senate Bill (SB) 1997 (stat. 1988, ch. 1544, Presley), and enforced from 1991 to 1993. It was suspended in October 1993, when the Board redirected staff to investigate reformulated fuels issues. The Board adopted the fleet program in December 1992, but until recently it had not been enforced. Enforcement of these amended programs commenced in the Spring/Summer of 1998.

Compared to having no heavy-duty vehicle inspection programs, the roadside and fleet programs with the amendments are expected to achieve the following emission reductions (in tons per day) of reactive organic gases (ROG), NOx and PM:

	ROG	NOx	PM-10
1999	6.37	12.24	5.24
2010	5.3	14.03	3.19

Diesel fuel consumption will be reduced by approximately 16.7 and 19.2 million gallons annually in 1999 and 2010, respectively. This represents a savings over the 12-year period of approximately 250 million gallons of fuel or over $212 million (at current fuel prices.)

INTRODUCTION

To meet legislative mandates to reduce excess smoke emissions from in-use heavy-duty diesel-powered vehicles, the ARB adopted, in December 1997, amendments to the regulations governing the operation of the HDVIP and the PSIP. Both of these programs are enforcement programs designed to reduce excessive smoke emissions from mal-maintained and tampered heavy-duty diesel-powered vehicles. These amendments modify existing program regulations.

The initial HDVIP was enforced from November 25, 1991 to October 15, 1993 when it was suspended and staff was redirected by the Board to investigate reformulated fuels issues. Also in 1993, the California Legislature enacted a new statute, Assembly Bill (AB) 584 (Statutes of 1993, Chapter 570, Cortese), which directed the Board to make additional changes to the programs. The Board adopted the fleet program regulations on December 9, 1992. Due to the redirection of the staff and program technical issues, enforcement of the fleet program was never implemented. Both programs were administered on a voluntary compliance basis from October 1993. Enforcement of the HDVIP was reinstated on June 1, 1998 and enforcement of the PSIP began on July 1, 1998.

The regulatory amendments to the existing programs were designed to comply fully with the mandates of AB 584 and AB 1460 (Statutes of 1996, Chapter 292, Morrissey). Assembly Bill 584 requires that the smoke test procedures used for both the roadside and fleet programs produce consistent and repeatable results. Pursuant to AB 584, these requirements are met with the adoption of the Society of Automotive Engineers (SAE) J1667 test procedure[1] into the programs' regulations. Assembly Bill 584 also requires that the HDVIP's inspection procedures produce "no false failures". Should false failures occur, they must be remedied without penalty to the vehicle owner. The amendments have provisions that meet these requirements. Assembly Bill 1460 requires limited additional changes to the statute authorizing the HDVIP. The most significant requirement under AB 1460 is that "excessive smoke" must be defined in the regulations governing the HDVIP; a definition that ties excessive smoke emissions to the regulations' opacity cutpoints was proposed and adopted in December 1997.

BACKGROUND

Emissions from Heavy-Duty Vehicles

Emissions from heavy-duty diesel trucks and buses are well known to seriously impact California's air quality. Heavy-duty vehicles account for approximately 30 percent of the NOx and 65 percent of the PM emissions from the entire California on-road fleet, even though these vehicles comprise only approximately 2 percent of that fleet. The NOx emissions, when combined with various hydrocarbon (HC) emissions and sunlight, form ozone, commonly referred to as "smog". Consequently, NOx, and to a lesser degree, HC exhaust emissions from heavy-duty trucks and buses significantly contribute to violations of the state and federal ambient air quality standards for ozone. Diesel exhaust particulate emissions consist of fine particles designated as PM-10, most of which are designated as PM-2.5[2]. The NOx emissions also contribute to PM pollution by forming nitrates in the atmosphere. These particulate emissions contribute to violations of the state and federal ambient air quality standards for particulate matter and contribute to reduced visibility. The HDVIP and PSIP are designed to reduce the excessive in-use emissions that result from improper vehicle maintenance practices and tampering.

Ozone and particulate matter pollution are of great concern because of their adverse effects on human health. Ozone is a known respiratory irritant that harms lung tissue and reduces breathing capacity. Its effects are strongest in sensitive individuals such as asthmatics, the elderly, and children. Based on recent epidemiological studies[3], particulate matter pollution has been consistently related to premature mortalities. According to a recent Natural Resource Defense Council study[4], particulate matter pollution causes between 8,600 and 19,400 premature deaths in California every year. In response to evidence relating ozone and particulate matter pollution to these and other health effects, the United States Environmental Protection Agency recently tightened both the federal ozone and particulate standards.

Constituents of diesel exhaust have been identified as toxic air contaminants under the ARB's Toxic Air Contaminant Program, and whole diesel exhaust is currently under review for identification. The International Agency for Research on Cancer has identified diesel exhaust as a probable human carcinogen[5]. Diesel exhaust was identified in 1990 under California's Proposition 65 as a chemical known to cause cancer. Also, excessive exhaust emissions (black smoke) from on-road heavy-duty vehicles continue to be the number one target of public complaints regarding air pollution.

History and Legal Basis for the HDVIP and PSIP

In response to these environmental and public health impacts, SB 1997 was enacted in 1988 directing the ARB to design and enforce an effective in-use heavy-duty vehicle smoke enforcement program. The regulations governing this program, the HDVIP, were adopted by the ARB on November 8, 1990 and became operative on November 21, 1991.

Under the HDVIP, heavy-duty diesel-powered trucks and buses are tested for excessive smoke emissions, and heavy-duty diesel- and gasoline-powered trucks and buses are inspected for tampering. Intrastate, interstate, and international[6] heavy-duty vehicles are tested statewide by ARB inspectors at California Highway Patrol (CHP) inspection facilities and weigh stations, and at random roadside locations. The owners of vehicles failing prescribed test procedures[7] are issued citations which require the prompt repair (within 45 days) of the vehicle and carry civil penalties ranging from $300 to $1800 per violation. Failure to clear citations can result in vehicles being removed from service by the CHP, at the request of the ARB (Health and Safety Code section 44011.6 (j) and Vehicle Code section 27159). Vehicle owners may appeal citations through the ARB's Administrative Hearing Program[8].

In concert with the HDVIP, regulations for a companion enforcement program requiring California fleet owners to self-inspect their vehicles for excessive smoke emissions were adopted in 1992 in accordance with SB 2330 (Statutes of 1990, Chapter 1453, Killea). This program, the PSIP, and the HDVIP use the <u>same</u> smoke test procedure as required under their governing statutes and regulations. With the adoption of the PSIP, the Legislature's mandate to control excessive smoke emissions from heavy-duty diesel vehicles was enhanced.

Under the PSIP, California-based truck and bus fleet owners with two or more vehicles are required to conduct annual smoke opacity and tampering self-inspections for all of their vehicles. To ensure program compliance, ARB inspectors are required to audit fleet maintenance and inspection records and test a representative sample of vehicles. The PSIP includes fleet vehicles that would normally not be captured by the HDVIP roadside enforcement operations (i.e., local service and delivery vehicles).

The regulations governing the PSIP were originally scheduled to become effective on January 1, 1995. Due to delays in the completion of the SAE J1667 test procedure, these regulations were amended to postpone their effective date to January 1, 1996. In a March 1996 notice, the ARB staff advised fleet operators that the PSIP would be administered on a voluntary basis, pending adoption of the SAE J1667 procedure into the program's governing regulations.

Presently, several states have enforcement programs for in-use heavy-duty diesel vehicles. Arizona was the first to implement such a program in 1970, and four other states have active programs in effect today. Other states have regulations in place but to date have not enforced their programs. California's HDVIP has been recognized as the nation's most comprehensive and effective enforcement program. The HDVIP proved very effective for the two years (1991 - 1993) it was enforced. During this time, the *overall* program failure rate was reduced from 34 percent to 21 percent, resulting in an estimated 38 percent reduction in the number of heavy-duty smoking trucks and buses operating in California.

Issues Associated with the Programs and Compliance with AB 584

Although the HDVIP has been effective in reducing emissions and the number of smoking heavy-duty vehicles, its "snap-acceleration" test (previously referred to as the "snap-idle" test) has been the focus of controversy[9]. The California Trucking Association (CTA) has argued that the test can be unreliable and can fail "clean" trucks. This debate has been ongoing since the program's implementation in 1991, and has led to litigation four times. In all cases, the test has been upheld by the California courts, including two decisions from the Third District Court of Appeals that were left standing by the California Supreme Court.

To resolve this lingering controversy, in 1993, the Legislature enacted AB 584 that was sponsored by the trucking industry. As discussed earlier, AB 584 requires that the smoke test procedure used in the HDVIP must produce "consistent and repeatable" results. This requirement is satisfied with the adoption of the SAE J1667 smoke test procedure into the HDVIP's and PSIP's governing regulations. The SAE J1667 test procedure was adopted by the SAE in February of 1996. Subsequent to the SAE's adoption of the J1667 test procedure, the ARB staff, in consultation with the regulated industries, designed two studies to assess the effectiveness of the J1667 test procedure, and to determine the smoke opacity cutpoints for inclusion in the regulations.

These two studies, the Random Truck Opacity Survey (RTOS) and the Truck Repair Study (TRS) were conducted in late 1996 and in 1997. The data from these studies served as the technical basis for staff's proposed regulatory amendments. The RTOS provided a profile of the California heavy-duty vehicle fleet's opacity. The TRS produced the post-repair opacity statistics upon which the cutpoints were based. (See Figure 1.)

From 1992 through 1996, the ARB staff participated on the SAE J1667 committee. This broad-based committee was charged with developing a heavy-duty diesel engine smoke test procedure. This committee was comprised of trucking and bus industry representatives, smokemeter manufacturers, federal and state air quality regulators, heavy-duty diesel engine manufacturers and representatives from various universities and colleges. As stated above, this procedure was adopted unanimously by this committee in 1996. This process resolved most of the issues of controversy associated with the HDVIP and PSIP.

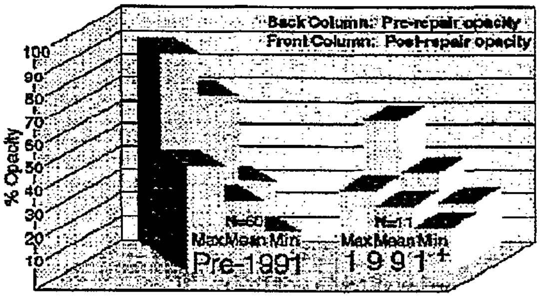

Figure 1

SUMMARY OF REGULATORY AMENDMENTS

Statutory Requirements Under AB 584 and AB 1460

As discussed earlier, AB 584 requires that the smoke test procedure used in the HDVIP must yield consistent and repeatable test results and result in no "false failures". Should false failures occur, they must be remedied without penalty to the vehicle owner. These requirements are codified in Health and Safety Code section 44011.6.

The regulatory amendments were designed to comply fully with these mandates by adopting the SAE J1667 test procedure, adding additional safeguards to minimize occurrences of false failures and by retaining procedures that provide remedies for false failures, should they occur, without penalty to vehicle owners. Additionally, a definition for "excessive smoke" was included to meet the requirements of AB 1460.

Regulatory Amendments

The following amendments were adopted by the Board in December 1997 to fulfill the requirements of AB 584 and AB 1460, and to improve the regulations:

(1) Designate the SAE J1667 "Snap Acceleration Smoke Test Procedure for Heavy-Duty Diesel Powered Vehicles," issued February 1996, as the test procedure for determining smoke opacity under the HDVIP and PSIP.

(2) Maintain the existing snap-acceleration opacity standards of 55 percent for pre-1991 model year and 40 percent for 1991 and newer model year heavy-duty diesel-powered engines, without reference to the engines' federal peak smoke certification level. These standards reflect data on maximum emissions from vehicles in good operating condition and set to manufacturers' specifications, gathered from the ARB's Truck Repair Study. These standards also include a significant safety margin to account for variability in smoke measurement. (On average, an SAE J1667-type smokemeter reads about 5 to 10 opacity points less for mechanical and electronic engines, respectively, as compared to a SAE J1243-type smokemeter.)

(3) Establish a mechanism under which owners of pre-1991 model year heavy-duty diesel-powered engines that have roadside snap-acceleration opacity levels between 55 percent and 70 percent are initially issued a Notice of Violation in lieu of a citation. If, within 45 days, the owner demonstrates that the repairs have been made to bring the vehicle into compliance with the 55 percent opacity standard, there will be no penalty. If a demonstration of correction is not submitted within the 45 day period, a citation would be issued. The NOV mechanism would not apply where a previous NOV or citation had been issued for the vehicle in the preceding 12 months. Based on the initial experience with the NOV approach, the staff plans to report to the Board by the end of 1999 with its recommendation on whether the approach should be sunsetted.

A summary of the opacity standards discussed in (2) and (3) above is provided in Table 1.

(4) Retain exemptions to allow for technologically less stringent standards for specific engine families based on data submitted by the engine manufacturers, and "grandfather-in" exemptions of engine families issued under the preexisting HDVIP regulations.

(5) Require explicitly that a demonstration of correction for a vehicle failing a roadside smoke test or visual inspection must include evidence that the vehicle has passed a post-repair test or inspection of the pertinent components.

(6) Institute a new 15 month phase-in schedule for the PSIP, starting July 1, 1998.

(7) Allow the SAE J1243-type smokemeter to be used in PSIP testing at facilities and fleets that are not equipped with an SAE J1667 type smokemeter, until July 1, 1999.

(8) Exempt the newest four model years of heavy-duty engines from the PSIP requirements under a four year "rolling exemption" process. Vehicles equipped with these engines would remain subject to the roadside inspections under the HDVIP.

(9) Define "excessive smoke" in the regulations, as required by AB 1460, as smoke opacity in

Table 1
Smoke Opacity Standards and ARB Actions

Vehicles with Pre-1991 Model Year Engines
Opacity Standard 55%

Test Opacity	ARB Action	Post-Repair Standard
Higher than 70%	_Issue Citation_	_<55%_
Between 55% and 70%*	_Issue Notice of Violation_	_<55%_

*Applicable only to first violation in a 12-month period

Vehicles with 1991 and Newer Model Year Engines
Opacity Standard 40%

Test Opacity	ARB Action	Post-Repair Standard
Higher than 40%	Issue Citation	_<40%_

excess of the opacity standards set forth in (2) and (3) above and summarized in Table 1 above.

(10) Retain the administrative hearing process to challenge citations. The staff plans to propose various amendments to the Administrative Hearing Program's regulations to be considered by the Board in the Spring of 1998.

(11) Make various other changes to generally improve the regulations and to make them more clear and readable.

(12) During the December 1997 hearing, the Board added language to the PSIP regulation that exempted from annual inspection requirements those heavy-duty diesel-powered vehicles that are not part of a fleet or are exclusively for personal use. (These vehicles would still be subject to the roadside HDVIP.)

OUTREACH AND PUBLIC RELATIONS

In preparation for the reinstatement of the smoke inspection programs, the ARB conducted an extensive outreach program. This took the form of numerous presentations at truck and bus association meetings and fleet facilities, and pre-enforcement smoke testing offered to fleets at no charge (and with no penalty.) During the period of October 1993 until the end of May 1998, the ARB visited over 1,000 fleets.

As an additional outreach program, the ARB participates in a partnership with community colleges and the heavy-duty vehicle industry to offer low-cost training. This partnership, called the California Council on Diesel Education and Technology (CCDET), provides an in-depth understanding of the smoke inspection regulations and training on the correct administration of the SAE J1667 smoke test procedure.

ENVIRONMENTAL AND ECONOMIC IMPACT ANALYSES

The evaluation of the air quality impacts of the amendments is based on a comparison of the HDVIP and PSIP with the amended regulations to the initial HDVIP and PSIP regulations. In conducting an emissions impact analysis, it was necessary to identify the "baseline" emissions, i.e., a starting point with which the initial and amended programs are compared. The baseline in this analysis consists of the emissions expected from heavy-duty trucks and buses in 1998 prior to resumption of either the original or amended programs. These estimated baseline emissions reflect the residual impact of the 1991-1993 HDVIP enforcement activities on the in-use emissions of heavy-duty trucks and buses in California.

The incremental environmental impacts in 1999 for the initial programs compared to the amended programs are: -1.34 tpd, -2.46 tpd, and -1.06 tpd for the emissions of ROG, NOx, PM10, respectively. For the year 2010, the amended programs indicate that fewer benefits will be realized when compared incrementally to the original programs. For 2010, the differences are: -1.92 tpd, -5.10 tpd, and -1.18 tpd for the emissions of ROG, NOx, PM10, respectively.

With respect to smoking vehicles, the amended programs, when compared to the initial program will be less effective because some heavy-duty vehicles that marginally exceed the opacity standards under the preexisting procedures will not fail under the new test procedures. In 1999, the initial programs would have reduced the numbers of smoking vehicles by an estimated 35.4 percent while the amended programs will realize estimated reductions of 29.0 percent. This is a difference of 6.4 percent of the overall fleet and equates to 6,324 more smoking vehicles. In 2010, under the initial programs, smoking vehicles would have been reduced by an estimated 48.9 percent, compared to an estimated 36 percent under the amended programs. This represents a difference of 12.9 percent, or 13,889 vehicles.

Although the amended programs result in fewer environmental benefits, when compared on an incremental basis to the initial programs, this is not to say that substantial reductions to the baseline will not occur due to their adoption. The reasons for the reduced benefits are due, in part, to the incorporation of the AB 584 requirements and the proposed four-year rolling exemption under the PSIP. Overall, adoption of the amended programs will result in estimated reductions (in tons per day) to the baseline statewide as follows:

	ROG	NO_x	PM-10
1999	6.37	12.24	5.24
2010	5.30	14.03	3.19

The HDVIP and PSIP will produce benefits by reducing the emissions of criteria and toxic pollutants resulting from the repairs performed to reduce excessive smoke emissions. Based on the estimated program costs and criteria pollutant emission reductions, the cost effectiveness of the benefits of the HDVIP and PSIP is estimated to be $1.12 per pound in 1999 and $1.05 per pound in 2010. These estimates compare favorably to alternative emission control programs which primarily target criteria pollutants and typically cost between $2.50 and $5.00 per pound of emissions reduced. Additionally, diesel fuel consumption will be reduced by 0.69 and 0.66 percent in 1999 and 2010 respectively. This is a result of the repairs to the engines found to be out of compliance under the programs. This reduced fuel consumption equates to approximately 16.7 and 19.2 million gallons annually in 1999 and 2010, respectively. Over this 12 year period, approximately 250 million gallons of diesel fuel will be saved or over $212 million based on current diesel fuel prices.

ACKNOWLEDGMENTS

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1. The SAE J1667 test procedure is entitled: "Snap Acceleration Smoke Test Procedure for Heavy Duty Diesel Powered Vehicles"

2. PM-10 is particulate matter less than or equal to 10 microns in size, and PM-2.5 is particulate matter less than or equal to 2.5 microns in size. Studies show that diesel exhaust is primarily PM-2.5.

3. Dockery, Douglas W. et al. "An Association Between Air Pollution and Mortality in Six U.S. Cities." New England Journal of Medicine, Vol 329, No. 24, pp. 1753-9.

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6. With the adoption of the North American Free Trade Agreement, NAFTA, commercial trucks and buses will be permitted to operate beyond the 25 mile commercial zone in the states bordering Mexico resulting in increased truck and bus activity in California and the other border states.

7. The test procedure consists of a "snap-acceleration" stationary vehicle test utilizing an electronic smokemeter and an engine and emissions controls system tampering inspection.

8. The hearing procedures are established in sections 60075.1 through 60075.47, title 17, California Code of Regulations, pursuant to Health and Safety Code section 44011.6(m).

9. In developing both the existing and proposed HDVIP and PSIP regulations, the ARB worked within a statutorily required (SB 1997 of 1988, AB 584 of 1983 and AB 1460 of 1996) Ad-Hoc Advisory Committee that includes, among others, the California Trucking Association and the Engine Manufacturers Association.

THE CONTINUING EMISSION CHALLENGE FOR DIESEL ENGINES

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BACKGROUND AND PERSPECTIVE

Diesel engines have been around for more than 100 years. Emission controls for diesel engines, however, have only been in existence for a small fraction of that time. While EPA's first meaningful exhaust emission standards for passenger vehicles went into place in 1972, the first meaningful emission standards for heavy-duty diesel vehicles did not go into effect until 1988, just 10 years ago (see Figure 1 below). The first meaningful emission standards for non-road diesel engines did not go into effect until 1996 and the first locomotive standards won't go into effect until 2000.

Year of First Meaningful EPA Standards

- 1972 LDV
- 1988 HDV
- 1996 Nonroad CI
- 1997 Small SI
- 1998 Marine SI
- 2000 Locomotive

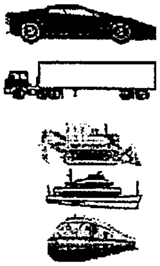

Figure 1

Consequently, while considerable progress has been made in reducing emissions from diesel engines, in comparison to gasoline passenger vehicles, controls on diesel engines are virtually in their infancy. The level of technology and sophistication used on passenger vehicles for the purpose of emission control, particularly in regard to aftertreatment, far surpasses that in place for diesel engines. Some of the diesel engine technologies now in advanced research and development, however, may be nearing that point.

One of the reasons progress has been slower on diesel engines has been the predominance of passenger vehicle emissions in the emission inventories. Over time, however, as passenger vehicle emissions have been controlled and diesel engine use has expanded, the picture has changed considerably. Mobile sources such as cars, trucks, and non-road equipment make up roughly half of the national oxides of nitrogen (NOx) emission inventory (see Figure 2 below). Of that, more than half comes from diesel powered equipment. Thus, more than one-fourth of all NOx emissions in the U.S. come from diesel powered equipment.

NOx Emission Inventory

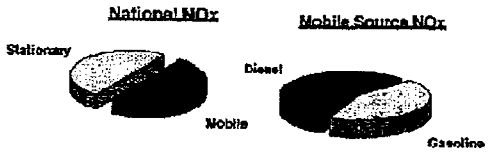

Figure 2

Diesel PM Inventory

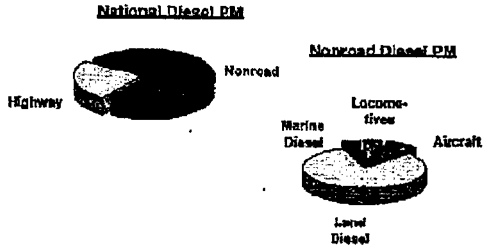

Figure 3

The story is similar for particulate matter (PM) emissions (see Figure 3 above). While a relatively small fraction of nationwide PM emissions come from mobile sources, the vast majority of mobile source PM comes from diesel engines. (Much of the nationwide PM emission inventory is comprised of relatively uncontrollable sources such as wind-blown dust.) Of that from diesel engines, the vast majority is actually due to non-road equipment which is still relatively uncontrolled compared to their on-highway counterparts.

While diesel engine still represent an area of considerable opportunity for nationwide emission reductions, considerable progress is being made to reduce their emissions. PM emissions from on-highway diesel engines have been reduced by 90% from uncontrolled levels. When the recently finalized NOx standard goes into effect in 2004, NOx emissions from on-highway diesel engines will be reduced nearly 85% below uncontrolled levels.[1] The technology being employed on today's diesel engines is considerably different than that employed little more than a decade ago. Not only has this advancement in technology resulted in dramatically reduced emissions, but it has also resulted in vastly improved performance, fuel economy, and durability.

The progress made in on-highway is also working its way down into the non-road market. The first tier of standards is being phased in right now. The Tier 2 and Tier 3 standards recently finalized will ultimately achieve a 70% reduction in NOx emissions below uncontrolled levels.[2] The recently finalized standards for locomotive engines, while slightly less aggressive, will nevertheless, result in roughly a 60% reduction in NOx and 50% reduction in PM emissions below uncontrolled levels.[3] In order to address the very slow turnover of the locomotive fleet, this rule also requires that all post 1972 locomotive engines be retrofit to reduced emission standards. This rather unique aspect of the rule will greatly reduce the contribution of locomotive engines to the emission inventory without the normal delay of waiting for the fleet to turnover.

The net result of the many recent advancements in emission controls from diesel engines is that new engines are and will be considerably cleaner than the uncontrolled engines that currently comprise much of the in-use fleet. Nevertheless, when you look at the relative level of control of diesel engines compared to passenger vehicles (see Figure 4), there is considerable opportunity remaining for further reductions.

CURRENT EPA ACTIVITIES

Accomplishing these further reductions in emissions from diesel engines is the current focus of much of the work of EPA's Office of Mobile Sources. We are currently developing a rulemaking to reaffirm the feasibility of the 2004 on-highway NOx standards and put in place onboard diagnostic requirements for heavy-duty vehicles not unlike those currently required for passenger vehicles. In addition we recently published an Advance Notice of Proposed Rulemaking (ANPRM) to address marine diesel engines.[4] Contemplated in the ANPRM is the carrying over of the Tier 2 and Tier 3 standards for land-based non-road engines to marine engines of similar size, and the carrying over of the locomotive standards for marine engines of similar size. Carrying over the technology from land-based applications will greatly enhance the emission performance of what is as of yet an uncontrolled emission source.

Emissions Reduction Potential

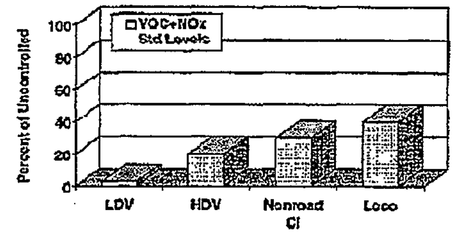

Figure 4

A third activity which is just underway is the 2001 technology review to reaffirm the feasibility of the recently finalized non-road Tier 3 standards. Work is beginning early on this rulemaking in order to sufficiently address the PM standard. The final rule contains PM standards, but only as measured using a steady-state test procedure. It is EPA's belief that in order to effectively control PM emissions in-use a transient test procedure will have to be put in place for non-road engines. The lead-time associated with the development of a transient test procedure, followed by the assessment of the feasibility of emission standards on that test procedure is what is prompting the need to begin work this year.

Finally, while not technically a diesel engine, but rather fueled with similar fuel, EPA is engaged with the Federal Aviation Administration in developing a retrofit program for commercial aircraft engines. As part of this effort we are also investigating options for addressing emissions from airport ground service equipment.

THE CHALLENGES AHEAD

In addition to the activities currently underway, EPA is contemplating, if not already in the process of initiating a number of actions which will further address emissions from diesel engines.

The first of these activities is to put in place requirements to better address in-use emissions from diesel engines. High in-use NOx emissions from heavy-duty diesel engines are a major concern. For some types of operation NOx emissions have been found on a wide variety of engines to be considerably higher than the standard. To resolve this issue the Agency has been in discussions with the heavy-duty diesel engine industry on ways to address the problem. The goal is that ultimately emissions under the wide range of in-use operating conditions should be at or near the emission standards.

While this issue has come up first in regard to on-highway diesel engines, it is the Agency's intent to adopt similar assurances of in-use emission control for non-road diesel engines and marine diesel engines as well. The exact nature of the requirements for the manufacturers will be developed over the course of the next couple years in the 1999 technology review rulemaking for on highway engines, the marine diesel rulemaking, and either the 2001 technology review rulemaking or a separate rulemaking action for non-road engines.

EPA fully anticipates that emission control technologies that have been in research and development in anticipation of the future emission standards, or that are only used in limited applications today will begin to see much wider use as a result of these requirements. Such technologies include electronically controlled exhaust gas recirculation, hydraulically actuated electronic unit injection, common rail and similar fuel injection systems, camless engines, variable geometry turbocharging, Miller cycle concepts, as well as potentially the use of lean NOx catalysts. Clearly the diesel engine is entering yet another phase in its evolution from the basic engines produced for much of its 100 year history.

The second major issue facing diesel engines will be further PM controls. The heightened concern over fine PM emissions and diesel PM emissions in particular (refer to other papers published in these proceedings) is causing a renewed focus to be put on controlling PM emissions further from diesel engines.

Considerable progress has been made on controlling PM from heavy-duty diesel vehicles, but the same cannot be said for non-road diesel engines. While PM standards have been put into place, as discussed earlier, EPA is convinced that to get meaningful in-use control of PM emissions from diesel engines we will have to put in place a transient emissions test for non-road engines which is more typical of how the engines are actually operated in-use. Consequently, we are currently evaluating the in-use operation of typical non-road equipment in preparation for developing a new test cycle. This new test cycle will then serve as the basis for new PM standards for non-road engines in Tier 3.

While considerable progress has been made in controlling PM emissions from heavy-duty diesel vehicles, the renewed focus on the health effects of diesel PM is also causing us to look again at what can be done to further control PM emissions from heavy-duty diesel vehicles. The feasibility of aftertreatment technologies to allow for more stringent PM standards either directly or indirectly via NOx aftertreatment will be addressed in the 1999 technology review. The key questions at the present time are how low can engine out emissions go, how low can tailpipe emissions go with the various aftertreatment technologies under development, will these technologies require the removal of sulfur from diesel fuel, and if so, how low will sulfur need to go? If no action is taken in that rule to make any PM standard changes, the expectation is that it will be revisited again in the very near future for application in the post-2004 time frame.

The third major issue facing diesel engines is their ability to penetrate into the light-duty vehicle (LDV) and especially light-duty truck (LDT) market. Many of the automobile manufacturers have been working with engine manufacturers to develop diesel engines for their light-duty truck and especially sport utility vehicle (SUV) market. Aside from the potential performance benefits provided by the diesel engine, the manufacturers are primarily driven by the need to improve their corporate average fuel economy (CAFÉ). If they can raise the fuel economy of their SUVs and large LDTs by transitioning to diesel engines, they can avoid less economically favorable means of meeting their CAFÉ requirements.

While the auto manufacturers are looking to light-duty diesel engines as a more lucrative means of meeting the current CAFÉ requirements, others are looking to diesel engines as a means of getting fuel economy benefits beyond the current CAFÉ requirements. Mobile sources are a major contributor to greenhouse gas emissions, particularly carbon dioxide emissions, which in turn is directly proportional to fuel economy. As fuel economy improves, carbon dioxide emissions decrease. Thus, the use of diesel engines in the LDV and LDT market could be a part of a national strategy to reduce greenhouse gas emissions. However, by improving fuel economy through a transition to the use of diesel fuel, the carbon dioxide benefit is much reduced. Due to the higher carbon density per gallon of diesel fuel, there is a greater emission rate of CO2 per gallon of fuel consumed compared to gasoline. This offsets much of the benefit of the improved fuel economy.

At the same time that there is a focus on transitioning to diesel engines for fuel economy gains, EPA is developing Tier 2 emission standards for light-duty vehicles and light-duty trucks. Since there are few diesel engines in this market, the vast majority of the regulatory effort has focused on developing emission standards for gasoline passenger vehicles and trucks. With the recent advancements in aftertreatment technology and electronic engine controls, gasoline passenger vehicles have been able to demonstrate extremely low emission levels. Elevated sulfur levels in the gasoline degrade this emission performance to some extent and, thus, EPA is also evaluating the need for gasoline sulfur control in the context of the Tier 2 light-duty vehicle rulemaking.[5]

There are two aspects of the Tier 2 rulemaking that are of significant import to diesel engines being used, or under development for use in the light-duty vehicle and truck market. First, is EPA's desire not to distinguish between light-duty trucks and light-duty vehicles with respect to the emission standards. The growth of the light-duty truck market in recent years has developed to the point where the majority of trucks on the road today are being driven as passenger vehicles, not as trucks. As the market has changed, EPA needs to adjust how it sets its emission standards. Thus, attaining the Tier 2 emission standards could represent a considerable challenge for light-duty trucks, which is the portion of the light-duty market where diesel engines are primarily targeted.

The second issue of import from the Tier 2 rule is EPA's desire if at all possible to maintain fuel neutrality in the rule. In other words, EPA has an objective of setting the same emission standards regardless of the fuel type used by the vehicle. While this approach is not universal in all of EPA's programs, the fact that diesel engine are virtually nonexistent in the light-duty vehicle and truck market at present argues that should they enter the market every attempt should be made to make them at least as clean as the gasoline engines they would displace.

How these issues are addressed in the Tier 2 rulemaking are critical to the future success of diesel engines in the light-duty vehicle and truck market in the future. Based on EPA's current understanding of the state of diesel engine technology, further advancements would be necessary for them to be able to attain the same level of emission performance as their gasoline counterparts. This is true at the default Tier 2 standards specified in the Clean Air Act, let alone at the more stringent California-type standards being considered. It is likely that aftertreatment technology will have to be developed which is capable of large percentage reductions below already low engine out emissions. As for heavy-duty diesel engines, the potential for aftertreatment once again calls into question the need for low sulfur diesel fuel.

CONCLUSION

Diesel engines have developed well beyond the engines that dominated the market even just a couple decades ago. In part in response to the emission constraints placed on the engines by EPA and others, diesel engine technology is continuing to evolve at a rather rapid pace. This evolution will have to continue into the future if we are to offset market growth and attain the Nation's air quality goals.

The engines that dominate the market a decade from now will be considerably different from the engines of today. These differences, driven by advancements in technology will not only dramatically reduce emissions, but also continue to enhance performance and durability.

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3. "Emission Standards for Locomotives and Locomotive Engines; Final Rule," April 16, 1998, 63-FR-18978.

4. "Control of Emissions of Air Pollution from New CI Marine Engines at or Above 37Kilowatts; ANPRM," May 22, 1998, 63-FR-28309.

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STRATEGIC ENVIRONMENTAL RESEARCH AND DEVELOPMENT PROGRAM
ENGINE EMISSIONS REDUCTION TECHNOLOGY DEVELOPMENT

Robert W. Holst, Ph.D.
Strategic Environmental Research and Development Program (DoD)

The Strategic Environmental Research and Development Program (SERDP) was established by law in 1991 to address environmental matters of concern to the Department of Defense and the Department of Energy. It is a Department of Defense Program planned, managed, and executed in full partnership with the Department of Energy and the Environmental Protection Agency with participation by numerous other Federal and non-Federal organizations.

SERDP's Pollution Prevention and Compliance Pillars address engine emissions problems along with other environmental pollution reduction and elimination issues. The extent of the problem within the DoD is that there are over 700 gas turbines in Navy ships, numerous jet engine aircraft, over 2700 diesel engines in Navy ships, and other and various power sources at DoD installations including flight line mobile power carts, bare base power generators, and jet engine test cells (JETC). DoD installations and weapons platforms, like any other large industrial plant, must comply with the Clean Air Act Amendments of 1990 - Title III promulgation of NESHAPS, and the NAAQS for ozone and NOx, and soon to be promulgated PM2.5 rule. Without compliance DoD installations can and are facing fines for non-compliance up to $25,000/day. Several SERDP projects are directly addressing the NOx and particulate emissions from diesel engines and jet engines.

The primary pollution prevention project that is addressing NOx and fuel efficiency in jet engines is that being performed at the Air Force Research Laboratory - Wright-Patterson AFB. A pilot scale trapped vortex (TV) combuster is being developed to reduce emissions from military aircraft and land and marine based electrical power generation gas turbine engines. Its goals are to reduce NOx by 60% and increase fuel efficiency by 3% while obtaining a ten-fold reduction in lean blow out. Other benefits are reduced weight and length of the engine while increasing the thrust.

Some of the compliance projects include the Steady-State/Non Steady-State Source NOx Emission Control Technology work that has been done through the Air Force at Tyndall AFB to address the problem of jet engine test cells (JETC) as a stationary source of NOx and other air pollutants. A series of NOx emission control devices were built based on regenerable adsorbent beds. The benefits include a greater than 90% NOx removal and a potential cost avoidance of over $300M/year. A project being conducted at Lawrence Livermore National Laboratory and Cummins Engine Company is addressing NOx through the use of a plasma assisted catalytic control device. This work is based on the use of a combination of plasma reactor and selective catalytic reduction (SCR) catalyst to reduce NOx from mobile diesel engines to meet increasingly stringent environmental standards. An R&D 100 Award winning project was done by the Air Force Research Laboratory - Armstrong and the U.S. Army Construction Engineering Laboratory to explore the possibilities of reducing NOx, SOx and soot (PM2.5) in diesel powered mobile power carts for flight lines and other uses. This was attained through the use of a collection system to reduce NOx emissions to below air district requirements.

Volatile Organic Carbon (VOC) emissions are as much a problem at DoD installations as NOx and other vehicle emissions. A SERDP project on Development of Non-Thermal Plasma Reactor Technology for Control of Atmospheric Emissions is being performed by the Los Alamos National Laboratory and the Army Research Laboratory. The objective of this work is to allow compliance with air emission regulations for oxides of nitrogen and hazardous air pollutants (HAPS) and with VOC emission abatement needs at depots and logistic centers through the use of a coaxial double-dielectric barrier non-thermal plasma (NTP) reactor. The approach includes the modeling of the reactor flow field - single and multiple discharges, along with the chemical kinetics mechanisms [expanded from 9 species to over 26 species tested including oxides of nitrogen, hydrocarbons and additional radicals such as aldehydes].

Characterization of particulate emissions has become of increasing interest with the impending 2.5 micron particulate matter air emissions regulation. The problem is that particles of unknown sizes and species are emitted by diesel and jet engines. SERDP is sponsoring a project at the University of Utah to develop an innovative sampling and analytical techniques for DoD emissions sources that is an integration of two sampling methods: Aerosol Time of Flight Mass Spectrometer (ATOFMS) and Photoelectric Detector (PED). Through this dual system, air emissions will be characterized in real-time by size and chemical specie simultaneously.

SERDP will continue to provide technology development guidance and support in order to address the highest priority environmental concerns that may affect the training, readiness and capability of the U.S. military Services.

AN OVERVIEW OF PARTICULATE CONTROL FOR DIESEL-POWERED NAVY VESSELS

Bill Remley and Laurie Saccani
John J. McMullen Associates

Michael Osborne
Naval Sea Systems Command

ABSTRACT

The impact on health of particulate matter (PM) (especially from diesel exhaust) in the air is an area of increasing concern. As a result, the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have tightened particulate air quality standards. In response to the growing health concerns and the tightening of particulate air quality standards, the Navy is interested in reducing the amount of particulate emitted from its shipboard diesels. This paper presents the results of a survey of particulate control technology for heavy-duty onroad diesel engines and identifies potentially economical systems or pieces of hardware for controlling emissions of shipboard diesel engine particulate from Navy vessels.

INTRODUCTION

The diesel engine community (including engine manufacturers, operators, researchers, aftermarket companies, and regulators)[1] is particularly interested in the growing concern about the effect of particulate matter (PM) in the air on health. California Air Resources Board (CARB) is currently evaluating diesel exhaust as a candidate Toxic Air Contaminant (TAC), and like the U.S. Environmental Protection Agency (EPA), is tightening particulate air quality standards. As part of the diesel engine community and because of its policy of trying to comply with all environmental regulations, the Navy is interested in reducing the amount of particulates emitted from its shipboard diesels (even though many are exempt under National Security exemption[2]). To better understand the viable options, we investigated systems for controlling diesel engine particulates in hopes of identifying economical, reliable, and effective systems for shipboard applications. This paper

first presents an overview of the health implications of diesel particulates and a discussion of some emerging regulatory requirements. The subsequent sections identify potential Navy sources and available technologies identified through the survey along with an assessment of their suitability for shipboard applications.

HEALTH IMPACT

A number of studies have shown the general consensus within the diesel engine community to be that small airborne, respirable particulates do, in general, affect human health. Those at higher risk (children, older adults, asthmatics, etc.) suffer more, but some studies show that everyone can be affected [2].

In the past, health concerns focused on oxides of nitrogen (NO_x) and volatile organic compounds (VOC), but now particulates are also being investigated. A large body of evidence shows that ground-level ozone, which is formed from the photochemical reactions of NO_x and VOC, causes harmful respiratory effects that include coughing, chest pain, and shortness of breath. But PM has also been linked to serious respiratory health problems caused by particles deposited deep in the lungs, resulting in increased respiratory symptoms and disease, decreased lung function, alterations in lung tissue and respiratory tract defense mechanisms, increased hospital admissions, and premature death. Other environmental effects of NO_x include secondary

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[1] The issue of PM emissions from marine vessels has not yet been dealt with at the international level.

[2] Section 89.908 (a) (1) of 40 CFR Part 89, "National Security Exemption", states that: Any nonroad engine, otherwise subject to this part, which is used in a vehicle that exhibits substantial features ordinarily associated with military combat such as armor and/or permanently affixed weaponry and which will be owned and/or used by an agency of the federal government with responsibility for national defense, will be considered exempt from these regulations for purposes of national security. No request for exemption is necessary. [1]

formation of PM (nitrates), acid deposition, and overgrowth of algae in coastal estuaries.

CARB is currently evaluating diesel exhaust as a candidate TAC under California's air toxics identification program. The reports prepared by CARB are quite exhaustive and indicate that diesel meets the definition of a TAC: a substance that "may cause or contribute to an increase in mortality and serious illness, or which may pose a present or potential hazard to human health." [3] In its report CARB could not, however, identify a threshold below which no significant health effects are anticipated. The component of diesel exhaust most cited in the reports was particulates, but until more research is done to identify the cause of toxicity in diesel exhaust, the identification of whole diesel exhaust is more appropriate to uncover all the toxic components present in diesel exhaust.

EPA AND CARB PM STANDARDS FOR NONROAD DIESEL ENGINES

The EPA estimates that, for 1996, nonroad diesel engines represented about 27 percent of mobile source NO_x and 13 percent of total NO_x emissions. The agency estimates that nonroad diesel engines currently contribute about 440,000 tons, or 48 percent, of PM directly emitted from mobile sources and 16 percent of total controllable PM emissions. EPA estimates also show that nonroad diesel engines currently contribute about 130,000 tons of PM in the form of secondary nitrate particles, based on the estimated 3.1 million tons of NO_x emitted by these engines [4].

CARB estimates that the biggest contributors to diesel exhaust emissions in California are mobile sources. Onroad sources in California contribute about 59 percent (21,420 tons per year); nonroad sources, which include ships and boats, contribute about 36 percent (13,090 tons); and stationary sources contribute about 5 percent (1,760 tons) [4].

In 1996, EPA, CARB, and the engine manufacturers Caterpillar, Cummins, Deere, Detroit Diesel, Isuzu, Komatsu, Kybota, Mitsubishi, Navistar, New Holland, Wis-Con, and Yanmar signed a Statement of Principles (SOP) pertaining to nonroad diesel engine emissions. The EPA issued an Advanced Notice of Proposed Rulemaking (ANPRM) in September 1997 that reflected the provisions of the SOP. These proposed standards apply to mobile nonroad diesel engines of all sizes used in construction, agricultural, and industrial equipment, and some marine applications. Locomotives, mining equipment, and marine diesel engines over 37 kilowatts (kW) (50 horsepower (hp)) were exempted.

A three-tiered progression for emission standards (Table 1) was proposed and applies as follows:

- Tier 1 - Set in 1994 for engines over 50 hp; being phased in from 1996 to 2000 (Table 2); proposed for unregulated engines under 50 hp; to be phased in from 1999 to 2000.
- Tier 2 - all engine sizes to be phased in from 2001 to 2006.
- Tier 3 - more stringent rules will apply from 2006 to 2008

Tables 2 and 3 show the current EPA and CARB standards for PM emissions for nonroad diesels.

EPA PROPOSED PM STANDARDS FOR MARINE DIESEL ENGINES

In March 1998, the EPA published an ANPRM for New Compression Ignition (CI) Marine Engines at or Above 37 Kilowatts [5]. Marine diesel engines less than 37 kW (50 hp) are covered in the proposed rules for nonroad diesel engines and their proposed emission limits are shown in Table 1. These rules would apply to engines installed on vessels registered or flagged in the United States.

In the ANPRM, EPA published its approach to regulating new marine propulsion and auxiliary diesel engines at or above 37kW (50 hp) on commercial and recreational vessels. Auxiliary includes all auxiliary engines except portable engines. The engines under these rules would be grouped into three categories:

- Category 1 – Engines similar to land-based nonroad diesel engines
- Category 2 – Engines similar to locomotive diesel engines
- Category 3 – Low-speed, high-horsepower diesel engines

Table 1. EPA-Proposed Nonroad Diesel Engine PM Emission Standards, g/kW-hr (g/bhp-hr)*

Engine Power Rating	Tier	Model Year	PM Standard
kW < 8(hp < 11)	1 2	2000 2005	1.0 (0.75) 0.80 (0.60)
8 ≤ kW < 19(11 ≤ hp < 25)	1 2	2000 2005	0.80 (0.60) 0.80 (0.60)
19 ≤ kW < 37(25 ≤ hp < 50)	1 2	1999 2004	0.80 (0.60) 0.60 (0.45)
37 ≤ kW < 75(50 ≤ hp < 100)	2 3	2004 2008	0.40 (0.30) -
75 ≤ kW < 130(100 ≤ hp < 175)	2 3	2003 2007	0.30 (0.22) -
130 ≤ kW < 225(175 ≤ hp < 300)	2 3	2003 2006	0.20 (0.15) -
225 ≤ kW < 450(300 ≤ hp < 600)	2 3	2001 2006	0.20 (0.15) -
450 ≤ kW < 560(600 ≤ hp < 750)	2 3	2002 2006	0.20 (0.15) -
kW ≥ 560(hp ≥ 750)	2	2006	0.20 (0.15)

*grams per kilowatt-hour (grams per brake horsepower-hour)

Table 2. Current EPA PM Emission Standards for Heavy-Duty Nonroad Diesel Engines (g/bhp-hr)

Year	PM Standard	Power Range
1996	0.40	175 - 750 hp
1997	*	100 - 175 hp
1998	*	50 - 100 hp
2000	0.40	>750 hp

*These engines only have to meet a NO_x standard.

Table 3. CARB PM Standards for Heavy-Duty Nonroad Diesel Engines (g/bhp-hr)

Year	PM Standard	Power Range
1996	0.40	175 - 750 hp
1997	*	100 - 175 hp
1998	*	50 - 100 hp
2000	0.40	>750 hp

*These engines only have to meet a NO_x standard.

The proposed emission limits for the Category 1 engines are the same as the Tier 2 and 3 limits proposed for the nonroad engines shown in Table 1. Since the greater than 560 hp engines will not be regulated until 2006, EPA is considering an interim standard using the International Maritime Organization (IMO) rules or Tier 1 limits to be effective in 2000.

For the Category 2 engines, the EPA is proposing the IMO emission limits or the new locomotive rules shown in Table 4. Emission limits for these engines would be effective on or after 1 January 2000.

For Category 3 engines, the IMO NO_x code would apply. The effective date would be based on date

Table 4. Locomotive Standards (line-Haul Only)

Tier	Hydro-carbons (HC) (g/kW-hr)	Carbon Monoxide (CO) (g/kW-hr)	NO_x (g/kW-hr)	PM (g/kW-hr)
Tier 0	1.3	6.7	12.7	0.80
Tier 1	0.7	2.9	9.9	0.6
Tier 2	0.4	2.0	7.4	0.27

Note: Tier 0 = Locomotive engines and locomotives originally manufactured 1973-2001.
Two-year phase begins in 2000. Emission limits will apply at time of remanufacture.
Tier 1 – Locomotive engines and locomotives originally manufactured 2002-2004 and at time of remanufacture.
Tier 2 = Locomotive engines and locomotives originally manufactured 2005 and later and at time of remanufacture.

of engine manufacture or ship construction but in either case would be January 1, 2000. Table 5 compares the IMO emission limits with the 1994 EPA Tier 1 limits.

The EPA is not proposing any new smoke limits for marine diesel engines. This is not to say that marine diesel engine manufacturers will not have to worry about smoke since a number of states have local smoke ordinances on the books for ships in harbor environments.

The EPA is proposing the following (duty) test cycles for certification of marine diesel engines:

> Category 1 – ISO E3 (propulsion engines) and E5 (recreational boating engines). EPA is considering proposing the requirement of the E3 cycle for all Category 1 engines.
>
> Category 2 – Use ISO or category 1 cycles.
>
> Category 3 - Use IMO E2 and E3 cycles.
>
> Auxiliary engines – All categories, use ISO D-2.

To ease the certification burden, EPA is considering crossover testing and allowing the ISO C1 cycle (8-mode) in place of the marine cycles for Category 1 and 2 engines.

EPA is considering applying remanufacturing (rebuild) requirements to Category 2 and 3 engines because of the slow rate of fleet turnover. This slow turnover prevents the significant reduction of emissions from these categories of engines until well into the future.

AMBIENT AIR PM STANDARDS

On 16 July 1997, the U.S. EPA issued final air quality standards for PM and ozone under the National Ambient Air Quality Standards (NAAQS). These are not equipment standards, but rather the standards for sampling ambient air where particulates are found from multiple sources. EPA will conduct a 3-year monitoring program of mostly urban areas. The data gathered over this period will be analyzed and the areas classified as attainment or nonattainment. For an area identified as nonattainment, the air samples will be analyzed and the affected states will propose an implementation program (plan) of how to comply with the EPA's ambient air standards for PM. The samples are taken to see if they meet air quality standards and are not intended to test the performance of a piece of equipment.

The current standards for PM measuring 10 microns or less in diameter (PM_{10}) are:

Table 5. Comparison of EPA and IMO Emission Limits

Agency	Engine Speed	HC (g/kW-hr)	CO (g/kW-hr)	NO_x (g/kW-hr)	PM (g/kW-hr)
EPA (Nonroad Tier 1)	All	1.3	11.4	9.2	0.54
IMO	n <130 rpm	None	None	17.0	None
	130 rpm ≤ n <2000 rpm	None	None	$45{*}n^{(-0.2)}$	None
	n≥ 2000 rpm	None	None	9.8	None

- Annual - 50 micrograms per cubic meter ($\mu g/m^3$) (annual arithmetic mean)
- 24-Hour - 150 $\mu g/m^3$ (allowed to be exceeded once per year)

The EPA is revising these PM standards by adding the following new annual and 24-hour standards for PM that measures 2.5 microns or less in diameter ($PM_{2.5}$):

- Annual - 15 $\mu g/m^3$ (annual arithmetic mean)
- 24-hour - 65 $\mu g/m^3$ (revised upward from originally proposed 50 $\mu g/m^3$)

NAVY SHIPBOARD DIESELS

Table 6 shows the populations of the various diesel engines used by the Navy. The engines shown in the table are onboard ships not subject to decommissioning in the near future. The list does not include engines on Military Sealift Command Ships or small harbor craft other than those listed such as training patrol craft (YP), large harbor tugs (YTB), etc. The small boat (SB) engines listed are for the boats carried by the ships. Another 1800 engines are estimated to be on the Navy's small boats and craft. The estimated particulates from Navy ship, boat, and craft engines worldwide for 1997 was 4,158 tons.

As the table shows, the Navy has a considerable number of shipboard diesel engines used in a variety of applications from propelling ships to powering fire pumps. Nearly every shipboard Navy diesel engine is a candidate for PM reduction.

When it comes to protecting human health, the greatest benefit would probably come from reducing the particulates emitted in or near highly populated areas from engines that operate at the dock (such as ship service diesel generator (SSDG) sets) or in harbors and waters close to shore (such as auxiliary vessels of the YTB type, etc.).

The candidate engines would be shipboard SSDG or emergency diesel generator (EDG) sets that operate while the ship is at the dock and the main propulsion and generator sets on the smaller (auxiliary) ships (YTBs, YPs, etc.) that operate in harbors and along the coast. Because of their low usage and the associated high cost of installing PM reduction equipment, shipboard SB engines and emergency diesel engines are not considered viable candidates for particulate reduction control.

Table 6 also shows the horsepower range of the Navy shipboard engines. Since the amount of particulates that an engine emits is directly proportional to its horsepower, larger-horsepower engines fitted with particulate reduction devices will show a greater reduction than smaller-horsepower engines, assuming they are in similar service and operate for approximately the same amount of time. When engine populations are factored into the equation, however, the greater PM reduction may come from smaller-horsepower engines if their population is quite large.

DIESEL ENGINE PARTICULATE EMISSIONS

Particulates are mainly soot, soluble organic fractions (SOF), and oxides. Soluble organic fractions are basically unburned HC (UHC) from both fuel and, to a lesser degree, lubricating oils. Soot, the main component, is a carbonaceous material that comes from incomplete combustion. Oxides such as sulfate (SO_4), water or Di/Bi hydrogen monoxide (H_2O), nitrogen trioxide (NO_3), and phosphate (PO_4) come from the combustion of fuel and lubricating oil with SO_4 from sulfur in the fuel [6].

Given the various components comprising PM, a number of methods can be used to reduce particulate emissions. Improved fuel combustion and decreased lube oil consumption are engine modifications that will help reduce PM. Reducing the amount of sulfur in the fuel reduces the SO_4 produced and hence the particulates (see the following discussion on the effect of SO_4 on particulate emissions). Flowthrough oxidation catalysts for HC and CO effectively reduce the SOF in PM. Soot reduction and the highest particulate reduction overall are accomplished by soot filters or traps that catch the soot particulates in a ceramic matrix or other fine filtering setup.

Table 7 compares the actual particulate exhaust emissions of eight Navy diesels with the proposed EPA nonroad particulate standards. Since these are existing marine engines, they are not required to meet the proposed standards. Note, however, that some of the engines are close to being in compliance with and some are well within the limits of the proposed standards.

The sulfur content of the fuel has a big impact on the particulate level. In general, the lower the sulfur content the lower the particulates. The U.S. Navy typically burns marine diesel fuel, which has a fuel sulfur limit of 1 percent by weight, but a study of Navy fuelings shows that the Navy typically buy 0.5 percent or less.

Table 6. Fleet Diesel Engine Population Summary - Manufacturers (10/97)

Manufacturer	Series/Model No.	Engine Population	Bhp Rating	Application
ALCO	251C	30	2750	EDG[1], MPDE[2]
	251E	6	1010	SSDG[3]
CAT	D-334TA	1	550	EDG
	D-353	4	335	CRANE
	D-379	2	470	EDG
	D-398	4	675	SSDG
	D-399	30	1125	EDG, SSDG, MPDE
	3304	2	90	SSDG
	3306B DITA	26	200	SSDG
	3512	14	1175	MPDE, SSDG
	3608	15	3355	SSDG, SS/EDG
Coltec	38F5-1/4	22	410	EDG
	38FS-1/4	11	670	EDG
	38D8-1/8	124	1000-2000	SSDG, EDG, MPDE
	38ND8-1/8	19	1440	EDG
	PC 2.5	44	8500	MPDE
Detroit Diesel	Series 53	67	33-220	MPDE, SB[4], WELDER[5]
	Series 71	498	190-460	SB, MPDE, SSDG, CRANE, FP[6], EDG, WELDER
	Series 149	156	1350	SSDG
Westerbeke	4-107	64	25	SB
	108U-14088	70	25	SB
Waukesha	L1616DSIN	14	500-600	SSDG, MPDE
EMD	16-567C	6	1350	EDG
	16-645E5	32	2700	EDG
	12-645E2	1	1350	EDG
Isotta Fraschini	ID 36 SS 6V-AM	84	600	SSDG, MPDE
	ID 36 SS 8V-AM	45	440-800	SSDG, MPDE
Cummins	KTA-2300-G	1	1100	EDG
	KTA-38-G1	1	875	EDG
	KTA-50	3	1280	MPDE
Volvo Penta	AQAD-41A	38	165	SB
Paxman	16RP200M	52	3350	MPDE
Total		1486		

[1] EDG – Emergency Diesel Generator
[2] MPDE – Main Propulsion Diesel Engine
[3] SSDG – Ship Service Diesel Generator
[4] SB - Small Boat
[5] Welder - Welder Generator
[6] FP - Fire Pump Engine

There is a definite correlation between fuel sulfur content and the particulate emission rate as shown in Figure 1 from the Lloyds study on diesel engine stack emissions [7]. By burning a fuel with low sulfur content, the particulate emissions can be reduced significantly.

DIESEL ENGINE EXHAUST PARTICULATE REDUCTION TECHNOLOGIES

We contacted nine diesel engine manufacturers (five United States' and four foreign) regarding PM reduction technologies for diesel engines. The following sections describe our findings.

Diesel Engine Manufacturers' PM Technology Overview

U.S. diesel engine manufacturers have begun to address the problem of controlling emissions from their nonroad engines. Initial efforts were directed toward NO_x emissions but lately they have focused on PM emissions as a result of the EPA's latest rulings. Because the exhaust emission

Table 7. Navy Diesel Engine Exhaust Particulate Emissions

Engine	hp	PM (g/hp-hr)	Proposed EPA Nonroad Standard (g/hp-hr)	Comments
1	550	0.17	0.15	@ Rated hp & rpm, 0.2 % fuel sulfur by weight, No. 2 diesel
2	1380	0.30	0.15	@ Rated hp & rpm, 0.2 % fuel sulfur by weight, No. 2 diesel
3	1501	0.39	0.15	@ Rated hp & rpm, 0.2 % fuel sulfur by weight, distillate fuel
4	3084	0.18	0.15	@ Rated hp & rpm, 0.2 % fuel sulfur by weight, distillate fuel
5	3393	0.20	0.15	@ Rated hp & rpm, 0.2 % fuel sulfur by weight, distillate fuel
6	8500	0.12	0.15	@ Rated hp & rpm, fuel sulfur <0.5%, No. 2 diesel
7	16,290	0.12	0.15	@ Rated hp & rpm, fuel sulfur <0.5%, No. 2 diesel
8	252	0.28	0.15	@ 2300 rpm

standards for larger marine diesels are just starting to emerge, manufacturer's efforts have been directed toward those product lines with earlier timetables for emission standards. Most engine manufacturers have environmental or certification departments responsible for keeping abreast of the latest proposed emission standards issued by the EPA, CARB, or IMO. They lobby independently and as a consortium through the Engine Manufacturer's Association (EMA) to comment on and propose changes to emerging standards based on best available technologies.

Many of these available technologies are currently being applied to the diesel engines used in highway (truck/bus) service and locomotives because emission standards for these platforms must be met sooner. The technologies developed for these purposes, according to the manufacturers, will be easily transferred to marine applications with modifications for seawater cooling and other off-engine equipment.

Some of the manufacturers we contacted are pursuing technologies that will meet EPA guidelines for onroad diesel engines and locomotives because they will come into effect before the guidelines for diesel marine engines. Such technologies include increasing injection and cylinder pressures; new or improved turbochargers; oil, air/fuel, and timing control; additional aftercooling; combustion system

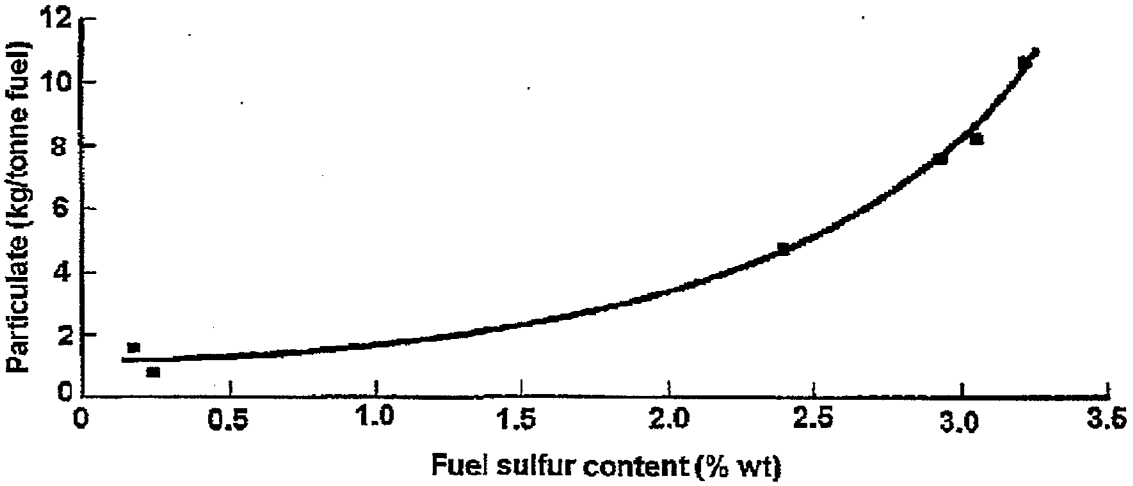

Figure 1. Relationship Between Fuel Sulfur Content and Mass Specific Emissions of Particulates (kg/tonne fuel) at 85 Percent Maximum Continuous Rating

development; electronic fuel systems to regulate injection and pressure; and changes in piston/ring geometry to control oil-based particulates. Additional techniques include the use of electronic unit injection (an engine-mounted computer to electronically inject fuel) and other forms of electronic engine control. Others install post-treatments such as catalysts or filters to reduce PM emissions to acceptable levels. Some manufacturers stated that aftertreatment of the exhaust stream, such as particulate traps and chemical injection, is being pursued, but is considered a last resort to meet emission standards if other technologies do not lower exhaust emissions sufficiently.

Fuel additives are also receiving much attention. Engine manufacturers and oil companies are actively pursuing additive research for the reduction of engine emissions.

Because the engines of some manufacturers already meet the current proposed PM standards, they are focusing on emissions other than PM since it is not a major problem with their engines. There appeared to be a consensus that the foreign manufacturers, although conducting research to curb a variety of emissions, were more interested in reducing NO_x emissions than PM.

PM Reduction Technologies

We investigated potential particulate emission reduction devices and technologies to determine their cost, particulate reduction capability, special requirements for installation or operation, and possible installation on board a Navy ship. The feasibility of installing a device on board a Navy ship was determined based on our review of the literature sent by the equipment manufacturer, vendors, and various after-market companies; and on Internet searches, including the DieselNet website, at http://www.dieselnet.com.[3] Another source of information was a list of participants and abstracts from the 1997 Diesel Engine Emissions Reduction (DEER) Workshop, July 27-31, 1997 at the University of California, San Diego. We wrote to most of the vendors asking for cost and other information for those engine types typically found on board Navy ships. We provided the horsepower, size, exhaust flow, and exhaust temperature ranges of Detroit Diesel series 71 engine (a 250-hp 6-71), a Caterpillar generator engine (Model 3608), and a large main propulsion engine (Colt Pielstick PC 2.5, 8500 hp) for identifying applicable technologies.

After completing our investigation of particulate emission reduction devices, we organized the data we collected into six categories: fuel conditioning devices, catalytic filters/traps, flowthrough oxidation catalyst, devices in developmental stages, fuel additives, and catalyst vendors.

Fuel Conditioning Devices

We found only one fuel conditioning device. This is likely due to the fact that the technology is patented based on the findings published in an SAE paper, which stated that increased fuel temperature improves combustion, the main factor in the creation of diesel particulates. The following list summarizes some of the aspects of that technology:

- Increases fuel temperature prior to injection (heat exchanger).
- Reduces fuel consumption.
- Requires no maintenance.
- Reduces CO 19.6 percent.
- Reduces HC 67 percent.
- Reduces NO_x 14.1 percent.
- Reduces PM 40.8 percent.
- Requires modification of the engine cooling system.
- Patented technology stems from SAE paper 860306.
- Prices range from $675 to $6,500 based on flow rate and the diameter of the fuel supply.
- Installation could take 2 hours to 3 days depending on application.

Catalytic Filters/Traps

Most devices available with completed commercial designs are particulate filters/traps with and without catalytic coatings. These devices operate primarily as a filter that collects the soot, which burns off if exhaust temperatures reach 550°C (1022°F) for 20 percent of the duty cycle. This process is referred to as "regeneration." Because such high temperatures are not always reached (engine at light load or idle), a catalyst is sometimes used to help lower the regeneration temperature. The filter should be installed as close to the exhaust manifold as possible. If the temperature required by the catalyst is not achievable, an outside source such as a heater or heated fuel injected into the exhaust stream will be required to raise the temperature. Such devices may be used to further increase the exhaust temperature because the higher the temperature, the more effective the

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[3] Copyright ©1997 Ecopoint Inc. DieselNet is a public site, but the technical data requires a subscription to assist with the costs of maintaining and updating it.

trap. One concern of the particulate trap is increased backpressure when the filter becomes plugged; it should be monitored to indicate when the filter needs to be cleaned or is not working properly. The following list summarizes the characteristics of the particulate filter/trap:

- Reduces HC and CO 90 to 95 percent.
- Reduces PM 50 to 95 percent.
- Low sulfur fuel is recommended for best operation.
- Poses risk of increase in exhaust backpressure.
- Imposes 1- to 3-percent fuel penalty due to increased system backpressure.
- Is installed as close as possible to the exhaust manifold.
- Exhaust temperature trace must be conducted under normal working conditions before installation can be recommended.
- Soot will burn naturally at temperatures of 550°C (1022°F), however, catalyst coating can be used to initiate regeneration at 400°-420°C (752° - 788°F).
- Soot (particulate) and HC are converted to CO_2 and H_2O.
- CO is converted to CO_2.
- Involves various methods of maintenance from weekly inspections and preventive maintenance to removing and cleaning after every 2500 hours of operation.
- Has been used in yacht applications (DG sets) and tested on buses and trucks in Europe.
- May possibly increase NO_2 emissions.
- Price quotes range from $7,000 to $90,000 for the Detroit Diesel and from $145,000 to $300,000 for Colt Pielstick from a variety of vendors.

Flowthrough Oxidation Catalyst

The flowthrough oxidation catalyst device is similar to a filter or trap except that it does not impede the flow of the exhaust to trap the particulates. It effectively removes CO and HC and some particulates (especially the HC portion). Information about the flowthrough device includes the following:

- Metallic catalyst substrate of "folded" design will not crack or telescope.
- May reduce CO and HC 90+ percent if exhaust gas temperatures reach 900°F (482°C).
- Typically reduces particulates 25 to 50 percent.
- Minimum exhaust temperature of 200°C (392°F) is necessary to "light off" catalyst (results in ~25-percent reduction in HC and 55-percent reduction in CO). Efficiency increases with temperature.
- As the exhaust temperature rises, the catalyst becomes more efficient.
- Catalyst oxidizes HC and CO by forming CO_2 and H_2O.
- Maintenance requirement is minimal.
- Recommended installation is near the exhaust manifold flange.
- Can be mounted in any position.
- Prices ranged from $675 to $6,490 for exhaust pipe outside diameter (OD) below 6 inches. For larger OD, use multiple devices.

Devices in Developmental Stages

We also discovered many technologies in the developmental stages, which are summarized below:

1. Microwave-regenerated particulate trap
   - Initially developed for small engine ~ 5.9 liters.
   - Microwave heats particulate substrate.
   - Reduces particulate by 80 percent, HC by 90 percent and CO by 85 percent.

2. Catalyzed wall flow particulate filter
   - Reduces NO_x (over 95 percent) and particulate (80-90 percent).
   - Requires 661°F exhaust gas temperature for soot oxidation.
   - A few prototypes are installed on urban buses.
   - Filter units can be fabricated to accommodate engines up to 30-liter displacement.
   - Is the size of a small muffler.

3. Chemical treatment of the exhaust gas
   - Chemical is sprayed into exhaust stream.
   - No catalyst is required.
   - Chemically treats exhaust gases using low-cost nonhazardous liquid chemical.
   - Exacts 8-percent fuel penalty to heat exhaust gas to maintain reaction temperature of 1400° to 1500°F.
   - Liquid chemical storage could be 10 percent of volumetric fuel capacity.
   - Operating full-scale prototype and a few additional prototypes have been installed.
   - Initial system would range from $15,000 to $100,000 based on size.
   - For future units of greater production, prices are expected to drop 50 to 70 percent.

4. Nonthermal plasma assisted catalyst process
   - Lab tests show 90-percent reduction in NO_x and particulate.

- No onboard chemicals or heating is needed.
- Small amount of electricity is required to generate nonthermal plasma on a ceramic surface.
- Developmental, commercial prototypes are expected in 1997 and commercialization by 1999.
- Emission reduction begins immediately–no wait for the exhaust temperature to rise.

5. Oxygen and nitrogen enrichment by compact membrane system
   - Permeable membrane separates ambient air into oxygen-rich and nitrogen-rich streams for use in the engine.
   - Reduces particulates 60 percent.
   - Increases engine power output 50 percent.
   - Oxygen stream is provided to engine to improve combustion.
   - Nitrogen stream is fed to exhaust as a plasma to reduce NO_x emissions.
   - Increases the in-cylinder concentration of oxygen from ambient 21 to 25 percent.

6. Oxygen-enrichment and an optimized diesel-electric hybrid system
   - Both techniques increased NO_x, but exhaust gas after-treatments can be used.
   - Project applied oxygen-enriched diesel and a hybrid engine technology on Chicago Transit Authority buses - both reduced emissions and met the mandated limits of the Clean Air Act Amendments.

Fuel Additives

Fuel additives were not heavily pursued for naval applications because of logistics problems, but they were considered because the fuel savings balanced the cost of the additive, resulting in no additional cost to the consumer. We learned the following about using fuel additives:

- Reduces CO, HC, NO_x, and particulates.
- Eliminates visual smoke.
- Improves fuel economy between 4 and 10 percent depending on the engine.
- Specifies marine industries under possible applications.
- Savings in fuel and maintenance result in no additional cost.

Catalyst Manufacturers

Most catalyst manufacturers team with a "canner" (manufacturer of catalyst container) to supply the end product. When contacted, these catalyst manufacturers put us in contact with a number of "canners."

After reviewing all the information we gathered, it became obvious that while the problem of substantially reducing the PM from diesel exhaust has been solved, the practicality and cost of some of the solutions leave much to be desired.

The filter/trap devices that achieve the greatest reduction and capture soot particles are particularly fraught with drawbacks. They are costly and, under varying engine load conditions when the exhaust temperature drops, require an auxiliary or regeneration system (electric heater or combusted fuel to burn off the accumulated soot) to keep the filter from clogging and harming the engine.

The flowthrough oxidation catalyst, which is primarily used to reduce HC and CO for machinery operating in enclosed spaces (forklifts in warehouses, mining equipment, etc.), will provide some PM reduction of the SOF but does not capture soot particles, which are the most harmful particulate constituents. Its lower cost, better reliability, and ability to reduce PM, however, make it a somewhat attractive candidate.

The number of PM reduction devices in the developmental stages indicates the inadequacy of existing technologies. Perhaps from these developmental devices and technologies will come a reliable, low-cost, and effective solution.

Retrofit of PM Reduction Devices

To install any such device on an existing shipboard engine, a shipcheck will be necessary to answer the following questions:

- Is there sufficient space to install the device? If not, what items have to be relocated to make room for its installation?
- Will the existing exhaust piping require any modifications to accept the device and auxiliary equipment such as installation of flanges for support, and heaters for maintaining the exhaust temperature for regeneration, etc.?
- Will it be necessary to design and install new parts, such as brackets, to support the weight of the device?

- Will other systems have to be checked for availability and capacity, such as electrical systems for power to heaters, alarms, etc.?
- Will documentation for the operators be necessary so they can maintain and troubleshoot the device?
- Will modification to the system result in backpressure that exceeds the OEM's maximum allowable? Exhaust system backpressure calculations should be done to ensure that this does not happen.
- What is the cost of the device?
- What are the installation costs (labor hours, any special equipment or personnel needed, etc)?
- What are the annual maintenance costs or hours (including spare parts)?
- Are the weight and size (volume) acceptable for the ship?
- What additional components are associated with the installation (piping, control systems, electrical service)?

Selection Process

To determine which device or technology would be the best overall choice, we developed a set of five criteria that were essential for success. These five criteria were then weighted (Good, Satisfactory, or Bad) according to how well the equipment met them. The five criteria are:

1. **Reduction Benefit** – How well the equipment reduces the exhaust emission under consideration.

   Good = 90+%
   Satisfactory = Some reduction up to 90%
   Bad = No reduction

2. **Acquisition Cost** (as % of Engine Cost) – The approximate costs for the engines used in this study were:

Detroit Diesel (6-71)	- $47,260.00
Caterpillar 3508 -	$2,260,000.00
Colt Pielstick (PC 2.5)-	$4,200,000.00

   Acquistion cost weighting factors are:

   Good= <10% of engine cost
   Bad = >10% of engine cost

3. **Installation Effort** – The estimated hours needed to install the equipment and support systems, plus any removals required to make room for them.

   Good = <24 Hours
   Satisfactory = >24 hours <48 hours
   Bad = > 48 hours

4. **Operating Costs** – Those costs associated with operation of the equipment such as the addition of chemicals, power for electric heaters, replacement of filters, etc.

   Good = Minimal cost
   Satisfactory = Minimal to significant
   Bad = Significant cost compared to normal operating costs

5. **Maintenance Costs** - Those costs associated with doing maintenance on a piece of equipment such as periodically changing a filter, etc.

   Good = Little or no maintenance required for the equipment.
   Satisfactory = Some maintenance required but of routine nature and at sufficient intervals so as not to be burdensome.
   Bad = Short maintenance intervals with procedures that are not easily performed.

Figure 2 shows how the criteria can be used to select the equipment or technology best suited for use on the Navy engines. As we had concluded from our research, the equipment that provides the best reduction (catalytic filter/trap) is also costly and has higher than normal operating costs associated with it. But since this is the only device that will substantially reduce exhaust emissions, the decision must be made to live with the shortcomings or decide on a compromise solution. The ideal exhaust reduction equipment should have the many good qualities of the fuel-conditioning device and fuel additive coupled with the good reduction qualities of the catalytic filter/trap.

CONCLUSIONS

- Given the cost of the add-on PM reduction devices and complexity of installation, it may not be practical to backfit every engine with a particulate reduction device.
- The survey determined that a number of companies manufacture and sell PM-reducing devices that can be adapted (added) to Navy shipboard diesel engines. But there is no clear-cut choice of device or technology available for cost-effectively reducing PM.
- The majority of the commercially available devices are of the filter or flowthrough catalyst design.
- The flowthrough catalyst device effectively removes the SOF portion of the particulates

and is more reliable than the filter trap, but it is not as effective in reducing the total amount of particulates.

- The filter traps are the most effective in that they also capture the soot portion of the particulate, however, they are subject to clogging that can produce backpressures that can damage the engine.

- The filters or flowthrough type-employing catalysts are temperature-dependent: the higher the engine exhaust temperature the more effective they are. To raise the exhaust temperature when the engine exhaust is too cool (partial or low load), some type of heating element is installed in the exhaust system. Not only does heating of the exhaust at low loads ensure proper operation of the filter/trap, but it also provides protection against a clogged filter that can overheat and become damaged during the regeneration cycle.

- The requirement for high operating temperatures requires that the filters be located as near to the engine exhaust manifold as possible.

- The filter/trap and flowthrough devices can replace the existing muffler, but in marine applications we examined, this results in the device being placed too far from the exhaust manifold and increasing the exhaust backpressure.

- At this time, original equipment manufacturers (OEMs) do not plan to rely on filters/traps to reduce exhaust particulate emissions to required levels. This does not bode well for lowering the cost of the equipment.
- There is a high correlation between fuel sulfur content and the particulate emission rate. The burning of distillate low-sulfur fuel results in significantly lower exhaust particulates by reducing the sulfate portion.

- To meet the emerging marine diesel engine emission limits, it appears that most OEMs plan to adopt methods used in heavy-duty highway and other nonroad engines.

- Foreign OEMs are concentrating their exhaust emission reduction work on NO_x rather than PM.

- Most OEMs with the exception of the small engine manufacturers have their own research and development organization working on reducing engine exhaust emissions.

- OEMs are working independently to reduce diesel exhaust emissions. There seems to be very little teaming or collaboration in this area, other than to sell each other patented emission reduction equipment.

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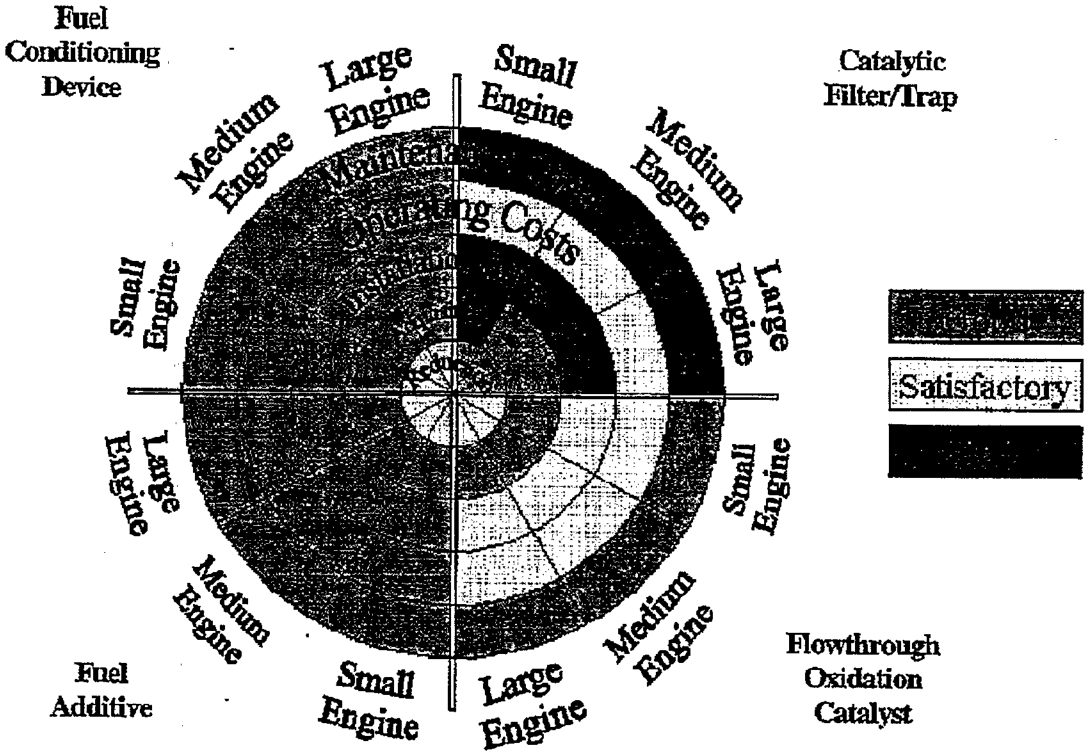

Figure 2. Criteria for Selecting Equipment

UPDATE ON IMO NO_x EMISSION REGULATIONS FOR DIESEL ENGINES

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ABSTRACT

The International Maritime Organization (IMO) Annex VI protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 Convention has entered the ratification phase. Regulation 13 of this Annex addresses NO_x emission limits for marine diesel engines. This paper will provide a brief overview of the new regulations and their expected impact on the diesel engine community.

HISTORY

The increased public awareness of how air pollution affects the quality of life has spurred environmental regulatory agencies around the world to consider plans to mitigate it. The California Air Resource Board (CARB) is one such regulatory body that, in 1990, issued a proposed State Implementation Plan (SIP) for the 1990 Clean Air Act Amendment proposing stringent limits on the emission of oxides of nitrogen (NO_x) exhaust from existing and new marine engines. It was the catalyst that focused the attention of the marine community on the role ships play in air pollution.

Coincidentally, efforts were also underway in the United Nations to draft an annex to the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 agreement. The annex, which was later to be identified as "Protocol of 1997 To Amend the International Convention for the Prevention of Pollution From Ships, 1973, As Modified By The Protocol of 1978 Relating Thereto" (or Annex VI to MARPOL 73/78), proposed regulations and standards for new ships relating to fuel sulfur content, disposal of hazardous material, engine emissions, and inspection criteria. The Marine Environment Protection Committee (MEPC) drafted the proposed Annex VI based on comments from member country representatives and their constituents. Engine manufacturers from around the world were invited to participate in the review process and concluded that the emerging NO_x limit curve could be met for engines produced by the year 2000.

California eventually deferred its proposed regulations for oceangoing marine vessels to the Environmental Protection Agency (EPA), which, in turn has incorporated the MARPOL Annex into its proposed engine rules for diesel engines 37 kW and above. The EPA would still regulate diesel engines on non-oceangoing marine vessels.

Annex VI has undergone its final committee review and will soon begin the ratification process.

MARPOL ANNEX VI PROPOSED REGULATIONS

The proposed Annex VI protocol contains 19 regulations covering emissions from ships. Regulations 3, 5, 13, and 14 refer to diesel engines; the remaining regulations are either administrative or refer to other shipboard operations or systems. Regulation 13 further requires compliance with the "Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines" otherwise referred to as the NO_x Technical Code. Only new or substantially modified diesel engines over 130 kW are covered by Annex VI.

Regulation 3 address scenarios in which crew, equipment, or ship safety is involved Regulation 5 addresses surveys and inspections of the ship and its diesel engines. Regulation 13 defines the explicit requirements for diesel engine NO_x emissions. Regulation 14 limits the sulfur content in diesel fuel.

Compliance with Regulation 13 is essential for marine diesel engines on international voyages. It does not apply to lifeboat engines, emergency diesel generator engines, or engines on vessels that operate solely within sovereign waters.

Diesel engines under Regulation 13 cannot be certified if their weighted emissions exceed the limits shown in Figure 1. If an engine's weighted NO_x emission number in grams per kilowatt-hour (g/kW-hr) exceeds the limit shown in Figure 1, a NO_x treatment system or other modification to lower NO_x is required.

The test cycles and weighting factors used to calculate an engine=s NO_x emission number are shown in Table 1. The letters and numbers refer to the engine application and test cycle. D2 is for a generator set operating at constant speed. E2 is for a propulsion engine operating at constant speed such as would be the case with an electric drive ship or a ship with a controllable pitch propeller. E3 is for a propulsion engine with a fixed pitch propeller.

The NO_x Code specifies the following formula for calculating the NO_x emission number:

$$GAS_x = \frac{\sum_{i=1}^{i=n} M_{GAS_i} \cdot W_{F_i}}{\sum_{i=1}^{i=n} P_i \cdot W_{F_i}}$$

where:

GAS_x = average weighted NO_x emission value (g/kW-hr)
i = 1 to 4 for the E2 and the E3 application; i = 1 to 5 for the D2 application.
W_F = weighting factor
M = emissions mass flow rate (g/hr)
P = power, brake, uncorrected (kW)

Substantial modification to an existing engine will also require that it be brought into compliance with the proposed Annex. Examples of substantial modifications include but are not limited to the following:

(a) Increasing the maximum continuous rating of the engine by 10 percent or more

(b) Replacing the engine with a new engine built on or after 1 January 2000

(c) Any engine modification that could potentially cause an engine to exceed the emission standard

Routine replacement of engine parts or components that do not alter emission characteristics is not considered a modification.

IMPLEMENTATION PROCESS

This regulation applies to ships constructed on or after 1 January 2000 and requires that marine engines on those ships possess an "Engine International Air Pollution Prevention (EIAPP) Certificate@ and that the ships will have to possess an "International Air Pollution Prevention" (IAPP) Certificate. The process for demonstrating compliance with Annex VI has several tiers. First, a precertification is performed for the EIAPP Certificate. This certification step would normally be performed at the engine manufacturer's plant and is designed to ensure that the engine meets the NO_x Technical Code. The second certification step occurs once the engine is installed aboard the vessel. This step is designed to ensure that the engine adjustments made for optimization do not void its compliance with the NO_x Technical Code. The ship is issued an IAPP Certificate based on being certified. Subsequently, the ship and its engine must be surveyed roughly every 2-½ years.

ENVIRONMENTAL TECHNOLOGY CHALLENGES AND OPPORTUNITIES

By 2005, it is estimated that 23 percent of the world=s ships will have been replaced [1]. Many of these ships will be diesel-powered. Although many diesel engine manufacturers will produce engines that have no problem meeting the proposed NO_x limitations, some may elect to use exhaust treatment systems. Exhaust treatment systems, such as Selective Catalytic Reduction (SCR), suitable for marine environments will suit these needs. But SCR systems require storage and consumption of a reagent (such as urea or ammonia) to reduce NO_x. Systems that use technology not based on the resupply of various products would be more desirable for shipboard applications and thus represent an opportunity to introduce new technology.

Many ship owners will also explore various options for demonstrating their continued compliance once certified. Economical and maintenance-free methods for monitoring and reporting NO_x emissions will be considered for emission-compliant engines.

Table 1. ISO Weighting Factors and Application Codes

% of rated speed	100	100	100	100	100	100	91	81	63
% of rated load	100	75	50	25	10	100	75	50	25
D2	0.05	0.25	0.30	0.30	0.10				
E2	0.20	0.50	0.15	0.15					
E3						0.20	0.50	0.15	0.1

Although many marine diesel engines are derivatives of land-based diesel engines, the manufacturer may choose not to transpose land-based technology to the marine sector for any one of several reasons, for example, different operating environment and engine size. Emission reduction equipment for marine applications poses a new challenge for the manufacturers of these devices.

FUTURE TRENDS

Several resolutions were drawn up at the final review of the proposed Annex VI. Resolution 3, "Review of Nitrogen Oxides Emission Limitations," invited the MEPC to review the NO_x emission limits at a minimum of 5-year intervals after entry into force and, if appropriate, amend Regulation 13 and the NO_x Technical Code for more stringent limits. So it is expected that the NO_x limit curve of Figure 1 will be lowered in the not so distant future.

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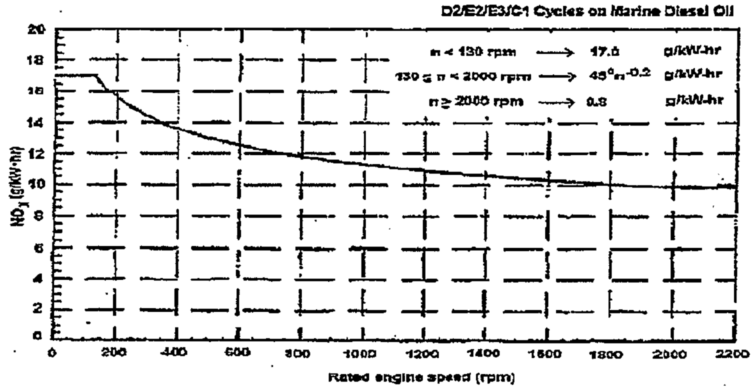

Figure 1. IMO NO_x Limit Curve

DIESEL ENGINES, EMISSIONS REDUCTION, AND "STEP FUNCTIONS" — IMPACTS AND OPPORTUNITIES FOR GOVERNMENT AND THE TRUCKING INDUSTRY

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There are several themes in this paper. They are not meant to sound critical or utopian or outlandish. They are meant to get you — regulators, researchers and equipment developers alike - to think about what you are doing and why you are doing it the way you are. This paper will be, in the minds of some of you, too general and not specific enough. That is because in speaking as a user of emissions spewing vehicles I don't have a lot of specifics. We, as users, don't have a lot of say in how you build things to meet government regulations and our specifications as well. Thus we have to fall back on generalities. But these generalities, if broad enough can draw us into the world of philosophy, where we can all benefit from thinking about how and why we do things; and even if we don't quite get that basic, they will at least indicate some of the hopes and concerns of truck users, who after all, haul about 84% of the nation's general freight and 65% of its bulk goods (reference 1).

The thoughts in most of this paper spring from experience with a small trucking company the author owned/operated, and the remainder is based on material from the Environmental Affairs Department of the American Trucking Associations (ATA).

The general themes in this paper are: there is no free lunch; there are a lot of contradictions (policy and others) out there; be on the lookout for "step functions"; and let's get positive, look at opportunities, and get rid of the adversarial flavor that seems to pervade relations between regulators and the regulated. If these themes seem far removed from diesel engine emissions per se consider that you do not operate in a vacuum but in a larger context, in a very large system. I will try to cover each theme separately, but of course they are interrelated and one will weave its way into others and there will be overlaps.

THERE AIN'T NO FREE LUNCH

The basic concerns here are that we are ignorant of the total system in which we operate and thus many unintended consequences will follow; and we have to pay a price for the standard of living we have. A high standard of living requires high levels of pollution — society kills, it requires some (many?) to do the dirty work so the rest of it can enjoy the highest standard of living in the world, yet has the idea that no one should die "prematurely". It routinely accepts 40,000 or more traffic deaths annually (mostly premature) to have "freedom through mobility".

Navin, et.al. in a paper, (ref. 2) put forth a relationship between deaths per person and motorization. Figure 1 gives this general relationship. Traffic deaths increase as a function of the number of vehicles. Note that social action can decrease deaths, but they will increase linearly regardless. The same pattern holds for aircraft fatalities, as shown in Figure 2, redrawn from reference 3. Both figures indicate what will happen absent "social" action. I submit that traffic and airline deaths are a surrogate for standard of living. Which means that a lot of people will die as a result of our standard of living and the number will increase regardless of social measures to prevent this.

A Transportation Research Board (TRB) Report (ref. 4) contains the sentence: "But continuing growth in vehicle travel of 2 to 3 percent per year will make air quality goals a moving target. A still cleaner generation of vehicles will be required to accommodate yet another doubling of vehicle travel". Why is the target moving? The target has no volition of its own. We make the target and can make it realistic or so unrealistic (e.g. zero defects, zero accidents, zero emissions) as to cripple the nation by unleashing a set of unfavorable, unintended, consequences.

That is what bothers me the most — that those who craft legislation are largely ignorant of, or only superficially aware of that which they legislate; and the bureaucrats obligated to implement these laws are (as I suppose they must be) overly specialized and attend to their duties with a narrow view; and no one is looking at the total picture. There are no renaissance men anymore. We are, and will continue to be, vexed by a never ending parade of unpleasant unintended consequences. For example, the surge in sales of pickup trucks and sport utility vehicles (SUVs), a reaction of the market place to CAFÉ standards that resulted in "toy" cars that did not do what people wanted; and air bags, a safety item killing people.

We are all part of a vast, little understood, dynamic system and we tinker with tiny parts of it at our peril.

What this argues for is sensible social action, action which recognizes what is achievable rather than what sounds good or is patently ludicrous. A rational society, looking at Figures 1 and 2 would conclude that since we can't avoid the trend we should ask by how much its slope can be reduced and how much social action is required to do so, and what is the cost of this action. This open ended moving target business is a nasty trap.

CONTRADICTIONS

There are several apparent contradictions, both in policy and implementation that bewilder and confuse a simple trucker who is not allowed the luxury of ambiguity nor uncertainty (the load better be here at 3:00PM or else!). For example, the effort by the DOE to "dieselize" class 1,2, and 3 trucks and sport utility vehicles, a logical and sensible proposition, is controversial because diesel fuel will be used.

Also, consider "...the federal system for regulating fuels and vehicles is rigid and is tied to existing technology. It is not well suited to the different emissions, energy, and safety attributes of new fuels and vehicles; it hinders innovation, does not allow trade-off between different attributes, and is insensitive to regional differences." (ref. 4).

Any move toward alternative fuels is seen as a threat to the Highway Trust Fund revenue stream. Also, in the alternative fuel area, it would be nice to see less infighting among the various proponents. There is a petroleum industry, but there doesn't appear to be an alternative fuel industry.

Another inconsistency is the difference between the Clean Fuel Fleet requirements and the EPACT requirements. This confuses truck users.

What also bewilders is the fact that an environmental regulation/rule/law is never really in place because there is no end to the parties who use the courts delay, revise or overturn what was apparently something we would have to live by. There is no certainty here. A certain "a pox on all your houses" attitude can grow up in this fluid circumstance. One would almost plead that all parties shut up and get on with it! It is one thing to exercise one's rights under a democratic system; quite another to use that system for narrow, selfish interests. Unfortunately, the concept of the common good doesn't seem to be alive anymore, which means we are frittering away precious time arguing in the courts rather than doing something concrete.

STEP FUNCTIONS

Some would call these innovations. By this term I mean an innovation that spikes up out of the linear trend line. The transistor was a step function. While others were seeking evermore refinements/innovations to vacuum tubes Bell Labs invented the transistor — a step function in its day. Jet propulsion was another. Innovations in dictaphones and typing pools were overcome by word processors, and on and on. I bring the subject up because it may be that while government and industry are so intently focused on cleaning up diesel exhaust an innovation may be quietly under development that will make the effort pointless, i.e. we can be overtaken by events This would not be a concern except that resources are being wasted that otherwise might accelerate the development of innovations that would accomplish the same ends being sought by regulators more cost effectively.

Examples of innovations which could be leapfrogging advances are hybrid drivetrains, either diesel- electric, or fuel cell — gas turbine, or diesel — gas turbine (the "giesel", being looked at by the U.S. Army). Why is it important to track these potential breakthroughs? Because while regulations are being litigated and thousands of people are trying clean up the diesel engine (at great cost ultimately to truck users and eventually consumers) a new development may render all that activity pointless and the time wasted irretrievable.

Innovations are not necessarily limited to things. It may be that truck users will eventually opt to "buy" only the service a truck provides. The truck builder contracts to provide a truck that meets all regulatory stipulations and accounts for degradation, and guarantees a certain fuel efficiency. Or "compliance contractors" may spring into being, companies who will undertake to ensure that a fleet's trucks are always in compliance with all regulations, regardless of source, including state and federal DOTs, EPAs, and alternative fuel mandates. The trucking company merely operates the truck. The liability for proper maintenance of emissions components, and other mandated equipment is passed to the builder, or compliance contractor. It might be that rental companies would do this, but regardless of who takes on that role this approach would radically change how vehicles are cared for and whom regulators would regulate.

This approach would deal with the concern ATA has that we are on the leading edge of a shift in responsibility for truck emissions from engine manufacturers (emissions warranty period, certification) to what happens when the truck is in-use in the hands of the owner. This would require more intensive preventive maintenance (PM) programs, fuel quality checks and conduct of emissions tests by the truck fleet.

Further, think about being overtaken by events; think about China, which is raising its standard of living. Reference 5 contains the prediction that China will be the world's largest source of acid rain by 2010. It is ranked 3rd in emission of greenhouse gases, behind the U.S. and the former Soviet Union; and if China's economy grows at 8.5% for the next 30 years, by 2025 it will produce 3 times as much CO_2 as the U.S.

OPPORTUNITIES

I think a great step toward reducing emissions for practical commercial vehicles, in a timely manner, is to drastically reduce their fuel consumption. This means lower tare weight and improved aerodynamics. The great effort being expended on reducing diesel engine emissions has worked against reducing fuel consumption. Figures 3 and 4 compare brake specific fuel consumption (BSFC) for a 1985, 350hp, turbocharged and aftercooled, mechanically controlled engine and a 1997, 300hp class turbocharged, intercooled, electronically controlled, diesel engine by the same manufacturer. In the early 1980s the DOE had a target BSFC of 0.25 by 2000 for heavy duty diesel engines.

The net effect is implied in Figure 5, a history of the fuel efficiency of heavy trucks over the past 18 tears. Figure 5 reports actual over the road fuel economy of heavy trucks used in line haul and less- than- truckload applications. The latest survey, the 1997 ATA one seems to indicate a slight leveling off in performance. Whether this is indeed the case is uncertain, but we do know that speeds are higher and there is a trend toward higher horsepower engines.

If we can't get reduced fuel consumption through reducing the engine's inherent appetite then we have to go elsewhere, and shaping sheet metal and reducing weight can be the answer. There has been steady improvement in reducing a heavy truck's aerodynamic drag. More improvement is possible, on the order of a further 30% reduction (a drag coefficient of 0.25 is possible per ref. 6). Achieving such a drag coefficient could allow a typical tractor-semi-trailer, used in over the road applications where it could benefit from aerodynamic improvements, to save 4,400 gallons of fuel annually.

Reducing idling is another opportunity, one that is currently addressed by the larger fleets, which program their engines to shut down after idling a specified duration, such as 5 or 10 minutes. However, this does nothing to keep the driver warm in winter and cool in summer, so drivers who can (independent non-company) idle.

Not idling might be enthusiastically embraced if truck stop electrification was to become widespread. In 1995 the Edison Electric Institute proposed wiring truck stops so trucks could plug in and have electrical power to accomplish with electricity what idling with diesel fuel now does. The proposal suggested that electrification would cost a trucker 85 cents an hour to heat and/or cool versus $2.00 an hour to burn diesel fuel to do this. This would reduce idling emissions of CO_2 by 69%, NOx by 98%, CO by 99%, and VOCs by 99% per truck. Truck stops are in fact being wired now, but only to support communications and entertainment features (e.g., cable TV) in the cab.

Alternative fuels are a major opportunity. Their use could leapfrog any problems, real or imagined with diesel fuel, and the debate between engine manufacturers and the petroleum industry, reduce emissions and potentially cost less. A 1994 ATA Maintenance Council (TMC) survey indicated that, even then, there was more interest in alternative fuels on the part of fleets, than one might suspect. Forty-five percent of the fleets surveyed would experiment with alternative fuels; and 50% of these, or 22.8% would consider using these fuels on a larger scale. This percentage, applied to the 1994 fleet membership of TMC, would be about 270 fleets. These numbers presuppose a viable refueling infrastructure and reasonable fuel costs. The interest is even stronger today, based on discussions with numerous fleet personnel.

One of the spurs for thinking along the lines sketched out above, in addition to personal experience with a small fleet, was the questions and comments in the Proceedings of a 1995 Forum on Future Directions in Transportation Research and Development, ref. 7.

The statement was made that research was needed on environmental policy, that policy based solutions that focus on the demand side deserved equal attention. **How much transportation (mobility) is enough?** And research was needed to answer the question: **who are people and who are citizens? How are their wants and needs measured? What are these national values that are held most dear?**

These questions represent the ultimate opportunity- the opportunity to change the context within which we work , to rethink why we are doing what we are doing. Does growth have to mean more vehicles and more pollution? Does "standard of living" have to denote levels of material goods rather than levels of life quality? If you can change expectations and provide a better vision than the treadmill of chasing a moving target then you will truly have made a contribution and eliminated the need for future diesel engine emissions conferences. This is where the majority of our efforts and resources should be going. I just wish we would ask some fundamental questions before continuing down the road we are on — chasing moving targets and being so fixated on the targets that we miss opportunities and fail to discern unintended consequences.

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CALIFORNIA'S SINGLE STATE DIESEL DILEMMA: FACT VS. FICTION

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ABSTRACT

The Office of Environmental Health Hazard Assessment (OEHHA), a part of the California Environmental Protection Agency, is responsible for implementation of the Safe Drinking and Water Act of 1986. Proposition 65 requires the Governor to publish a list of chemicals that are known to the state of California to cause cancer, birth defects, or other reproductive harm. Only the chemicals on the list are regulated under law. Businesses that produce, use, release, or otherwise engage in activities involving those chemicals must comply with requirements for clear and reasonable warnings and prohibition from discharges into drinking water.

Diesel exhaust was added to the Governors list in 1991. In 1993, the California Air Resources Board (CARB) mandated that clean burning CARB fuel be manufactured and sold in California. The cost to the industry was $5 billion to re-tool refineries, which was and is, passed on to California companies who use CARB diesel. In 1988, the state of California found that the clean, more expensive diesel fuel, removed toxic chemicals and improves public health. Today's diesel emission standards boast 90% less particulate matter and 77% less nitrous oxides than technology purchased just 15 years ago. Hundreds of millions of dollars of investment for tomorrow's diesel technology will be wasted if diesel exhaust remains at target in California for lawsuits.

Currently, over 200 lawsuits have been filed against diesel truck users for emitting CARB diesel from heavy-duty trucks. The evidence that environmental trial lawyers use to prosecute diesel users is the California Draft Document on the Toxicity of Diesel Exhaust. The science used to allege diesel exhaust is a cancer threat is opposed by the majority of the science community, which includes the original scientists who conducted the rat and human studies California relies on. California's controversial risk assessment found diesel exhaust exposure at ambient levels responsible for 200 - 2,000 lung cancers per million people. California claims that no safe threshold exists for ambient exposure to diesel exhaust exists. Federal EPA's Clean Air Science Advisory Committee (CASAC) rejected a watered down version of the California report claiming limited evidence in humans. The California legislature is looking into this California diesel problem.

California's Single State Diesel Dilemma: Fact vs. Fiction

1998 Diesel Emission Reduction
Workshop

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California's Trucking Industry

- 76% of CA communities rely only on trucks for their freight needs.
- CA trucking payroll generates $31 billion in salaries and employs diverse populations
- Trucks move 960 million tons of manufactured goods
- An average product moves by truck 7 times before it is offered for sale.

California's Diesel Dilemma

- Trucks do not see state lines
  - Fuel prices change buying habits
  - Interstate trucks domiciled outside of CA gain a competitive advantage when regulations only apply to CA companies
- 60% of the trucks operating in California are domiciled in other states
- Trucking rates are extremely competitive
- Small increases in price shift freight movement

California's Diesel Dilemma

- Criteria pollutants dramatically reduced in last decade
  - 77% reduction in oxides of nitrogen
  - 90% reduction in particulate matter
- Federal standards implemented to reduce sulfur from diesel fuel in 1993
  - CA reformulation
    - Reduce aromatics to 10%
    - Reduced toxicity

California's Diesel Dilemma

- Cost of improved technology for trucks
  - $5 million per engine through lifecycle
- Cost of reformulated fuel in CA alone
  - $5 billion
- Capital investment in diesel over last decade over $25 billion

California's Diesel Dilemma

- The Safe Drinking Water and Toxic Enforcement Act
- Toxic Air Contaminant

The Safe Drinking Water and Toxic Enforcement Act

- Ballot Initiative passed in 1986
- Referred to as Prop 65
  - Prohibition of contaminating drinking water with chemicals known to cause cancer or reproductive toxicity
  - Requires warning before exposing public to chemicals known to cause cancer or reproductive toxicity

The Safe Drinking Water and Toxic Enforcement Act

- Prop 65 requires a "clear and reasonable warning" before exposing people to a **chemical** with a risk of more than 1/100,000 for cancer
- Authoritative body mechanism for **chemicals** that are listed under IARC
  - 1990 an IARC listing for diesel exhaust triggered a listing on the Prop 65 Governor's List of chemicals known to the state to cause cancer.

The Safe Drinking Water and Toxic Enforcement Act

- International Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 46: "Diesel and gasoline exhausts and some Nitroarens, IARC, Lyon, France 1989.
  - Diesel exhaust was not classified by IARC as a known carcinogen (Group 1)
  - Classified in Group 2 under probable/possible

The Safe Drinking Water and Toxic Enforcement Act

- Ballot stated:
  - "Singles out chemicals scientifically known to cause cancer or reproductive harm"
  - "tells businesses don't expose us to any of these same chemicals without a clear and reasonable warning"
  - **Allows citizen groups to collect attorneys fees and enforce statute should Attorney General not prosecute in 60 days.**

The Safe Drinking Water and Toxic Enforcement Act

- Federal counterpart called Hazardous Air Pollutants (HAP)
  - Diesel exhaust not listed
- Federally, diesel exhaust is not considered a known carcinogen in ambient air or occupational settings

California's Diesel Dilemma

- The Safe Drinking Water and Toxic Enforcement Act
- Toxic Air Contaminant

Toxic Air Contaminant

- AB 1807 created a process to address potential public health effects from TACs
  - "a substance 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" H&S 39655
  - Risk assessment determines if a substance is toxic and to what extent (OEHHA)
  - Risk management determines the need for and appropriate degree of control measures (CARB)
  - Risk management occurs only if CARB identifies the substance as toxic

Toxic Air Contaminant

- 1991 diesel exhaust entered into the TAC process for risk assessment by OEHHA
- 1991-94 OEHHA conducts literature search on diesel exhaust exposure and finds ambient exposure responsible for 22-4,400 additional lung cancers per million people
- 1998 OEHHA releases document finding ambient exposure to diesel exhaust responsible for 200-2,000 additional lung cancers per million people
- Best guess number is 450 per million

Toxic Air Contaminant

- OEHHA study relies on three studies
  - Cohort of railroad workers, Garshick et al conducted during the 1950-60
  - Rat studies, Mauderly et al
  - Meta analysis of 29 studies, Bhatia et al
- Federal EPA CASAC rejected a watered down version of this report in May 1998

California's Diesel Delimma

- The Safe Drinking Water and Toxic Enforcement Act
- Toxic Air Contaminant
- AND THE 260 Lawsuits against California businesses that receive shipments from diesel trucks
  - (260 today, the with a draft document…2,600 on July 30 when finalized by CARB

California's Diesel Dilemma

- The same week the OEHHA document was finalized, a press release from environmental bounty hunters read "Citing cancer risks, Environmental Coalition, State of California sue 4 major L.A. supermarket chains for exposing neighbors to hazardous diesel exhaust"
- National Resources Defense Counsel
- Environmental Law Foundation
- Coalition for Clean Air

Lawsuits

- Unfair business practices
- Violation of Prop 65
- Seek order to require companies to warn residents in communities surrounding grocery stores and their workers that they are being exposed to a known carcinogen-diesel exhaust
- Settle for huge penalties and phase out of diesel engines over 5 years

California's Diesel Dilemma

- CARB tries to move ahead as if Prop 65 and TAC process unrelated
- CARB ignores lawsuits
- Legislature wants oversight hearing to invite the original scientists to speak on the science
- Truckers introduce bill to require federal conformity on risk assessment

Conclusion

- Diesel exhaust is heading for the legislature
- Clean CARB fuel causes cancer but federal fuel does not?
- Was $5 Billion in refinery re-tooling to reformulate diesel in 1993 wasted in CA?
- Why don't miners get cancer when exposed to 1000 times the concentration of diesel exhaust?