Heavy Duty Diesel Vehicle Pollution Control: What Drives the Regulators

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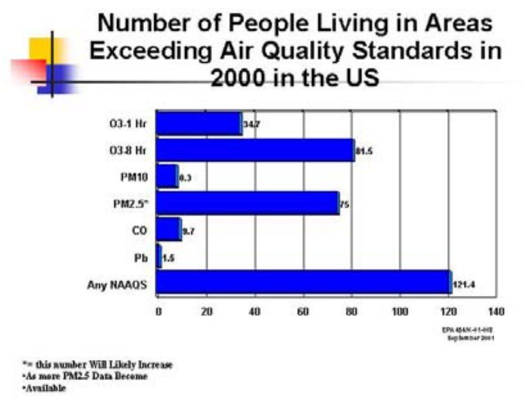
1. INTRODUCTION

Over the past decade, diesel technology has advanced tremendously. As a result, diesel cars are faster, more efficient, drive better and are quieter than ever before. Not surprisingly, therefore, diesel sales continue to grow especially in Europe. Last year, approximately two out of five new cars sold in Europe were powered by a diesel engine and all new heavy-duty trucks were diesel fueled. Principal reasons for the success of the diesel are its superior fuel efficiency and durability.

However, at the same time that market forces are stimulating increased diesel sales, regulatory officials around the world are giving greater scrutiny to these diesel vehicles and their fuels. Why? What are the forces that are driving the regulators? This paper will attempt to answer this question. It will review and summarize the health and environmental effects related to diesel vehicle emissions and the government responses to these effects.

2. HEALTH AND ENVIRONMENTAL CONCERNS ABOUT DIESEL PM EMISSIONS

Each year, more and more studies continue to point to particulate in general and diesel particulate specifically as the cause of thousands of premature deaths. In Japan, even the courts have weighed in, awarding damages to asthma sufferers because of the diesel vehicles emissions in the vicinity of their homes.[1] In addition, ozone (or photochemical smog as it is commonly known) remains a widespread problem. For example, as illustrated below, over 100 million Americans still live in areas that exceed one or more air quality standards. By far the largest numbers are subjected to high levels of ozone (especially 8 hour average levels above standards) and $PM_{2.5}$.



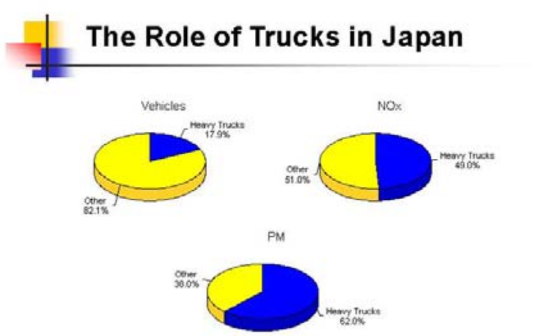
Similarly in Japan, total suspended particulate levels have not improved significantly in approximately twenty years.

1. "Gov't to cough up over air pollution", Mainichi Shimbun, February 1, 2000

In Europe, while noting the significant progress which has occurred to date and the anticipated additional emissions reductions which should result from the tighter standards for cars, trucks and fuels which have already been adopted and will be phased in over the next several years, the European Commission has identified the key remaining challenges to be:

- Particulate Matter
- Localized NO2 Exceedences
- Ozone (compliance with NOx and VOC emissions ceilings), and
- Current or emerging problems associated with non-regulated pollutants such as PAH.

While many sources contribute to these problems, diesel trucks are increasingly becoming the major mobile source of both NOx and PM as light duty vehicles are increasingly controlled. For example, as illustrated below, while only 17% of the vehicles in Japan are diesel trucks, they contribute almost half the NOx and more than 60% of the PM.



A. NEW US PARTICULATE STUDIES

At its annual conference in Atlanta, Georgia in 2000, the Health Effects Institute (HEI) released the results of two major studies focused on fine particle health effects. The first report is a re-analysis of two long-term community health studies: the Harvard Six Cities Study (1993), and the American Cancer Society Study (1995). The second, called the National Morbidity, Mortality, and Air Pollution Study (NMMAPS), is original research on hospitalization and deaths associated with air pollution in major U.S. cities.

i. The Particle Epidemiology Reanalysis Project

The Harvard Six City Study and the American Cancer Society study examined the long-term effects of exposure to particulate air pollution on mortality. In the Harvard Six-Cities Study, researchers followed the health of more than 8,000 people in six small cities that fell along a gradient of air pollution concentrations for a period of 14 to 16 years. As particle concentrations increased, there was an almost directly proportional increase in the death rate in the residents studied. Residents of the most polluted city in the study, Steubenville, Ohio, had a 26 percent increased risk of premature mortality, compared to the residents of the cleanest city studied, Portage, Wisconsin. According to study authors, this translates into a shortened life expectancy of one to two years for residents of Steubenville compared to residents of Portage.

The March 1995 American Cancer Society study found an association between chronic exposure to fine particle air pollution and premature death in a study group of over half a million people in 151 cities. Sulfate pollution was also associated with early death. The study reported strong associations between sulfates and fine particles and death by cardiopulmonary causes.

Dr. Daniel Krewski of the University of Ottawa and his associates conducted the newly released reanalysis of these two studies for the Health Effects Institute. First, they undertook a reanalysis of the original studies and a quality audit of the underlying data. Then they performed an extensive sensitivity analysis using alternative statistical methods, and considering the role of 20 potential confounders such as other pollutants, climate, and socio-economic factors on study results. **The reanalysis validated the original studies.**

ii. The National Morbidity, Mortality and Air Pollution Study (NMMAPS)

The Health Effects Institute also commissioned an original nationwide study of the short-term effects of air pollution on human health in the 90 largest American cities. NMMAPS found strong evidence linking daily increases in particulate pollution to increases in death. The association between particulate matter and mortality persisted even when other pollutants were included in the analysis.

In addition, NMMAPS found stable and robust associations between particulate pollution and increased hospital admissions for cardiovascular disease, pneumonia, and chronic obstructive pulmonary disease. As noted in a subsequent publication, the study found “consistent evidence that the level of PM_{10} is associated with the rate of death from all causes and from cardiovascular and respiratory illnesses. The estimated increase in the relative rate of death from all causes was 0.51 percent (95 percent posterior level, 0.07 to 0.93 percent) for each increase in the PM_{10} level of 10 Fg per cubic meter.”[2]

iii. Update of ACS Study

Long-term exposure to levels of air pollution common in many US metropolitan areas increases the risk of death from lung cancer and other heart-lung diseases, according to another study published in the Journal of the American Medical Association.[3]

The analysis is based on data collected by the American Cancer Society (ACS) as part of the Cancer Prevention Study II (CPS-II), an ongoing prospective mortality study of approximately 1.2 million adults. ACS volunteers enrolled individual participants in the fall of 1982. Participants resided in all 50 states, the District of Columbia, and Puerto Rico, and was restricted to persons who were aged 30 years or older and who were members of households with at least 1 individual aged 45 years or older. Participants completed a confidential questionnaire, which included questions about age, sex, weight, height, smoking history, alcohol use, occupational exposures, diet, education, marital status, and other characteristics.

This study demonstrated associations between ambient fine particulate air pollution and elevated risks of both cardiopulmonary and lung cancer mortality. **Each 10-μg/m^3 elevation in long-term average $PM_{2.5}$ ambient concentrations was associated with approximately a 4%, 6%, and 8% increased risk of all-cause,**

2. ”Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987-1994", Samet, Dominici, Curriero, Coursac and Zegar, The New England Journal of Medicine, December 14, 2000.
3. “Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution”, C. Arden Pope III, PhD; Richard T. Burnett, PhD; Michael J. Thun, MD; Eugenia E. Calle, PhD; Daniel Krewski, PhD; Kazuhiko Ito, PhD; George D. Thurston, ScD, Journal of the Amercian Medical Association, Vol. 287 No. 9, March 6, 2002

cardiopulmonary, and lung cancer mortality, respectively, although the magnitude of the effect somewhat depended on the time frame of pollution monitoring. In addition, this analysis addresses many of the important questions concerning the earlier, more limited analysis of the large CPS-II cohort, including the following issues.

- **First, does the apparent association between pollution and mortality persist with longer follow-up and as the cohort ages and dies?** The present analysis more than doubled the follow-up time to more than 16 years, resulting in approximately triple the number of deaths, yet the associations between pollution and mortality persisted.
- **Second, can the association between fine particulate air pollution and increased cardiopulmonary and lung cancer mortality be due to inadequate control of important individual risk factors?** After aggressively controlling for smoking, the estimated fine particulate pollution effect on mortality was remarkably robust. When the analysis was stratified by smoking status, the estimated pollution effect on both cardiopulmonary and lung cancer mortality was strongest for never smokers vs. former or current smokers. This analysis also controlled for education, marital status, BMI, and alcohol consumption. This analysis used improved variables to control for occupational exposures and incorporated diet variables that accounted for total fat consumption, as well as for consumption of vegetables, citrus, and high-fiber grains. The mortality associations with fine particulate air pollution were largely unaffected by the inclusion of these individual risk factors in the models. The data on smoking and other individual risk factors, however, were obtained directly by questionnaire at time of enrollment and do not reflect changes that may have occurred following enrollment. The lack of risk factor follow-up data results in some misclassification of exposure, reduces the precision of control for risk factors, and constrains the ability to differentiate time dependency.
- **Third, are the associations between fine particulate air pollution and mortality due to regional or other spatial differences that are not adequately controlled for in the analysis?** In this analysis, significant spatial autocorrelation was not observed after controlling for fine particulate air pollution and the various individual risk factors. Furthermore, even after accounting for random effects across metropolitan areas and aggressively modeling a spatial structure that accounts for regional differences, the association between fine particulate air pollution and cardiopulmonary and lung cancer mortality persists.
- **Fourth, is mortality associated primarily with fine particulate air pollution or is mortality also associated with other measures of particulate air pollution, such as PM_{10}, total suspended particles, or with various gaseous pollutants?** Elevated mortality risks were associated primarily with measures of fine particulate and sulfur oxide pollution. Coarse particles and gaseous pollutants, except for sulfur dioxide, were generally not significantly associated with elevated mortality risk.
- **Fifth, what is the shape of the concentration-response function?** Within the range of pollution observed in this analysis, the concentration-response function appears to be

monotonic and nearly linear. However, this does not preclude a leveling off (or even steepening) at much higher levels of air pollution.

- **Sixth, how large is the estimated mortality effect of exposure to fine particulate air pollution relative to other risk factors?** A detailed description and interpretation of the many individual risk factors that are controlled for in the analysis goes well beyond the scope of this report. However, the mortality risk associated with cigarette smoking has been well documented. The risk imposed by exposure to fine particulate air pollution is obviously much smaller than the risk of cigarette smoking. Another risk factor that has been well documented is body mass as measured by BMI. Mortality risks associated with fine particulate air pollution at levels found in more polluted US metropolitan areas are less than those associated with substantial obesity (grade 3 overweight), but comparable with the estimated effect of being moderately overweight (grade 1 to 2).

In conclusion, the findings of this study provide the strongest evidence to date that long-term exposure to fine particulate air pollution common to many US metropolitan areas is an important risk factor for cardiopulmonary mortality. In addition, the large cohort and extended follow-up have provided an unprecedented opportunity to evaluate associations between air pollution and lung cancer mortality. Elevated fine particulate air pollution exposures were associated with significant increases in lung cancer mortality. Although potential effects of other unaccounted for factors cannot be excluded with certainty, **the associations between fine particulate air pollution and lung cancer mortality, as well as cardiopulmonary mortality, are observed even after controlling for cigarette smoking, BMI, diet, occupational exposure, other individual risk factors, and after controlling for regional and other spatial differences**.

B. EUROPEAN PM STUDY

Another study published in the British journal, Lancet, concludes that air pollution kills more than 40,000 people a year in Austria, France and Switzerland and contributes to 25,000 new cases of asthma and half a million asthma attacks[4].

Epidemiology-based exposure response functions for a 10-µg/m^3 increase in particulate matter (PM_{10}) were used to quantify the effects of air pollution. Cases attributable to air pollution were estimated for mortality (adults=>30 years), respiratory and cardiovascular hospital admissions (all ages), incidence of chronic bronchitis (adults =>25 years), bronchitis episodes in children (<15 years), restricted activity days (adults =>20 years), and asthma attacks in adults and children. Population exposure (PM_{10}) was modeled for each km^2. The traffic-related fraction was estimated based on PM_{10} emission inventories.

About half of all mortality caused by air pollution was attributed to motorized traffic, accounting also for: more than 25,000 new cases of chronic bronchitis (adults); more than 290,000 episodes of bronchitis (children); more than 0.5 million asthma attacks; and more than 16 million person-days of restricted activities.

The researchers calculated that the health costs of pollution from traffic across the

4. Public-health impact of outdoor and traffic-related air pollution: a European assessment, *Lancet* 2000; **356:** 795 - 801

three countries amounted to about 1.7 percent of the gross domestic product.

C. DIESEL TOXICITY

The concern for the carcinogenic health hazard resulting from diesel exhaust exposures has existed for several years and is increasingly widespread. Several national and international agencies have designated diesel exhaust or diesel particulate matter as a 'potential' or 'probable' human carcinogen.[5],[6] The International Agency for Research on Cancer (IARC) in the late 1980s concluded that diesel exhaust is a 'probable' human carcinogen.[7] Based on IARC findings, the State of California identified diesel exhaust in 1990 as a chemical known to the State to cause cancer and after an extensive review in 1998 listed diesel exhaust as a **toxic** air contaminant.[8] The National Institutes for Occupational Safety and Health has classified diesel exhaust a "potential occupational carcinogen." The World Health Organization recommends that "urgent efforts should be made to reduce [diesel engine] emissions, specifically of particulates, by changing exhaust train techniques, engine design and fuel composition." More recently, the US National Institute For Environmental Health Sciences (NIEHS) added diesel particulate to its list of substances that are reasonably anticipated to be human carcinogens in its 9th National Toxicology Report on Carcinogens.

Based on the available information, EPA concluded that diesel particulate is a probable human carcinogen. The most compelling information to suggest a carcinogenic hazard is the consistent association that has been observed between increased lung cancer and diesel exhaust exposure in certain occupationally exposed workers working in the presence of diesel engines. Approximately 30 individual epidemiological studies show increased lung cancer risks of 20 to 89 percent within the study populations depending on the study. In mid October of 2000, the Clean Air Science Advisory Committee approved this report subject to minor changes in the text.

D. THE MATES STUDY OF TOXICITY

The toxicity problems associated with diesel particulate was brought into sharp focus in the Multiple Air Toxics Exposure Study (MATES-II), a landmark urban toxics monitoring and evaluation study conducted for the South Coast Air Basin (Basin). It represents one of the most comprehensive air toxics programs ever conducted in an urban environment and contained several elements - a comprehensive monitoring program, an updated emissions inventory of toxic air contaminants, and a modeling effort to fully characterize Basin risk.

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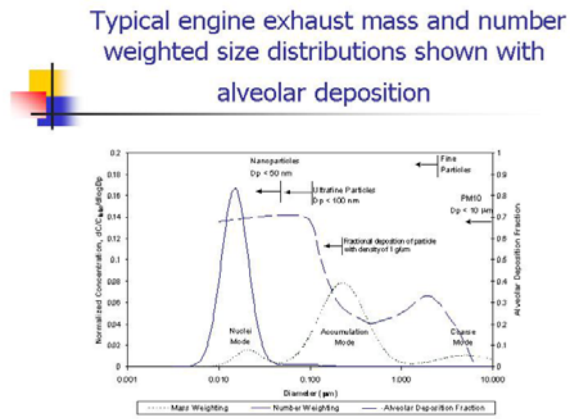
5. National Institute for Occupational Safety and Health (1988) Carcinogenic effects of exposure to diesel exhaust. NIOSH Current Intelligence Bulletin 50. DHHS (NIOSH) Publication No. 88-116. Centers for Disease Control, Atlanta, GA.
6. World Health Organization (1996) Diesel fuel and exhaust emissions: International program on chemical safety. World Health Organization, Geneva, Switzerland.
7. International Agency for Research on Cancer (1989) Diesel and gasoline engine exhausts and some nitroarenes, Vol. 46. Monographs on the evaluation of carcinogenic risks to humans. World Heath Organization, International Agency for Research on Cancer, Lyon, France.
8. California EPA (1998) Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant Appendix III Part A: Exposure Assessment. California Environmental Protection Agency. California Air Resources Board April 22, 1998.

In the monitoring program, over 30 air pollutants were measured including both gases and particulates.

The key result of the MATES-II study was that the average carcinogenic risk due to air pollution in the Basin is very high, about 1,400 per million people. Mobile sources (e.g., cars, trucks, trains, ships, aircraft, etc.) represent the greatest contributor. About 70% of all risk is attributed to diesel particulate emissions; about 20% to other toxics associated with mobile sources (including benzene, butadiene, and formaldehyde); about 10% of all risk is attributed to stationary sources (which include industries and other certain businesses such as dry cleaners and chrome plating operations.)

E. ULTRAFINE PARTICLES

Another aspect of diesel particulate that continues to be a cause for concern is its size. Approximately 80-95 percent of diesel particle mass is in the size range from 0.05-1.0 micron with a mean particle diameter of about 0.2 microns. These fine particles have a very large surface area per gram of mass, which make them excellent carriers for adsorbed inorganic and organic compounds that can effectively reach the lowest airways of the lung. The number of ultrafine particles from a conventional diesel is roughly 2 to 3 orders of magnitude greater than from a comparable gasoline fueled vehicle. However, the data also indicates that if a particulate trap is used the number of ultrafines comes down even below gasoline fueled vehicles.



Approximately 50-90 percent of the number of particles in diesel exhaust is in the ultra fine size range from 0.005-0.05 microns, averaging about 0.02 microns. While accounting for the majority of the number of particles, ultra fine diesel particulate matter only accounts for 1-20 percent of the mass of diesel particulate matter.

In a recent study in Germany, levels of both fine and ultrafine particles were associated with increased mortality. In the HEI funded study, Erich Wichmann and colleagues characterized the sizes of particles in the ambient air of Erfurt, Germany, and determined whether they were related to changes in daily mortality[9]. They reported that over a three-year period the concentrations of both ultrafine (PM< 0.1) and fine particles (PM0.1–2.5) were associated with increased daily mortality.

These findings provided the first evidence that ultrafine particles were associated with human mortality, but did not indicate

9. Wichmann H-E, Spix C, Tuch T, Wölke G, Peters A, Heinrich J, Kreyling WG, Heyder J. 2000. Daily Mortality and Fine and Ultrafine Particles in Erfurt, Germany. Part I: Role of Particle Number and Particle Mass. Research Report 98. Health Effects Institute, Cambridge MA.

whether ultrafine particles were more toxic than larger particles.

In another HEI study, Morton Lippmann and colleagues compared day-to-day fluctuations in hospital admissions of older people and deaths in the Detroit-Windsor area with day-to-day fluctuations in levels of different ambient PM size fractions[10]. They found that four of the five size fractions they evaluated were associated with increased morbidity and mortality. These were total suspended particles (TSPs; i.e., all particle types and sizes up to about 40 µm in aerodynamic diameter found in ambient air); PM10; PM0.1–2.5 (i.e., particles between 2.5 µm and 10 µm in aerodynamic diameter); and PM2.5. The magnitude of the association was similar for all four fractions. The largest particle size fraction (between 10 µm and about 40 µm) was not associated with increased morbidity and mortality. The investigators also reported that the particles fractionated by size were more significantly associated with health outcomes than were the two chemical components of ambient PM, acidity and sulfate, evaluated in the study.

Mechanistic studies using animal subjects, and *in vitro* studies have also shown that compounds of transition metals in ultrafine form can generate so-called oxidative stress in the respiratory system[11]. However there is still more work to be done to demonstrate similar activity in ambient ultrafine particles.

Ultrafine particles are difficult to measure on a routine basis, but the UK DETR research program has been making such measurements for the last few years at three sites (London curbside, London background and rural Oxfordshire). While it is too early to quantify contributions precisely, it is clear that motor vehicles are proportionally a much larger source of ultrafines than they are of PM10, and probably PM2.5.[12]

Available data indicates that exposure to ultrafines is greatest in the first 300 meters from a major source, with levels decreasing to ambient upwind concentrations at distances greater than 300 minutes.

There still remain many uncertainties and unknowns in the science of ultrafine particles, not least on the health effects and the identification of the harmful components in the particles mix. However the evidence for the link between health and ultrafines is beginning to accumulate. On the precautionary principle therefore, it would be prudent for regulators to consider how any decisions taken now on related issues might affect ultrafines in the future. To the extent that particle filters are used to comply with PM mass standards, the concern with ultra fines will likely diminish since these systems have been shown to dramatically reduce ultra fines as well as total mass. However, to the extent that new vehicles can comply with standards without the use of the filtering systems, as is increasingly likely in Europe, it is likely that pressure will continue to adopt additional standards to assure that they are introduced.

The issue of ultra fine particles appears to have influenced the EU Council of Environment Ministers when they indicated following their December 2000 meeting that they are interested in lowering sulfur levels,

10. Lippmann M, Ito K, Nádas A, Burnett RT. 2000. Association of Particulate Matter Components with Daily Mortality and Morbidity in Urban Populations. Research Report 95. Health Effects Institute, Cambridge MA.
11. K Donaldson et al, J Aerosol Sci 1998;29:553-60.
12. "ULTRAFINE PARTICLES-SCIENCE SIGNALS AND POLICY MESSAGES", Dr Martin Williams, DETR, UK, July 2000

reducing the number of nanoparticles and tightening diesel vehicle NOx standards to levels equivalent to those of gasoline fueled vehicles.

F. GLOBAL WARMING IMPACT OF BLACK CARBON

While no one questions that there are substantial fuel economy benefits of diesel vehicles relative to gasoline fueled vehicles, the overall potential global warming benefits of diesel vehicles, have been questioned by recent studies, which indicate that diesel particles may, by reducing cloud cover and rainfall, more than offset any CO_2 advantage. As noted by NASA's Dr. James Hansen, "Black carbon reduces aerosol albedo, causes a semi-direct reduction of cloud cover, and reduces cloud particle albedo."[13]

The landmark Indian Ocean Experiment for example, "…revealed that dark particles such as soot can have a warming effect by absorbing solar energy".[14] The Indian Ocean Experiment results suggest that the pervasive presence of dark hazes contributed to the scarcity of clouds. It is likely that the lack of clouds was largely due to the dryness of air flowing off the Indian subcontinent, and the soot-effect served to diminish cloud cover even further.

Based on these results, other researchers have concluded "The magnitude of the direct radiative forcing from black carbon itself exceeds that due to CH_4, suggesting that black carbon may be the second most important component of global warming after CO_2 in terms of direct forcing."[15]

G. HEALTH AND ENVIRONMENTAL IMPACTS FROM PHOTOCHEMICAL OXIDANTS (OZONE)

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and nitrogen oxides (NOx) in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs also are emitted by natural sources such as vegetation. NOx is emitted largely from motor vehicles, nonroad equipment, power plants, and other sources of combustion.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight.[16] As a result, differences in NOx and VOC emissions and weather patterns contribute to daily,

13. /"Global Warming in the 21st Century: An Alternative Scenario", James Hansen, NASA Goddard Institute for Space Studies Research at www.giss.nasa.gov/research/impacts/altscenario/
14. "Reduction of Tropical Cloudiness by Soot", **A. S. Ackerman, O. B. Toon, D. E. Stevens, A. J. Heymsfield, V. Ramanathan, E. J. Welton, Science,** Volume 288, Number 5468, Issue of 12 May 2000, pp. 1042-1047.
15. "Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols", Mark Z. Jacobson, Department of Civil & Environmental Engineering, Stanford University, Stanford, California 94305-4020, USA, *Nature* **409**, 695 - 697 (2001)
16. Carbon monoxide also participates in the production of ozone, albeit at a much slower rate than most VOC and NOx compounds.

seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and produce more ozone than typically would occur on a single high temperature day.[17] Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NOx emissions.

Based on a large number of recent studies, several key health effects caused when people are exposed to levels of ozone found today in many areas have been identified.[18, 19]

i. Health Effects From Short-Term Exposures to Ozone

A large body of evidence shows that ozone can cause harmful respiratory effects including chest pain, coughing, and shortness of breath, which affect people with compromised respiratory systems most severely. When inhaled, ozone can cause acute respiratory problems; aggravate asthma; cause significant temporary decreases in lung function of 15 to over 20 percent in some healthy adults; cause inflammation of lung tissue; may increase hospital admissions and emergency room visits; and impair the body's immune system defenses, making people more susceptible to respiratory illnesses. Children and outdoor workers are likely to be exposed to elevated ambient levels of ozone during exercise and, therefore, are at greater risk of experiencing adverse health effects.

Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. For example, studies conducted in the northeastern U.S. and Canada show that ozone air pollution is associated with 10-20 percent of all of the summertime respiratory-related hospital admissions. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma. Exposure to ozone can cause repeated inflammation of the lung, impairment of lung defense mechanisms, and irreversible changes in lung structure, which could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema, chronic bronchitis and chronic asthma.

Children are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest. For example, summer camp studies in the eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors. Further, children are more at risk than adults from ozone exposure because their respiratory systems are still developing. Adults who are outdoors and moderately active during the summer months, such as

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17. There is a growing concern that climate modification resulting from the increased buildup of greenhouse gases such as carbon dioxide may increase the amount of ozone produced from a given amount of NOx and VOCs.

18. U.S. EPA, 1996, Review of National Ambient Air Quality Standards for Ozone, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-96-007.

19. U.S. EPA, 1996, Air Quality Criteria for Ozone and Related Photochemical Oxidants, EPA/600/P-93/004aF.

construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to ozone during periods of moderate exertion.

Evidence also exists of a possible relationship between daily increases in ozone levels and increases in daily mortality levels. While the magnitude of this relationship is still too uncertain to allow for direct quantification, the full body of evidence indicates a likely positive relationship between ozone exposure and premature mortality.

ii. Health Concerns from Prolonged and Repeated Exposures to Low Levels of Ozone

A large body of scientific literature regarding health and welfare effects of ozone has associated health effects with certain patterns of ozone exposures that do not include any hourly ozone concentration above the 0.12 parts per million (ppm) level of the 1-hour US NAAQS. The science indicates that there are health effects attributable to prolonged and repeated exposures to lower ozone concentrations. Studies of 6 to 8 hour exposures showed health effects from prolonged and repeated exposures at moderate levels of exertion to ozone concentrations as low as 0.08 ppm.

Studies of acute health effects have shown transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital and emergency room visits, and transient pulmonary respiratory inflammation. Such acute health effects have been observed following prolonged exposures at moderate levels of exertion at concentrations of ozone well below the current standard of 0.12 ppm. The effects are more pronounced at concentrations above 0.09 ppm, affecting more subjects or having a greater effect on a given subject in terms of functional changes or symptoms.

With regard to chronic health effects, the collective data have many ambiguities, but provide suggestive evidence of chronic effects in humans. There is a biologically plausible basis for considering the possibility that repeated inflammation associated with exposure to ozone over a lifetime, as can occur with prolonged exposure to moderate ozone levels below peak levels, may result in sufficient damage to respiratory tissue that individuals later in life may experience a reduced quality of life, although such relationships remain highly uncertain.

iii. Other Effects

In addition to the effects on human health, ozone is known to adversely affect the environment in many ways. These effects include reduced yield for commodity crops, for fruits and vegetables, and commercial forests; ecosystem and vegetation effects in such areas as National Parks; damage to urban grass, flowers, shrubs, and trees; reduced yield in tree seedlings and non-commercial forests; increased susceptibility of plants to pests; materials damage; and visibility.

3. JAPANESE COURT RULING REGARDING HEALTH DAMAGE

Early in 2000, the Kobe District Court ordered the Japan central government and Hanshin Expressway Public Corporation to pay 210 million yen in compensation to residents of Amagasaki, Hyogo Prefecture and take responsibility for pollution caused by vehicle exhaust emissions.[20] The court ruled that the onus is on the government and the corporation to keep the permissible daily exposure to suspended particulate matter (SPM) at 0.15 milligrams per cubic meter or less.

4. GOVERNMENT RESPONSES

As a result of the forces described above – adverse health effects, environmental damage, potential impacts on global warming, legal challenges - government regulators have continued to dramatically tighten exhaust emissions standards. In an effort to enable manufacturers to achieve these very low pollution levels, fuel quality improvements, especially with regard to sulfur content are also being mandated. Restrictions have not been limited to new vehicles and engines, either, as many areas are now aggressively pursuing retrofit programs for existing vehicles. In some cases, efforts have been directed at restricting the use of existing diesels or even banning them.

A. UNITED STATES

i. Heavy Duty Vehicle And Engine And Diesel Fuel Requirements

EPA has also put in place a strategy to significantly reduce emissions from on-highway heavy-duty vehicles. The first phase of the strategy takes effect starting with the 2004 model year; the second phase in 2007. Several of the provisions included in the new program are based on elements of the Consent Agreement previously negotiated between most of the major US diesel engine manufacturers and the US Department of Justice.[21]

Phase One - On August 1, 2000, US EPA Administer Browner signed a Final Rule regarding the 2004 standards for heavy-duty vehicles and engines.[22] The Final Rule concludes that the previously adopted 2004 NMHC+NOx standard for heavy-duty diesel engines (HDDEs) is technologically feasible, cost-effective, and appropriate under the Clean Air Act, in the context of the current PM standard. This includes a finding that a change in diesel fuel formulation is not required to meet these standards.

In addition, the Rule finalizes a new set of supplemental test procedures to more closely represent the range of real world driving conditions of heavy-duty diesel engines. These elements are specifically designed to provide additional certainty that the standards will be met under a wide range of operating conditions. These elements apply to all heavy-duty diesel engines, except those in Medium-duty Passenger Vehicles, which are subject to the Tier 2 program. (See discussion above) First, EPA is adding a steady-state test requirement to the current Federal test procedures (FTP) for HD diesel engines. Emission results from this test must meet the numerical standards for the pre-existing Federal test procedure (i.e., the NMHC+NOx standards noted above, a CO standard of 15.5 g/bhp-hr, and a PM standard of 0.10

20. /"Gov't to cough up over air pollution", Mainichi Shimbun, February 1, 2000

21. See "Global Trends in Diesel Emissions Control - A 1999 Update", SAE Paper #1999-01-0107.
22. The majority of the seven HDE manufacturing companies covered by the U.S. Department of Justice NOx consent decree have agreed to produce engines beginning in October 2002 that will meet the applicable NOx+NMHC standard over the expanded certification test procedure.

g/bhp-hr). This steady-state test requirement becomes effective starting with the 2007 model year. Second, EPA also finalized Not-to-Exceed (NTE) test procedures for testing of in-use engines. These NTE procedures apply under any conditions that could reasonably be expected to be seen in normal vehicle operation and use, including an expanded range of ambient conditions. Emission results from this test procedure must be less than or equal to 1.25 times the pre-existing Federal test procedure standards. The NTE test and associated emission limits are effective starting with the 2007 model year. Third, EPA finalized a Load Response Test (LRT) certification data submittal requirement, effective starting with the 2004 model year.

Phase Two - On December 21, 2000, EPA adopted a final rule regarding tighter NOx and particulate standards for heavy-duty trucks and low sulfur diesel fuel. Key provisions are summarized below:

Low Sulfur Fuel Requirements - As proposed, the maximum sulfur level in diesel fuel will be reduced to 15 PPM by July 1, 2006. Within each region of the country (so called PADDs) refiners and distributors will be allowed to produce and sell up to 20% of their fuel at the current level (maximum of 500 PPM) to minimize any risk of supply disruptions; this exemption will expire by the end of 2009, by which time 100% of the fuel must meet the 15 PPM requirement.

Small refiners, which sell approximately 5% of the diesel fuel across the country, are also allowed to delay producing the low sulfur fuel until 2010. However, in order to encourage the small refiners to provide the low sulfur diesel fuel in 2006, EPA will offer them the option of either delaying the low sulfur diesel until 2010 or delaying the production of low sulfur gasoline (which was required by the Tier 2 package a year ago) until 2010; EPA expects that many small refiners will choose the gasoline option.

Overall, EPA expects that about 90% of all diesel fuel sold in the country by mid 2006 will be low sulfur and that this will rise gradually to 100% by 2010.

Heavy Duty Engine Emissions Standards - A particulate standard of 0.01 grams per brake-horsepower hour will go into effect on 100% of new heavy-duty diesel engines in 2007. The new NOx standard of 0.2 grams per brake-horsepower-hour will be phased in - 50% of the engines sold by each manufacturer must meet the standard in each of model years 2007, 2008 and 2009 and then 100% in 2010.

With respect to PM, this new standard represents a 90 percent reduction for most heavy-duty diesel engines from the current PM standard and is projected to require the addition of highly efficient PM traps to diesel engines, including those diesel engines used in urban buses.

The new NOx standard is projected to require the addition of a highly efficient NOx emission control system to diesel engines.

In addition to the new FTP standards for HD diesel engines, EPA also adopted supplemental emission standards to help ensure that HD diesel engines achieve the expected in-use emission reductions over a wide range of vehicle operation and a wide range of ambient conditions, not only the test cycle and conditions represented by the traditional FTP. The supplemental provisions for HD diesel engines consist of two principal requirements, the supplemental emission test and associated standards (SET), and the not-to-exceed test and associated standards (NTE).

B. CALIFORNIA

The California Air Resources Board (ARB) has released its risk reduction plan that outlines strategies to require particulate matter (PM) traps on all new and most existing diesel engines in California. Diesel engines that are affected by the proposal include heavy-duty trucks and buses, construction equipment, passenger vehicles and trash haulers, generators, agricultural and marine engines.

The ARB estimates that about 27,000 tons of diesel PM are emitted each year into California's air. The staff proposal calls for ARB to work with local and federal agencies, engine manufacturers, fuel providers and the public to develop additional emission standards to reduce diesel emissions by up to 90 percent from the 1.25 million diesel engines in the state.

The plan calls for 12 control measures to be adopted within one to five years, with full implementation by 2010. Some of the strategies proposed in the plan consist of equipping all new diesel engines with PM traps, requiring low-sulfur diesel fuel, in-use emission testing, broader use of alternative fuels and providing funding to offset the cost of upgrading to cleaner alternative fuel engines. The plan also recommends retrofitting existing diesel engines with PM traps.

C. EUROPEAN UNION

i. HEAVY DUTY VEHICLES AND ENGINES –

The European Parliament approved new rules to limit emissions from trucks and buses, paving the way for a final European Union accord in December 1999. The assembly voted to approve standards agreed earlier in 1999 by EU environment ministers.[23]

The final package requires engines to be tested on both the steady state and transient cycles except gas engines, which are only tested on the ETC cycle. The limit values for Enhanced Environmentally Friendly Vehicles (EEV's) are 2.0 g/kWh NOX and 0.02 g/kWh PM on both cycles. These standards should serve as the basis for voluntary purchases of urban vehicles such as buses.

The Heavy-duty directive 1999/96/EC envisages the adoption of further measures to take effect from 2005/6. These are:

- Provisions relating to the development of on-board diagnostic (OBD) and on-board measurement (OBM) systems to monitor in-service exhaust emissions
- Durability requirements and in-service control
- Limits for non-regulated pollutants that "may become important as a result of the widespread introduction of new alternative fuels."

In addition the Commission was to report by 31 December 2002 on the current status of technology needed to meet the mandatory NOx standard for 2008. The report is almost completed and will likely conclude that the 2008 standards are feasible.

Many if not most manufacturers are expected to be able to meet the Euro 4 standards without diesel particulate filters (DPFs). While it looks today as if some heavy-duty engines will require traps to

23. See "Global Trends in Diesel Emissions Control - A 1999 Update", SAE Paper #1999-01-0107.

comply with the 2008 standards, manufacturers are working hard to avoid them and they may succeed. At the same time pressure is building within the EU to require or at a minimum allow member states to incentivize these PM control systems. Approximately a year ago, Sweden requested authority to move in this direction or to have the Directive provision which prohibits incentives for standards beyond those adopted by the EU amended. The request was denied. However, recently France and Germany have sent a letter to the Commission raising several additional points:

- In spite of the significant improvement in diesel vehicle emissions, a substantial problem remains with both PM and NOx. They note that the WHO, the EU Commission, the National Research Council and the US EPA have all identified fine particulate as a high priority problem because of its roles in causing respiratory problems, heart disease and premature mortality.

- Air quality measurements show that the number of particles in the size range of 0.01 to 2.5 µm are high and have not declined in the past six years. In Germany, it is estimated that in the proximity to traffic, traffic emissions contribute 45% to 65% of the particle load of the breathing air.

- The portion of new diesel car registrations has more than doubled in recent years and is now at approximately 40% and while this technology has clear CO2 advantages it will result in PM emissions 60% higher than previously estimated in 2020.

- NOx reductions are also urgently needed to reduce the ozone burden. A modern diesel passenger car discharges about eight to ten times as much NOx as a petrol fueled car.

- It now appears that Euro IV for cars and Euro V for trucks can largely be met without PM filters; a further tightening of the limit values is needed to require this highly efficient technology and its associated health benefits.

- Particle filters are demonstrated to be available and effective under practical conditions as over 270,000 cars and more than 50,000 commercial vehicles are currently so equipped.

- The future US limits for commercial vehicles are approximately 90% lower for NOx and 60% lower for PM than Euro V limits. Tier 2 limit values for NOx and PM are approximately 80% lower than Euro IV car limits. Japanese PM limits approach zero.

In this context, France and Germany called upon the Commission to submit by mid 2004 suggestions on the updating of 98/69/EG and 99/96/EG with the goal of further NOx and PM reductions using the possibilities of the particle filter technology. Germany and France will support this work with all their efforts.

In light of these developments and in view of further work being carried out at the GRPE regarding test procedures and equipment to measure ultrafine particles, which is due to be completed by mid year, the Commission is beginning to consider several alternative approaches. These include:

- Adopting enhanced environmentally friendly vehicle limits which could be used by member states with tax incentives to encourage the early introduction of vehicles with PM filters, or

- Adopting Euro V limits for light duty vehicles which would include lower NOx levels and possibly a PM number limit, or

- Further tightening the PM or NOx limits for heavy commercial vehicles as part of the Euro V technology review, or

- All of the above.

ii. NEAR ZERO SULFUR FUEL

The Commission was required to bring forward a proposal to define the remaining fuel parameters that have not already been established to take effect from 1 January 2005. In May 2000 the Commissioner for Environment launched a "Call for Evidence" on whether petrol and diesel fuels with sulphur contents less than 50 parts per million (ppm) should be available on a European Union basis. She noted that developments in the marketplace and particularly with respect to the evolution of diesel and petrol fueled engines and their emission abatement technologies suggest that there may be additional benefits for fuel with a sulphur content that is lower than 50 parts per million to be available. There had been much discussion surrounding the appropriate sulphur content of petrol and diesel fuels and its potential contribution in meeting environmental emission targets for nitrogen oxides, particulate matter and carbon dioxide. The Commission decided, therefore, to conduct a consultation exercise to inform itself as to whether petrol and diesel with a sulphur content of less than 50 parts per million should be available on a Community wide basis.

After receiving comments from a broad cross section of stakeholders, the Commission proposed new legislation to phase out sulphur in petrol and diesel by 2011. As part of the European Union's ongoing strategy to reduce harmful pollutants and carbon dioxide (CO_2) from cars, the law would require every EU country to ensure that sulphur free petrol and diesel are available from 2005.

The European Union recently completed passage of the law, requiring much lower amounts of sulphur in petrol and diesel by 2005, with a total phase in of "sulphur free" fuels by 2009. The European Parliament voted Jan. 30 to set a deadline of Jan. 1, 2009, for an EU-wide changeover to "zero sulfur" gasoline and diesel fuels used in road transport, and the Council of Ministers approved the measure Feb. 7.

Limiting sulfur content to 10 parts per million (ppm) will allow industry to develop new generations of "lean burn" (fuel-efficient) engines and improve the efficiency of catalytic exhaust gas converters, according to EU Environment Commissioner Margot Wallström. Zero-sulfur road fuel also will help the EU reach its goal of reducing carbon dioxide emissions from new cars to 120 grams per kilogram of fuel on average.

The approval came nearly two months after the Parliament and Council of Ministers reached agreement on the issue the EU's Conciliation Committee, where legislative differences between the two institutions are resolved.

The final text also provides for review by 2006 of the purity standards of fuel used by "non-road mobile machinery," such as tractors used in farming and forestry, and construction equipment such as earthmovers and bulldozers.

Meanwhile, the new legislation will require the oil industry to ensure that by 2005 zero-sulfur fuels are available across Europe on a "sufficiently balanced geographical basis" to allow drivers to refuel without having to drive long distances.

A further amendment secured by the Parliament will require Wallström to review technical issues regarding fuel quality in light of EU moves to encourage use of biofuels. As part of the 2005 review of fuel quality standards, the European Commission has been instructed to look at the case for changing EU rules on fuel volatility to facilitate sales of environmentally friendlier blends of gasoline and bioethanol. Currently, straight blends of the two fuels risk contravening EU rules on volatility, particularly in high temperatures.

D. JAPAN

i. CURRENT REQUIREMENTS

In spite of the significant pollution control efforts to date in Japan, the NO_2, O_3 and particulate problems in major cities remain serious. Therefore, the Japanese EPA has moved forward with their regulation of diesel vehicles. On December 14th, 1998, the Air Quality Committee, Central Council for Environmental Pollution Control issued the new Short Term Targets for diesel vehicle pollution control.

With these short-term targets, NOx emissions will be reduced by 25 to 30 percent and particulate matter by 28 to 35 percent over a period from the year 2002 to 2004. Moreover, with a view to maintaining adequate performance of exhaust emissions controls in use, the durability requirements will be extended and the installation of OBD systems will become mandatory.

Expected control technologies include oxidation catalysts, cool EGR, high-pressure fuel injection, intercooling and Turbocharging.

ii. EMERGING DEVELOPMENTS

Serious and growing concerns regarding diesel vehicle emissions have, however, accelerated the process. In mid 1999, the Governor of Tokyo launched a campaign to ban diesels entirely from the city of Tokyo because of persistently high levels of NO2 and growing concerns over the health effects of diesel PM. Then on January 31, 2000, the Kobe District Court ordered the government and Hanshin Expressway Public Corporation to pay for the health damages to the plaintiffs who were residents in the roadside area of National Highway No. 43 and Hanshin Expressway. [24] In the finding, the Court acknowledged the relationship between asthma of the plaintiffs and suspended particulate matter (SPM), especially diesel exhaust particulate (DEP). The Court also ruled that the government and Hanshin Expressway should keep the SPM concentration level lower than 0.15mg/m3 within 50m from the roadside of both roads.

Subsequently, the Tokyo Metropolitan Government announced on 18 February the draft regulations for the mandatory installation of Diesel Particulate Filters (DPF) for all diesel vehicles that run in the Tokyo area. The government proposed to amend its anti pollution law by the end of 2000 to require particulate retrofitting of all existing diesel engines. The new regulation will be effective on April 1, 2001. There will be a 2-year's preparation time for retrofit, so the first group under the regulation is required to be equipped with diesel particulate filters (DPFs) after April 2003. The requirements will be phased in on a step-by-step basis but 100% of the vehicles are to be equipped with DPF by April of 2006.

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24. "Gov't to cough up over air pollution", Mainichi Shimbun, February 1, 2000

Approximately 190,000 diesel passenger cars and 460,000 commercial vehicles are registered in Tokyo. In addition to those, about 240,000 diesel vehicles come into Tokyo from other areas each day.

The Diesel Advisory Committee developed its recommended retrofit program at a meeting on May 18th and released it publicly on June 11th. In summary, if a 1989 truck or bus wishes to operate in Tokyo in 2003 and 2004, it must be equipped with a PM control device that reduces emissions by a minimum of 60%. In 2005, all these trucks must be off the road but diesel buses which wish to continue to operate must have a device installed which results in a minimum PM reduction of 70%.

If a 1994 truck or bus wishes to operate in 2003 and 2004, it must have a device installed that would have reduced its certification level to 0.25 g/Kw-hr. For example, if the particular engine family certified to a level of .69, it would need to install a device that reduced PM by 64% ([0.69-0.25]/0.69). To operate beyond 2005 it must have a device that reduces PM by at least 74%.

Japan's Central Environmental Council on March 7, 2002 released for public comment new, more stringent requirements on tailpipe emissions for new motor vehicles to be sold in 2005 and later, including foreign-manufactured vehicles. The interim final regulation issued for comment applies both to gasoline- and diesel-powered passenger cars, trucks, and buses and sets different requirements for different classes of vehicles.

The new regulation calls for reducing PM emissions from trucks and buses by up to 85 percent and NOx emissions by 50 percent from the levels set in the short-term diesel auto emission regulation. Domestic products and imported vehicles that fail to meet the regulation cannot be registered for use in Japan.

The Japanese New-Long-Term Regulations, decided on March 5, will start from October 2005. The test mode will be also changed; transient mode will replace the steady state mode.

E. OFF ROAD VEHICLES AND ENGINES

Because emissions from on road vehicles and engines are largely controlled, at least for CO, HC, NOx and PM, governments around the world are increasingly noting the important remaining role that non-road engines can play in the air pollution problem. According to one recent estimate, there are over 140 million off road vehicles and engines in the US alone, a potentially immense pollution control market.[25] However, the market has not evolved as fast as it could due to the inability to resolve difficult regulatory issues to date. This could change dramatically in the next year as EPA has indicated its intention to develop a rule which could require the same degree of control for off road heavy duty diesel engines as has been adopted for on road.

Nonroad HDDEs represent a substantial and growing share of the emissions inventories for both oxides of nitrogen (NO_x) and particulate matter (PM) – thus posing a substantial threat to public health. In fact, emissions from HDDEs are at least equal to,

[25] Nonroad Engine Population Estimates, Report No. NR-006A, December 9, 1997, revised June 15, 1998, Christian E. Lindhjem, Nonroad Emissions Modeling Team, Assessment and Modeling Division, US EPA, Office of Mobile Sources.

if not several times greater than, emissions from on road HDDEs in many countries.

Compared to highway vehicles, emissions from nonroad equipment are relatively under controlled. Given the current inequity in emission control requirements and the availability of known control technologies and strategies, reducing emissions from this source sector could represent one of the more cost-effective available control options.

5. CONCLUSIONS

Diesel technology has improved substantially in recent years. In some countries this has resulted in large increases in light duty diesel sales and heavy duty trucks worldwide are almost all diesel fueled. However, while the fuel economy and durability advantages of the diesel are well understood and appreciated, environmental regulators are increasingly concerned about diesel emissions. They are driven primarily by health concerns as there have been a steady stream of studies highlighting the need to further reduce diesel PM and NOx emissions. As a result, the US (including especially California), Europe and Japan have all substantially tightened diesel emissions requirements in recent years. Diesel fuel sulfur levels have also been reduced.

Growing attention has also been focused on emissions from existing in use vehicles and numerous cities and countries are actively pursuing diesel PM retrofit strategies.

Finally, the nonroad sector is an increasingly important source of emissions and is only now beginning to get the kind of regulatory attention that it deserves.