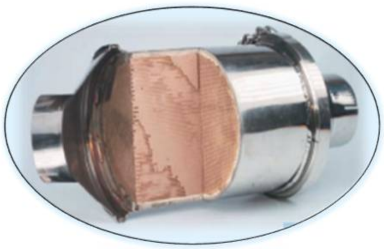
Diesel Emission Control Market



Worldwide Market Opportunities

with the right

Technology

Preface

The purpose of this document is to clearly articulate and outline the requirements on the implementation of nationwide regulations of diesel engine emissions specifically, but also of power plant emissions as part of a worldwide effort to reduce the health risks associated with those emissions. The regulators are no longer a lone voice in the wilderness, but an agent of change creating whole new industries. Although technologies are evolving on electrochemical devices and "brewing" of fuels, there is still a major gap to future regulations. Even small technical advancements can mean a multi-billion dollar per year industry.

One of the most difficult worldwide challenges today, and in the future, are the changing requirements on allowable emissions from the use of fossil fuels. In our research, we found many technologies or combination of technologies that provide incremental improvements, many of which are very costly to maintain and do not meet future regulatory mandates. We have also identified one of the most promising technologies today that exceed all future ambitions of even the most strident of environmental regulators. Even contemporary Luddites would have difficulty not embracing this technology.

This confluence of happenstance presents many opportunities for those visionaries with the abilities not only to recognize, but to act.

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Executive Summary

Air pollutant emissions from mobile sources have been regulated for almost half a century. During this time, the focus has largely been on tightening emissions standards for on-road vehicles and stationary energy generation equipment, particularly passenger cars, and small trucks (light-duty vehicles). Light-duty vehicle emissions control grew out of research that implicated the increasing use of vehicles in the deterioration of air quality conditions in the 1950s in Southern California. In 1967, the federal Clean Air Act (CAA) established the framework for controlling mobile-source emissions in the United States. Later amendments granted California the authority to set mission standards and regulations for some non-highway combustion equipment.

Many studies have been done over the last four decades examining the effects, solutions, costs and regulations needed to gain control of the emission problem. Over the next decade, regulations already in approved for new sources will substantially reduce emissions if the equipment is to be sold and used in the United States. Foreign countries in Asia and Europe are proceeding with similar regulation and in a few instances more stringent that the United States. Despite the substantial progress made over the past decades in reducing emissions from mobile and stationary sources further advancement in technology and new solutions must present themselves in order to achieve the goals.

There has been no “silver bullet” identified that can meet the final standard of producing no harmful emissions. Thus current plans are using historic emission reduction equipment and incrementally improving its effectiveness for light, medium and heavy on-road vehicles, rail, marine, off-road equipment and power generation. While the historic path will lead to reduced emissions, it has significant implementation issues and may not achieve the standards in the time allowed. Thus, timing is perfect for a new approach that not only will meet future standards, it will allow those standards to be achieved earlier than hoped. This breakthrough technology is simpler and easier to implement than the historic path we are headed down at the present time. It will benefit from both new product sales by use with existing manufacturers of on and off road vehicles, rail, marine and power generation, but can be retrofit to the vast market of existing equipment. This multi-fuel (diesel, gasoline, natural gas, propane and coal) technology is poised for scale up and field testing into the key markets for near term commercialization.

By:
Thomas A. Damberger, Ph.D., CEM

Health Effects of Diesel Emissions

An overview of regulations and technologies to control diesel emissions

1. Why is Diesel Exhaust an Air Pollution Problem?

1.1 Introduction

Diesel exhaust is a mixture containing over 450 different components, including vapors and fine particles. Over 40 chemicals in diesel exhaust are considered toxic air contaminants (TAC's) by the State of California. Exposure to this mixture may result in cancer, exacerbation of asthma, and other health problems.

For the same load and engine conditions, diesel engines spew out 100 times more sooty particles than gasoline engines. As a result, diesel engines account for an estimated 26 percent of the total hazardous particulate pollution (PM_{10}) from fuel combustion sources in our air, and 66 percent of the particulate pollution from on-road sources. Diesel engines also produce nearly 20 percent of the total nitrogen oxides (NO_X) in outdoor air and 26 percent of the total NO_X from on-road sources. Nitrogen oxides are a major contributor to ozone production and smog.

1.2 The Health Problem

Diesel exhaust has been linked in numerous scientific studies to cancer, the exacerbation of asthma and other respiratory diseases. A draft report released by the US EPA in February 1998 indicated that exposure to even low levels of diesel exhaust is likely to pose a risk of lung cancer and respiratory impairment. In August 1998, the State of California decided that there was enough evidence to list the particulate matter in diesel exhaust as a toxic air contaminant - a probable carcinogen requiring action to reduce public exposure and risk.

Dozens of studies link airborne fine particle, such as those in diesel exhaust, to increased hospital admissions for respiratory diseases, chronic obstructive lung disease, pneumonia, heart disease and up to 60,000 premature deaths annually in the US.

AMERICAN LUNG ASSOCIATION.

The health risk from diesel exposure is greatest for children, the elderly, people who have respiratory problems or who smoke, people who regularly strenuously exercise in diesel-polluted areas, and people who work or live near diesel exhaust sources. Studies have shown that the proximity of a child's residence to major roads is linked to hospital admissions for asthma, and there is a positive relationship between school proximity to freeways and asthma occurrence. Truck and traffic intensity and exhaust measured in schools were significantly associated with chronic respiratory symptoms.

Using established U.S. Environmental Protection Agency and California Air Resources Board methods to quantify the impact of air pollution, the Union of Concerned Scientists estimates that construction equipment emissions statewide are responsible for the following impacts on our health and economy: (see Figure 1)

Air Quality Act of 1967

The Act of Congress's first attempt at a comprehensive regulatory scheme for air pollution, which included:

- The establishment of atmospheric areas and air quality control regions and "control techniques" reports
- The issuance of "air quality criterion"

Figure 1

Health Endpoint	Mean Annual Incidences	Annual Costs (in thousands of 2005 dollars)
Premature Deaths	1,132	8,944,256
Respiratory Hospitalizations	669	22,758
Cardiovascular Hospitalizations	417	17,082
Asthma and Other Lower Respiratory Symptoms	30,118	572
Acute Bronchitis	2,494	1.053
Lost Work Days	182,940	32,929
Minor Restricted Activity Days	1,544,952	92,697
School Absences	331,040	29,131
Total Annual Cost		**9,140,480**

1.3 Diesel Particulate Matter

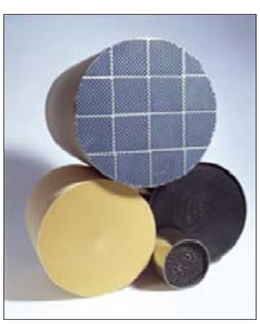
Diesel particulate matter (DPM) refers to the particulate components of diesel exhaust, which include diesel soot and aerosols such as ash particulates, metallic abrasion particles, sulfates, and silicates. When released into the atmosphere, DPM can take the form of individual particles or chain aggregates, with most in the invisible sub-micrometer range of 100 nanometers.

1.4 Health Risks of PM & TAC's

The main particulate fraction of diesel exhaust consists of small particles. Because of their small size, inhaled particles may easily penetrate deep into the lungs. The rough surfaces of these particles makes it easy for them to bind with other toxins in the environment, thus increasing the hazards of particle inhalation. Exposures have been linked with acute short-term symptoms such as headache, dizziness, light-headedness, nausea, coughing, difficult or labored breathing, tightness of chest, and irritation of the eyes and nose and throat. Long-term exposures can lead to chronic, more serious health problems such as cardiovascular disease, cardiopulmonary disease, and lung cancer.

Exposure to diesel exhaust and DPM is a known occupational hazard to truckers, railroad workers, and miners using diesel-powered equipment in underground mines. Adverse health effects have also been observed in the general population at ambient atmospheric particle concentrations well below the concentrations in occupational settings.

The TAC's produced by diesel combustion include a laundry list of hazardous air pollutants (HAPs). Many of these emissions are highly carcinogenetic. Figure's 2 and 3 expand on the various agencies determination of the TAC and HAP status. This is not a local phenomena; but a world-wide effort.



Toxic air contaminants and hazardous air pollutants found in diesel exhaust

Acetaldehyde*	Chlorine	Methyl ethyl ketone
Acrolein	Chlorobenzene	Naphthalene*
Aluminum	Chromium compounds*	Nickel*
Ammonia	Cobalt compounds*	4-nitrobiphenyl*
Aniline*	Copper	Phenol
Antimony compounds*	Cresol	Phosphorus
Arsenic*	Cyanide compounds	POM (including PAHs)
Barium	Dibenzofuran	Propionaldehyde
Benzene*	Dibutylphthalate compounds*	Selenium
Beryllium compounds*	Ethyl benzene	Silver
Biphenyl	Formaldehyde*	Styrene*
Bis [2-ethylhexyl] phthalate*	Hexane	Sulfuric acid
Bromine	Lead compounds*	Toluene*
1,3-butadiene*	Manganese compounds	Xylene isomers and mixtures
Cadmium*	Mercury compounds*	Zinc
Chlorinated dioxins*	Methanol	

*This compound or class of compounds is known by the state of California to cause cancer or reproductive toxicity. See California EPA, Office of Environmental Health Hazard Assessment, "Chemicals Known to the State to Cause Cancer or Reproductive Toxicity," May 31, 2002.

Note: Toxic air contaminants on this list either have been identified in diesel exhaust or are presumed to be in the exhaust, based on observed chemical reactions or presence in the fuel or oil. See California Air Resources Board, "Toxic Air Contaminant Identification List Summaries, Diesel Exhaust," September 1997, available online at http://www.arb.ca.gov/toxics/tac/factshts/diesex.pdf.

Figure 2

As defined by California Health and Safety Code, Section 39655 (a): an air pollutant which may cause or contribute to an increase in mortality or in serious illness, or which may pose a present or potential hazard to human health. Substances which have been identified by the United States Environmental Protection Agency as hazardous air pollutants (i.e., benzene, asbestos) shall be identified by the Board as toxic air contaminants.

CAA and Other Laws

The CAA interrelates with many other Federal laws, including:

- Resource Conservation and Recovery Act
- Comprehensive Environmental Response, Compensation, and Liability Act
- Emergency Planning and Community Right-to-Know Act
- Occupational Safety & Health Act

History of determinations of the carcinogenicity of diesel exhaust

Year	Agency	Determination
1988	National Institute for Occupational Safety and Health (NIOSH)	Potential occupational carcinogen
1989	International Agency for Research on Cancer (IARC)	Probable human carcinogen
1990	State of California (under provisions of Proposition 65)	Known by the state to cause cancer
1995	Health Effects Institute (HEI)	Potential to cause cancer
1996	World Health Organization International Programme on Chemical Safety (WHO-IPCS)	Probable human carcinogen
1998	California Air Resources Board (CARB)	Toxic air contaminant (determination based substantially on the cancer risk to humans)
2000	U.S. Department of Health and Human Services National Toxicology Program (U.S. DHHS/NTP)	Reasonably anticipated to be human carcinogen
2001	American Council of Government Industrial Hygienists (ACGIH) (proposed)	Suspected human carcinogen
2002	U.S. Environmental Protection Agency (EPA)	Probable human carcinogen

Sources:

National Institute for Occupational Safety and Health, "Carcinogenic Effects of Exposure to Diesel Exhaust," Current Intelligence Bulletin 50. August 1988. Available online at http://www.cdc.gov/niosh/88116_50.html . Last accessed August 13, 2004.

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Health Effects Institute, Diesel Exhaust: A Critical Analysis of Emissions, Exposure and Health Effects. Cambridge, MA: Health Effects Institute, 1995. Online resource, available at: http://www.healtheffects.org/Pubs/diesum.htm Last accessed on August 13, 2004.

American Conference of Governmental Industrial Hygienists, "Documentation of the Threshold Limit Values and Biological Exposure Limits, Notice of Intended Changes," 2001.

International Programme on Chemical Safety, World Health Organization, "Diesel Fuel and Exhaust Emissions," Environmental Health Criteria 171 (1996).

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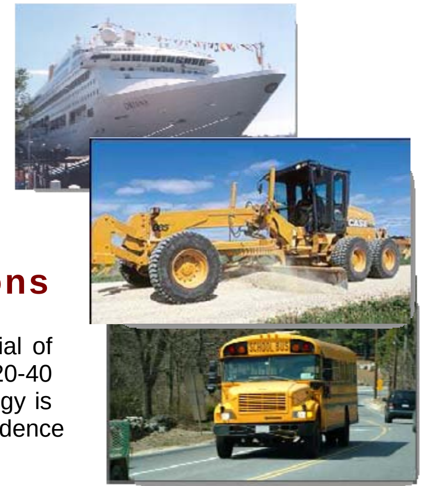
U.S. Environmental Protection Agency, Draft Health Assessment Document for Diesel Exhaust, July 2000, EPA/600/8-90/057E.

California Air Resources Board, "Statewide Portable Equipment Registration Program." Online resource, available at: http://www.arb.ca.gov/perp/perp.htm Last accessed on August 13, 2004.

Figure 3

Diesel Emission Control Market

An overview of regulations and technologies to control diesel emissions



2. Tractors, Trucks, Trains, Automobiles & Regulations

2.1 Background

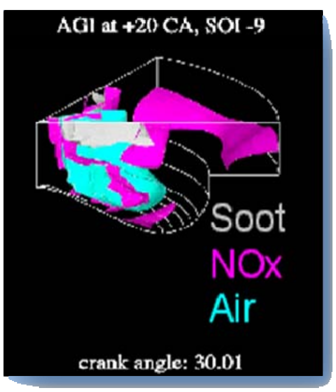
Diesel is the backbone of the American economy, contributing $85 billion each year to our domestic growth. Many of the vehicles we see every day are powered by diesel – from the equipment used in building and construction, to our emergency response and military vehicles, to the railways that move goods across the country. In short, diesel technology truly powers our economy.

Today, clean diesel plays a vital role in preserving our environment through its role in meeting the clean air challenge and the continuous progress and potential of advanced clean diesel systems. In addition, diesel's 20-40 percent greater fuel economy means that this technology is helping conserve precious resources and reduce dependence on foreign sources of oil.

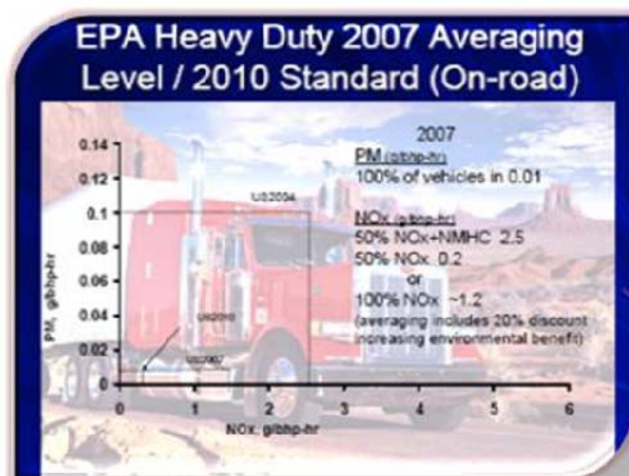
The diesel technology is the world's most efficient internal combustion engine, providing more power and fuel efficiency than other alternatives. Today's clean diesel engines are more environmentally friendly than ever before, making the noise and smoke previously associated with diesel a thing of the past.

Despite these advancements, the industry continues to push to virtually eliminate the key pollutants associated with on- and off-road diesel engines, demonstrating the industries commitment to being part of the solution in improving the nation's overall air quality.

Diesel has a number of environmental advantages over other types of internal combustion engines. Of the five major emissions from internal combustion engines - carbon monoxide, hydrocarbons, carbon dioxide, particulate matter (PM) and nitrogen oxides (NO_x) - diesel emits only small amounts of the first three. The entire diesel industry has accepted the challenge of reducing PM and NO_x emissions and has made great strides that will continue into the next decade.



The Challenge of Stoichiometric Balance



2.2 Searching for a Diesel Emissions Reduction Technology

Modern diesel trucks no longer produce visible smoke, but diesel exhaust continues to come under heavy scrutiny for producing nitrogen oxides (NO_X) and particulate matter (PM). Progress so far has been incremental and not of a quantum magnitude. So far, there is not "silver bullet" to a low-cost solution.

NO_X contributes to the formation of atmospheric ozone, and particulate matter, very small (nanometer-sized) carbon-based particles, is believed to be a health hazard. A trade-off exists between these two exhaust emission in which reducing PM increases NO_X and vice versa.

Diesel engine manufacturers have long sought techniques to achieve simultaneous reduction of particulate and NO_X emissions in order to meet new regulations taking effect in the next few years. To date, no single technique has succeeded in reducing both of these regulated emissions constituents without producing other negative impacts. If one were to guess, there would be a ceramic-based metallic-laminated/impregnated device capable of breaking, or converting pollution emissions into their basic non-toxic elements.

3 Methodologies to Reducing Diesel Emissions

Emissions from diesel engines are ultimately reduced by a combination of mechanical devices and fuel additives, however, there is usually a tradeoff between NO_X improvements and PM improvements. There is no one silver bullet currently on the market as a solution, but moreover a series of clean diesel solutions (Figure 4). In one tangible reduction of NO_X and particulates are reduced, simultaneously with gaseous hydrocarbons and carbon monoxide, by the combined use of exhaust gas recirculation or engine timing modification, with a particulate trap and a platinum group metal catalyst composition.

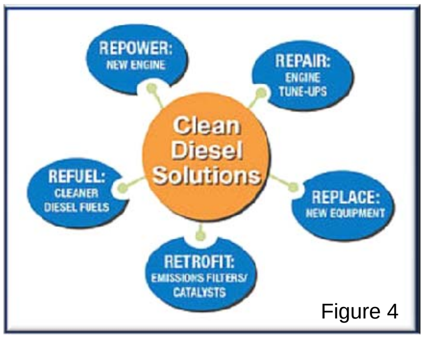


Figure 4

Currently, diesel emissions are reduced by turbo-charging, after-cooling, high pressure fuel injection, retarding injection timing, and optimizing combustion chamber design. Turbochargers reduce both NO_X and PM emissions by approximately 33 percent when compared to naturally aspirated engines. After-cooling with turbo-charging provides even larger NO_X and PM reductions by decreasing the temperature of the charged air after it is heated by the turbocharger. Retarding injection timing reduces the peak flame temperature, which improves NO_X emission but typically results in higher PM emissions. Combustion chamber improvements and air-fuel injection advancements are ongoing in the industry and result in improved fuel economy and emission reductions.

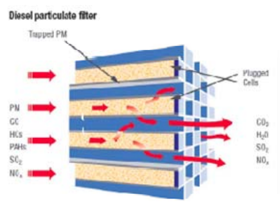
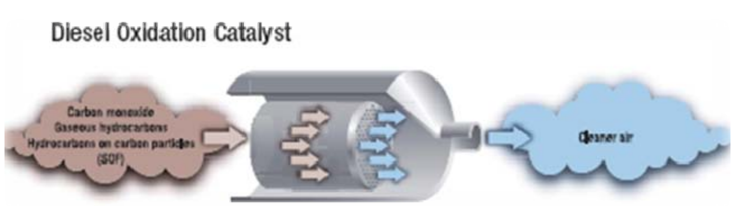


Figure 6

3.1 Diesel Oxidation Catalysts

Diesel oxidation catalysts have been used in some engines since the 1990s to reduce PM emissions (Figure 5) which are used to provide catalyst metal to the exhaust system including a diesel trap (Figure 6) to lower the balance point of the particulate trap (the temperature at which the rate of trap loading equals the rate of regeneration) while also lowering the emissions of carbon monoxide and unburned hydrocarbons. These devices have proven effective at reducing PM emissions by 25 percent or more. They are robust and require little or no maintenance. The problem is diesel oxidation catalysts will not allow engine manufacturers to meet this years (2007) emission standards.

In Figure 7, urea dosing is used to scavenge NO_X and unburned hydrocarbons as well as a significant fraction of the PM.



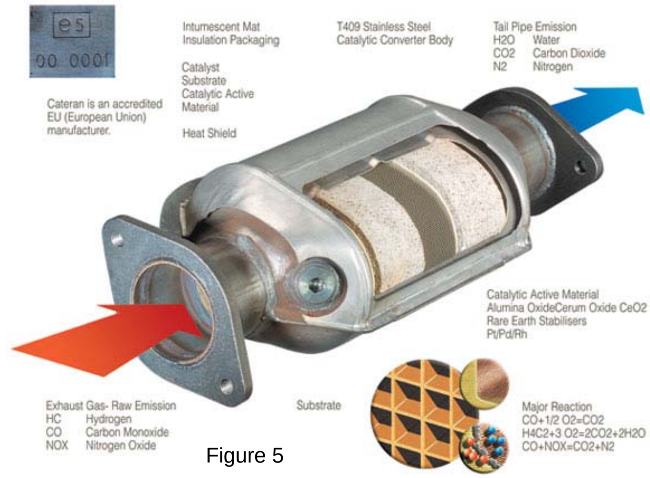


Figure 5

The urea/SCR system basically consists of a storage tank for urea solution, a urea injection system, and a catalyst. Removal of NO_X is accomplished through the controlled injection of urea into the hot exhaust gas where the urea decomposes into ammonia (NH_3). NO_X react with NH_3 on the surface of the catalyst to produce harmless nitrogen (N_2) and water vapor. Removal of hydrocarbons and particles takes place on the catalyst independent of the injection of urea.

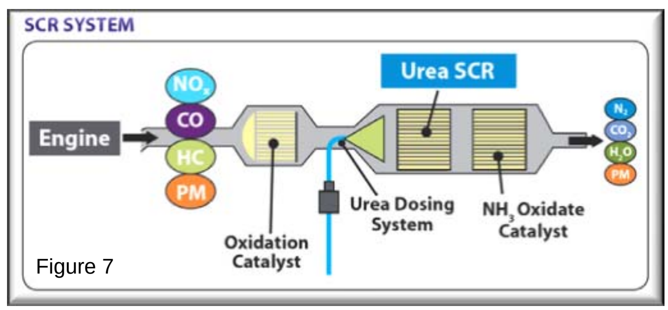


Figure 7

When coupled with ultra-low sulfur diesel, diesel particulate filters have achieved PM reductions of greater than 95 percent and have engine out PM emission levels of 0.008 g/bhp-hr. In its review of diesel engine technology developments necessary to meet 2007 standards, the U.S. Environmental Protection Agency identified diesel particulate filters (when coupled with ultra-low sulfur diesel) as the leading technology for PM compliance.

The catalyzed diesel particulate filter and the continuously regenerating diesel particulate filter have demonstrated their effectiveness in reducing particulate emissions to 2007 standards.

> **"Emission standards must require maximum achievable control technology to be used for both new and some existing sources."**
>
> **Title III — Hazardous Air Pollutants**

Over the last several years, interest in biodiesel has been driven by a variety of concerns including environmental quality, reducing reliance on imported oil and using renewable “home-grown” energy sources. Most efforts to date by the biodiesel industry have focused on financial incentives, supply, and production aspects, with less attention to the vehicle use and performance characteristics. While biodiesel does offer some advantages, there are many factors to be considered in making an overall assessment of the value of using biodiesel.

Title I—Air Quality and Emission Limitations

Title I addresses nonattainment areas (NAAs) for:

- Sulfur dioxide
- Nitrogen dioxide
- Carbon monoxide
- Ozone
- Lead
- Particulate matter (PM_{10})

4. Biodiesel Fuel

Biodiesel fuels are derived from a variety of biomass sources through a chemical process called transesterification, where glycerin is separated from methyl esters derived from fat or oil. The methyl ester product is what is known as biodiesel and must meet the standards set forth by the American Society of Testing and Materials (ASTM D6751).

The most common feedstock in the U.S. for biodiesel production is soybean oil, while rapeseed oil is used more frequently in Europe. Biodiesel may be blended with petroleum-based diesel fuel at which point it is designated as BXX, where XX represents the percentage of pure biodiesel contained in the blend (e.g. B5 or B20).

Biodiesel use can reduce emissions of sulfur oxides and sulfates as well as unburned hydrocarbons, carbon monoxide, and particulate matter. While biodiesel has been shown to increase NO_X emissions, recent studies indicate that emission levels may vary depending on the duty cycle of the engine, testing methods used and the particular blend. Since NO_X is a precursor to ozone, use of high percentage blends of biodiesel in areas with ozone problems should be considered in relation to local air quality conditions.

Other concerns include potential oxidation, microbial growth and changes in performance characteristics in vehicles and when stored in underground tanks over an extended period of time without use. Some biodiesel blends can negatively affect cold starts, fuel flow properties and result in an initial need for greater fuel filter maintenance. Depending on the blend, fuel economy may be reduced due to biodiesel’s slightly lower energy content.

Ultra-low Sulfur Diesel (ULSD) is 100% petroleum based, however the sulfur content has been drastically reduced from 500 to 15 parts per million (ppm). ULSD will be available at most diesel fueling stations by October 15, 2006. Use of ULSD alone will provide an approximate 10% reduction in PM emissions. Biodiesel blends for on-road use are not required to be mixed with ULSD, however light and heavy-duty vehicles manufactured after 2007 that require the use of ULSD can only use biodiesel blends if they are made with ULSD. Manufacturers are working to identify the feasibility and potential impacts of using various biodiesel blends on these next generation engines and new emissions control technology like particulate traps and catalytic converters.

4.1 Composite of Diesel Emission Technologies

The basic technology menu for 2010 includes:

- ✓Diesel particulate filters.
- ✓NO_x aftertreatment systems.
- ✓Advanced combustion, including a range of advanced system components (such as two-stage boosting, injection systems, and variable valve management among others).
- ✓Control systems and on-board diagnostics (OBD). OBD poses more of a risk issue than emissions.
- ✓ Hybrids
- ✓ Waste heat recovery, including the possibility of thermo-electric recovery.
- ✓ Fuels (biofuels and eventually synthetics)

The Diesel particulate Filter is already becoming common on heavy-duty platforms to meet the 2007 limits. As the manufacturers head into 2010, they all see a need for some form of NO_x aftertreatment.

Figure 8

5. Regulators & Emissions Inventory

Current air pollution laws are based on a progression of laws which include:

- Air Pollution Control Act of 1955
- Clean Air Act of 1963
- Air Quality Act of 1967
- Significant Amendments in 1970, 1977, and 1990

Emissions-control technology for mobile sources has developed in a series of interactive steps with the promulgation of emissions standards for new vehicles and engines and for fuel regulation. For light-duty vehicles, emissions-control hardware has changed greatly over the past 50 years to reflect the changes in emissions standards, vehicle design, fuel-efficiency standards, and technological capabilities. The efforts of motor vehicle manufacturers, the manufacturers of emissions controls and other equipment, the California Air Resources Board (CARB), and the U.S. Environmental Protection Agency (EPA) have made vehicles much cleaner and more durable. Although the relationship among the parties has not always been harmonious, it has produced benefits not only for the United States but also for the world. On-highway diesel vehicles have had emissions-control standards since the 1970s while EPA's emissions control activities have been authorized for nonroad sources only since the passage of the 1990 Clean Air Act (CAA) amendments.

> **"the prevention and control of air pollution at its source is the primary responsibility of State and local governments"**
>
> **Air Pollution Control Act of 1955**

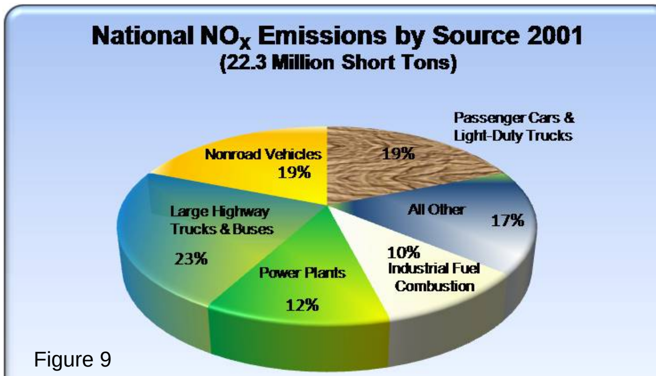


Figure 9

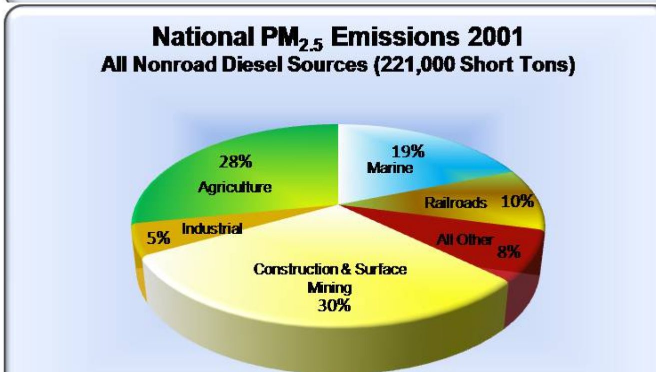


Figure 10

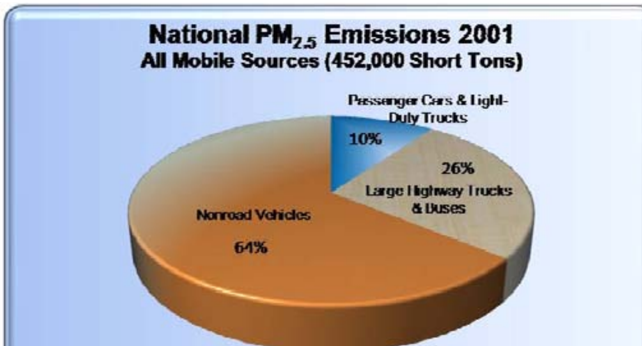


Figure 11

Source (Figures 9, 10, 11): National Emission Inventory (NEI): Air Pollutant Emission Trends. 1999 Online resource, available at: http://www.epa.gov/ttn/chief/net/1999inventory.html Last accessed 03/01/07.

Category	50,000 Miles/5 Years						100,000 Miles/10 Years1					
	THC	NMHC	CO	NO_X* Diesel	NO_X Gasoline	PM	THC	NMHC	CO	NO_X* Diesel	NO_X Gasoline	PM
Passenger Cars	0.41	0.25	3.4	1.0	0.4	0.08	-	0.31	4.2	1.25	0.6	0.10
LLDT, LVW <3,750 lbs	-	0.25	3.4	1.0	0.4	0.08	0.80	0.31	4.2	1.25	0.6	0.10
LLDT, LVW >3,750	-	0.32	4.4	-	0.7	0.08	0.80	0.40	5.5	0.97	0.97	0.10
HLDT, ALVW <5,750	0.32	-	4.4	-	0.7	-	0.80	0.46	6.4	0.98	0.98	0.10
HLDT, ALVW >5,750	0.39	-	5.0	-	1.1	-	0.80	0.56	7.3	1.53	1.53	0.12

1 – Useful life 120,000 miles/11 years for all HLDT standards and for THC standards for LDT
* - More relaxed NOX limits for diesels applicable to vehicles through 2003 model year

Abbreviations:
LVW – loaded vehicle weight (curb weight + 300 lbs)
ALVW – adjusted LVW (the numerical average of the curb weight and the GVWR)
LLDT – light light-duty truck (below 6,000 lbs GVWR)
HLDT – Heavy light-duty truck (above 6,000 lbs GVWR)

Table 1

EPA Tier 1 Emission Standards for Passenger Cars and Light-Duty Trucks, FTP 75, g/mi

> Title III — Hazardous Air Pollutants
>
> The 1990 Amendments:
>
> - Increased the number of Hazardous Air Pollutants (HAPs) from 8 to 188
> - HAP standards were changed from health-basted to technology-based

5.1 International Environmental Law

Worldwide aligned emission standards for transportation are now accepted by the European Union, China, Japan and the United States who have agreed to jointly address air pollution emitted by vehicles. The governmental agreement covers joint research on emissions and vehicle testing and the creation of a common scientific platform to measure and benchmark air pollution from traffic.

In the last two decades over two hundred and fifty international legal instruments have been adopted. Overall, almost one thousand international legal instruments have had at least one provision addressing the environment. The proliferation of global treaties, conventions, and protocols on environmental protection has been dramatic.

The EC regulates air quality through the Air quality framework directive 96/62 and its four daughter directives, and through source related legislation. The Air quality framework directive, amended in 2003 by an EP and Council Regulation 1882/2003, attempts to define the basic principles of a common strategy to establish objectives, assess and obtain adequate information on ambient air quality and to assure that this information is made available for the public.

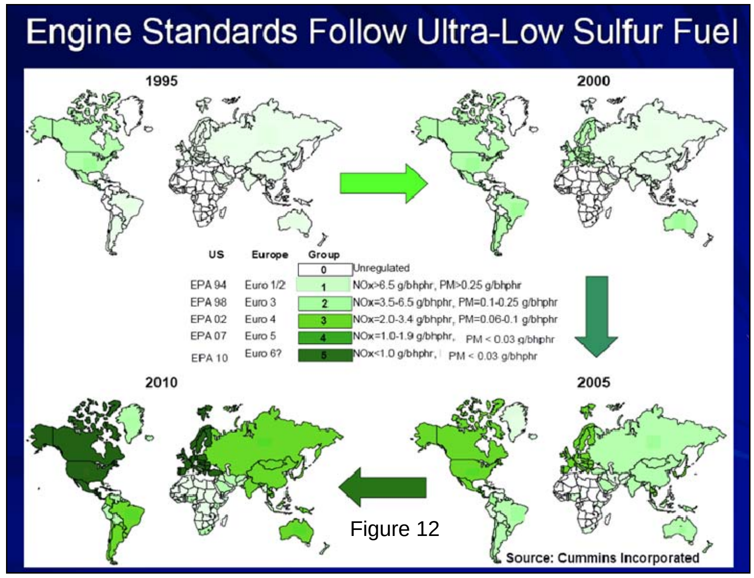


Figure 12

The first daughter directive relating to limit values for NO_X, SO_2, Pb, and PM_{10} in ambient air is directive 99/30/EC (amended by Commission Decision 2001/744). The most important deadlines in this directive are 2005 and 2010. The health limit values for SO_2 and PM_{10} (particles smaller than 10 micrometer in diameter with negative human health effects; see for further information the Explanations below) must be met by 2005 and the health limit values for NO_2 and Pb must be met by 2010. An annual report is to be submitted on the progress in limiting the values.

Tier 1—Cars and Light-Duty Trucks

Two sets of standards have been defined for light-duty vehicles in the Clean Air Act Amendments (CAAA) of 1990:

- Tier 1 standards, which were published as a final rule on June 5, 1991 and phased-in progressively between 1994 and 1997.
- Tier 2 standards, which were adopted on December 21, 1999, with a phase-in implementation schedule from 2004 to 2009.

Tier 1 standards applied to all new light-duty vehicles (LDV), such as passenger cars, light-duty trucks, sport utility vehicles (SUV), minivans and pick-up trucks. The LDV category included all vehicles of less than 8500 lb gross vehicle weight rating, or GVWR (i.e., vehicle weight plus rated cargo capacity). LDVs were further divided into the following sub-categories:

- passenger cars
- light light-duty trucks (LLDT), below 6000 lbs GVWR
- heavy light-duty trucks (HLDT), above 6000 lbs GVWR

The Tier 1 emission standards are summarized in Table 1. Car and light truck emissions are measured over the Federal Test Procedure test and expressed in g/mile.

In addition to the FTP 75 test, a Supplemental Federal Test Procedure (SFTP) was phased-in between 2000 and 2004. The SFTP includes additional test cycles to measure emissions during aggressive highway driving, and also to measure urban driving emissions while the vehicle's air conditioning system is operating.

6. Regulations for Locomotive & Marine

Existing EPA regulations in 40 CFR parts 92 and 94 include standards for emissions of PM, NO_X, HC and CO from locomotive and marine compression-ignition engines (also called diesel engines). These standards rely on engine-based technologies to reduce emissions. The opportunity to gain large additional public health benefits, as well as the similarities between these engines and highway diesel and nonroad engines, have led us to consider additional emission controls based on the high-efficiency aftertreatment technologies that will soon be in use by highway and nonroad engines.

6.1 Reduction of Locomotive & Marine Emissions

Locomotive and marine diesel engines contribute significantly to air pollution in many of our nation's cities and towns. In the coming decades, these engines are expected to account for an even greater share of overall emissions as other emission control programs take effects for cars, trucks, and other nonroad emissions sources. EPA estimates that, without the emission reductions from today's proposal, by 2030 locomotive and marine diesel engines would contribute more than 65 percent of national mobile source diesel $PM_{2.5}$ emissions and 35 percent of national mobile source NO_X emissions, a key precursor to ozone and secondary PM formation.

Recent air quality data show that about 157 million people live in areas that violate air quality standards for ground-level ozone, also called smog and about 88 million people live in areas that violate air quality standards from PM. These pollutants contribute to serious public health problems that include premature mortality, aggravation of respiratory and cardiovascular disease, aggravation of existing asthma, acute respiratory symptoms and chronic bronchitis. EPA believes that diesel exhaust is likely to be carcinogenic to humans by inhalation. Children, people with heart and lung diseases, and the elderly are thought to be most at risk.

Locomotive and marine diesel emissions reductions are expected to benefit those who live, work, or recreate in and along our nation's coastal areas, rivers, ports, and rail lines. Such reductions are expected to have beneficial impacts on visibility impairment and regional haze, as well as reducing crop damage and acid rain.

Railroad locomotives fall into three size categories:

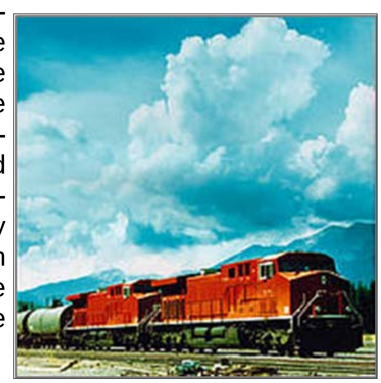
- The smallest of the locomotive engines (up to 2,000 horsepower) are used in switch operations in freight yards to assemble and disassemble trains, or are used in short hauls of small trains.
- Passenger locomotives (3,000 horsepower) are often accompanied by an auxiliary engine for "hotel" power to passenger train cars.
- The most powerful locomotive engines (up to 4,000 horsepower) are primarily used for long distance freight train operations.

Description of Engines Covered

The proposed requirements would cover all locomotives and many marine diesel engines already subject to EPA emission standards, as follows:

- **Locomotives**: With limited exceptions, the regulations would apply to all line-haul, passenger, and switch locomotives that operate extensively within the United States, including newly manufactured locomotives and remanufactured locomotives that were originally manufactured after 1972. The primary exception is that the new remanufacturing standards would not apply to the existing fleets of locomotives owned by very small railroads.
- **Marine Diesel Engines**: The regulations would apply to newly-built marine diesel engines with displacements less than 30 liters per cylinder installed on vessels flagged or registered in the United States. These are commonly referred to as marine diesel engines and are divided into three categories for the purposes of EPA's standards. Category 1 are engines above 50 horsepower (hp) and up to 5 liters per cylinder displacement. Category 2 are engines from 5 to 30 liters per cylinder. Category 3 are engines at or above 30 liters per cylinder. EPA is proposing to change the definition of Category 1 and Category 2 engines to reflect a 7 liter per cylinder cut-off.

Marine Diesel engines are used in commercial, recreation, and auxiliary power applications. Commercial propulsion applications range from tug boats to Great Lakes freighters. Recreational propulsion applications range from sailboats to super-yachts. EPA is also requesting comments on whether the Agency should tighten emission standards for certain existing marine diesel engines when they are remanufactured. Marine diesel engines at or above 30 liters per cylinder displacement are not included in this proposal; these engines, which are typically used for propulsion on ocean-going vessels, will be addressed in a separate EPA rulemaking.



6.2 Exhaust Emissions Standards

The proposal consists of a three-part emission control. First, EPA is proposing to adopt more stringent standards for existing locomotives when they are remanufactured. These standards would take effect as soon as certified remanufacture systems are available (as early as 2008), but no later than 2010 (2013 for Tier 2 locomotives). EPA is also requesting comment on similar requirements for certain existing marine diesel engines when they are remanufactured.

Second, EPA is proposing near-term emission standards, referred to as Tier 3 standards, for newly-built locomotive and marine engines. These standards would reflect the application of technologies to reduce engine-out PM and NOx emissions and would phase in starting in 2009.

Third, EPA is proposing long-term emissions standards, referred to as Tier 4, for newly-built locomotives and marine diesel engines. These standards are based on the application of high-efficiency catalytic aftertreatment technology and would phase in beginning in 2014 for marine diesel engines and 2015 for locomotives. These standards are enabled by the availability of clean diesel fuel with sulfur content capped at 15 parts per million, which will be available beginning by 2012. These marine Tier 4 engine standards would apply only to commercial marine diesel engines above 800 hp and recreational marine diesel engines above 2,000 hp.

The proposal would result in PM reductions of about 90 percent and NOx reductions of about 80 percent from engines meeting these standards, compared to engines meeting the current standards. The proposed standards would also yield sizeable reductions in emissions of HC, CO, and other air toxics.

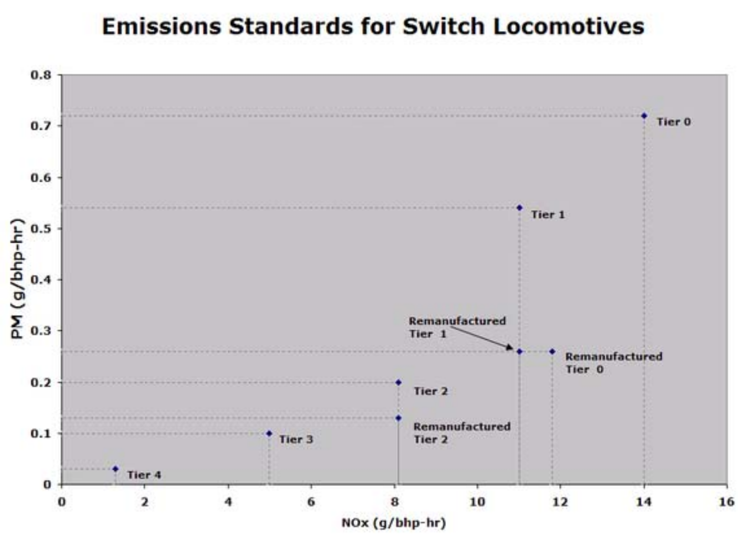
6.3 Program Costs

EPA estimates the annual cost of complying with the proposed program to be about $600 million in 2030. The average price in 2030 of a locomotive is expected to increase by less than three percent (about $49,000 per unit) as a result of the proposed standards. In the marine markets, the expected impacts in 2030 are different for engines above and below 800 hp. Increases in engine and vessel prices for commercial engines below 800 hp and recreational engines are expected to be small (less than one percent). The average price of a commercial marine diesel engine above 800 hp is expected to increase by about 8.5 percent for Category 1 engines and about 19 percent for Category 2 engines. The average price of a marine vessel using these larger engines is expected to increase much less, about 1 percent for vessels using Category 1 engines above 800 hp (about $16,000) and 3.6 percent for vessels using Category 2 engines above 800 hp (about $142,000). The expected impacts on prices in the locomotive and marine transportation service market would be less than one percent.

The diesel industry and rail manufacturers continue to invest resources and make strides toward producing the cleanest train technology possible. Diesel engine technology in railroad locomotives has advanced dramatically in recent years. Fuel-efficiency has increased 61 percent since 1980.

In 2004, the U.S. Environmental Protection Agency (EPA) released its Final Nonroad Diesel Rule that will require train engines meet strict air quality standards. As part of this standard, trains will achieve low emissions levels that will reduce sulfur emissions by 99 percent. These fuel improvements will create immediate and significant environmental and public health benefits.

At the same time, clean rail standards will also require the use of advanced emission-control technologies similar to those already upcoming for heavy-duty diesel trucks and buses. The availability of clean nonroad diesel fuel means that advanced clean diesel technology will reduce NOx and PM emissions by 90 percent in rail technologies.



The 2010 EPA emissions standard for heavy-duty vehicles is the culmination of years of stair-stepped emissions regulations that have driven the development cycle for all heavy duty manufacturers for more than a decade. Two of the key metrics in that standard are the 0.2 g/bhp-hr NO_x and 0.01g/bhp-hr PM limits.

> Clean Air Act of 1963
>
> The Department of Health, Education, and Welfare (HEW) was authorized to establish non-mandatory air quality criteria. The law almost exclusively concerned with stationary sources.

A lead-in to 2010 begins this year, with targets of 1.2 g/bhp-hr NO_x and the same PM target.

Given an average 3-year timeline to take a new product into production, all the manufacturers have made their basic technology decisions—albeit not yet announced—on 2010 technology, although some room for tuning remains. All the panelists were in agreement that, once the 2010 products are in development, they can turn more of their focus to what comes next.

Although urea-based SCR is the odds-on favorite at this point, with its greater than 80% conversion efficiencies, it is not the only choice nor is it without concerns, related to infrastructure, operational convenience, and vehicle layout.

While the extra tank and injector required for a urea-based system is likely not a problem on a long-haul Class 8 truck. There is also some worry that, given potential technology developments, urea SCR could become a stranded technology several years after its implementation.

Another option for NO_x control is a lean NO_x adsorber (trap). Such LNTs offer excellent NO_x reduction when new, but have some issues with cost, durability and engine management during desulfation. Some see it as likely on lighter duty applications, but questionable on the heaviest duty vehicles.

Cummins earlier this year paired a new 6.7-liter turbodiesel with an advanced aftertreatment system including a close-coupled diesel oxidation catalyst, a NO_x adsorber catalyst and a combined diesel oxidation/particulate filter to deliver the first 2010-compliant diesel powertrain on the market.

An option that some are exploring is a hybrid aftertreatment system—a combination of lean NO_x traps with Selective Catalytic Reduction—to meet NO_x limits without having to go to urea.

IMPLEMENTATION BY ENGINE MODEL YEARS

Group	Model years	Deadline
Group 1**	1988-2002	DEADLINE
	10%BACT	December 31, 2004
	25%BACT	December 31, 2005
	50%BACT	December 31, 2006
	100%BACT	December 31, 2007
Group 2a*	1960-87	(Fleets of 15 or more vehicles)
	15%BACT	December 31, 2005
	40%BACT	December 31, 2006
	60%BACT	December 31, 2007
	80%BACT	December 31, 2008
	100%BACT	December 31, 2009
Group 2b**	1960-87	(Fleets of 14 or fewer vehicles)
	25%BACT	December 31, 2007
	50%BACT	December 31, 2008
	75%BACT	December 31, 2009
	100%BACT	December 31, 2010
Group 3**	2003-06	(includes dual & bi-fuel engines)
	50%BACT	December 31, 2009
	100%BACT	December 31, 2010

*GROUP 2a: level1 technology may not be used as BACT.
**Owners with total fleets of 1-3 vehicles may delay compliance until the final deadline for each group.

Figure 13

What is BACT?

BACT is an California Air Resources Board-verified technology that best reduces PM emissions from the diesel engine of a solid waste collection vehicle*. Since one BACT does not work for all engines, the ARB has provided owners with several options to bring their vehicles into compliance. BACT is defined in the rule as one of four options:

✓An engine alone certified to the 2007 model year standard of 0.01 gram of PM per brake horsepower-hour (g/bhp-hr), for example a new truck purchased beyond 2007.

✓An engine certified to the existing 0.10 g/bhp-hr PM standard that is then equipped with the most effective ARB-verified Diesel Emission Control Strategy (DECS) such as a diesel particulate filter or diesel oxidation catalyst, for example replacing a 1990 tuck engine with a 1994 engine plus DECS.

✓An alternative-fuel engine, such as one that runs on natural gas.

✓Any diesel or dual-fuel engine retrofitted with an ARB-verified DECS that reduces PM by the greatest amount possible for the particular engine and application. The right DECS for an engine depends on three things: the DECS is verified for the engine; the duty cycle of vehicle matches the requirements of the DECS; and the engine warranty can not be voided by using the DECS.

*Title 13 Section 2700 et seq.

California Environmental Protection Agency

7. Diesel Retrofit Technologies Review

The diesel industry is constantly innovating new solutions to clean up existing diesel engines that run for millions of miles. Employing emissions control systems and devices, owners of diesel products are able to make the most out of their investment in diesel technology. The picture on the right shows a white handkerchief test demonstrating that a white handkerchief remains clean even when held in front of a diesel exhaust pipe.

•**High Efficiency Diesel Particulate Filters** (DPFs)
High efficiency diesel particulate filter (DPF) removes PM in diesel exhaust by filtering exhaust from the engine. The filter systems can reduce PM emissions by 80 to greater than 90 percent.

Wall-Flow Diesel Particulate Filter

• High efficiency filters are extremely effective in controlling the carbon fraction of the particulate, the portion that some health experts believe may be the PM component of the greatest concern.

• Since the volume of particulate matter generated by a diesel engine is sufficient to fill up and plug a reasonably sized filter over time, some means of disposing of this trapped particulate must be provided. The most promising means of disposal is to burn or oxidize the particulate in the filter, thus regenerating, or cleansing, the filter. This is accomplished through the use of a catalyst placed either in front of the filter or applied directly on the filter, a fuel-borne catalyst, or burners which are used to oxidize or combust the collected particulate.

• Low pressure EGR systems are used for retrofit applications in conjunction with high efficiency DPFs. In a low pressure EGR system, the recirculated exhaust is taken from downstream of the high efficiency DPF.

• Around the world, more than 200,000 DPFs have been installed as retrofits and more than 1 million DPF-equipped cars have been sold in Europe. DPFs have also been used successfully on a variety of off-road engines since the mid-1980s.

Flow-Through Filters

• Flow-through filter technology is a relatively new method of reducing diesel PM emissions that unlike a high efficiency DPF, does not physically "trap" and accumulate PM. Instead, exhaust flows typically through a catalyzed wire mesh or a sintered metal sheet that includes a torturous flow path, giving rise to turbulent flow conditions. Any particles that are not oxidized within the flow-through filter flow out with the rest of the exhaust.

• So far, there have been limited commercial use of the flow-through filters but there is an increasing interest in this technology due to its ability to significantly reduce PM emissions from older, "dirtier" diesel engines.

• Flow-through systems are capable of achieving PM reduction of about 30 to 70 percent.

Diesel Oxidation Catalysts (DOCs)

• Like catalytic converters already used on all new gasoline vehicles, diesel oxidation catalysts (DOCs) cause chemical reactions to reduce emissions without being consumed and without any moving parts.

Diesel Oxidation Catalyst Functional Diagram

• The catalysts reduce particulate emissions by as much as 50 percent, can reduce visible smoke, and can virtually eliminate the pungent odor of diesel exhaust.

• The catalysts can reduce the invisible gaseous ozone-forming hydrocarbons by more than 70 percent and carbon monoxide emissions by as much as 90 percent.

• DOCs have been equipped on over 250,000 off-road diesel engines worldwide for over 30 years, and on over 1.5 million new heavy-duty highway trucks since 1994 in the U.S.

• DOCs can be installed on new vehicles or can be retrofitted on vehicles already in-use.

• DOCs can be used not only with conventional diesel fuel, but have been shown effective with biodiesel and emulsified diesel fuels, ethanol/diesel blends, and other alternative diesel fuels.

Selective Catalytic Reduction (SCR)

• Selective catalytic reduction (SCR) systems use a wash-coated or homogeneous extruded catalyst and a chemical reagent to convert NO_X to molecular nitrogen and oxygen in the exhaust stream. In mobile source applications, an aqueous urea solution is usually the preferred reductant.

• As exhaust and reductant pass over the SCR catalyst, chemical reactions occur that reduce NO_X emissions. SCR system can reduce NO_X emissions by 75 to 90 percent, HC emissions by up to 80 percent, and PM emissions by 20 to 30 percent.

• SCR has been used on stationary sources since the 1980s and is beginning to find use in mobile source applications, including line-haul trucks, off-road equipment, marine vessels, and locomotives.

Air Quality Act of 1967

- The adoption of ambient air standards by States within air quality regions
- The development of plans by the States to implement the ambient air standards

NO_X Adsorbers

• NO_X adsorber technology is a catalyst technology for removing NO_X in a lean (i.e., oxygen-rich) exhaust environment for both diesel and gasoline lean-burn direct-injection engines.

• NO_X adsorber technology has made significant progress and is currently being optimized for diesel engine emission control. Reductions in engine out NO_X emissions of as high as 90 percent have been demonstrated and it appears possible to develop the system into a functional and durable NO_X control system for diesel exhaust.

Closed Crankcase Filters

• Closed crankcase filters are used to reduce emissions from crankcase breather tubes in most turbocharged aftercooled diesel engines by using a multi-stage filter designed to collect, coalesce, and return the emitted lube oil to the engine's sump.

• For MY 1994 to 2006 heavy-duty diesel engines, crankcase PM emissions reductions provided by crankcase emission control technologies are about up to 25 percent of the tailpipe emission standards.

8. Clean Diesel Combustion (CDC)

EPA emission standards – both 2007 heavy-duty engine and the Tier 2 standards for passenger vehicles – call for major reductions (ranging from 77 to 95 percent) in NO_X and PM emissions. Although several methods are being examined to meet these future standards, today's primary path option to reduce diesel NO_X emissions is through the use of aftertreatment devices. NO_X aftertreatment devices control emissions downstream from the engine's combustion chamber, in the exhaust system rather than in the engine.

Research on CDC technology suggests that cost-effective alternatives for long-term NO_X compliance may not need to rely exclusively on NO_X aftertreatment methods. CDC technology may be an attractive alternate method to achieve future stringent diesel emissions standard levels.

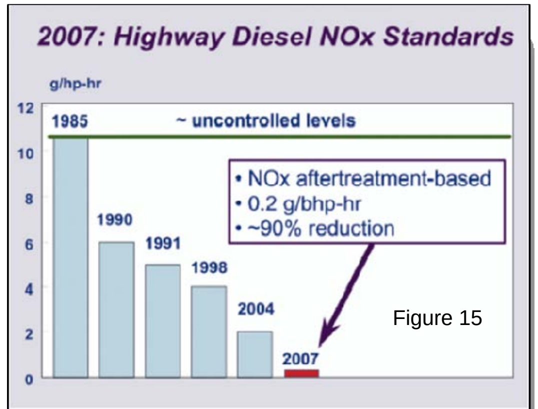


Figure 15

For model year 2007, NOx emission standards for heavy-duty engines are reduced over 90% of current standards.

Current Law

- DOE must meet EPA's CAA objectives and criteria for Federal air quality
- State and local programs (if approved by EPA) may administer the CAA
- State and local requirements may be more strict than EPA requirements

Key Features of CDC Technology

• *EPA Fuel System* – Uses a hydraulically intensified fuel system to lower PM and smoke emissions, and improve engine efficiency.

• *Boost System* – Increases the engine power and the efficiency of the combustion process, thus reducing emissions and increasing fuel economy.

• *Low Pressure Exhaust Gas Recirculation (EGR)* – Lowers the peak combustion temperature to reduce the formation of NO_X.

• *PM Aftertreatment* – Reduces the remaining smoke, unburned hydrocarbons (HC) and carbon monoxide in the exhaust to levels required for future emissions standards.

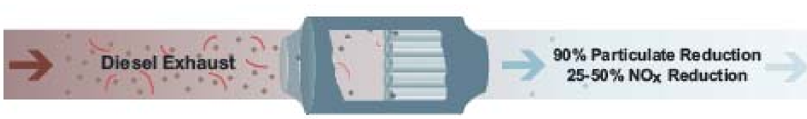
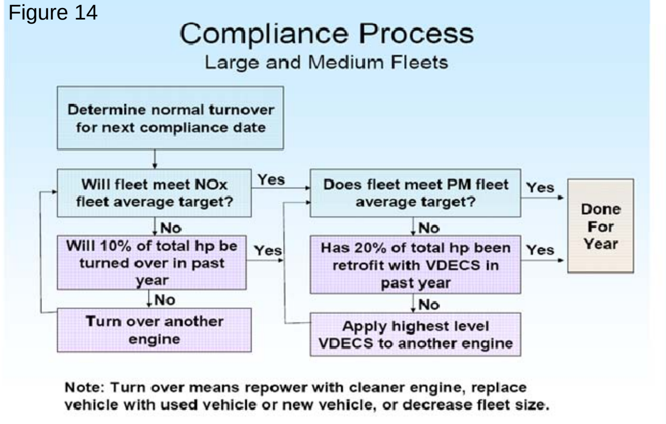
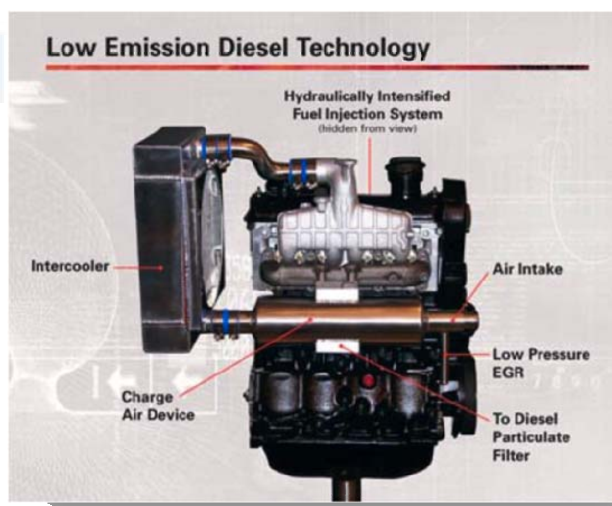


Figure 14





A Clean Diesel Combustion Engine with Various Component Technologies

Manufacturers of Diesel Emission Controls

Manufacturer	Website	Type
SCR-Tech, Inc 11701 Mt. Holly Road Charlotte, NC 28214 (704) 827-8933	http://www.scr-tech.com	SCR Catalyst Regenerative Patented Catalyst Rejuvenation & Regeneration
GreenUrban Technologies Limited 31 Windermere Drive Rainford, St Helens, Merseyside, WA11 7LD 01744-883166	http://greenurban.co.uk/.htm	SCR, Partial Flow, Full Flow Filter Active Regeneration
Johnson Matthey, Inc. 380 Lapp Road Malvern, PA 19355 (610) 341-3478	http://ect.jmcatalysts.com/	4-way, PM, NO_X, CO, HC
Engelhard Corporation 101 Wood Avenue Iselin, NJ 08830 (732) 205-5000	http://www.engelhard.com/	Diesel Oxidation Catalysts—3-Catalyst System—Meets Euro IV Emission Standards
Cateran Inc. 166 Saunders Rd, Unit #9 Barrie, ON, L4N 9A4 Canada (705) 726-1433	http://www.cateran.com.au/cateran/about.aspx	Catalytic Converters
Catalyst Products	http://www.catalystproducts.com/4436.html	Catalytic Converters
Corning Environmental Technologies One Riverfront Plaza Corning, NY 14831 (607) 974-9000	http://www.corning.com/environmentaltechnologies/	Corning DuraTrap AT Filters Corning DuraTrap CO Filter Corning DuraTrap RC Filter

Manufacturers of Diesel Emission Controls

Johnson Matthey Catalysts
Process Catalysts and Technologies

Technology	Engine Model/Application	Retrofit Fuel, Max Sulfur (ppm)	Reductions (%)*			
			PM	CO	NO_x	HC
Catalyzed Continuously Regenerating Technology (CCRT) (2005)	Highway, Heavy-Heavy, Medium-Heavy, Light-Heavy duty, Urban Bus, 4-Cycle, Non-EGR Model Year 1994 – 2003, Turbocharged or naturally aspirated Engines.	30	60**	60**	n/a	60**
Continuously Regenerating Technology (CRT) (2005)	All 2 & 4 Cycle, Model Year 1994 00 2003, Turbocharged or Naturally Aspirated Engines	30	60	60	n/a	60
CEM™ Catalytic Exhaust Muffler and/or DDC™ Catalytic Converter (2005)	Highway, Heavy-Heavy, Medium-Heavy, Light-Heavy Duty, Non-Urban Bus, 4-Cycle, Non-EGR Model Year 1991 – 2003, Turbocharged or Naturally Aspirated Engines	500	20	20	n/a	50

* - Baseline assumes an unmodified engine running on regular 2D (<500 ppm sulfur) fuel.
Note: The reductions are based on the installation of retrofits to engines that were originally produced without diesel oxidation catalysts or diesel particulate filters.
The following operating criteria must be met in order for appropriately retrofitted engines to achieve the above emissions reductions:
The engine exhaust temperature must be at least 210 degrees C for approximately 40 percent of the duty cycle. (As there may be significant variations from application to application, Johnson Matthey will review actual vehicle operating conditions and perform temperature data-logging prior to retrofitting an engine with their CCRT filter system to ensure compatibility.)
The engine's exhaust must produce a NOx/PM ratio of at least 8, with an optimum approaching 20. Johnson Matthey will make an assessment of the suitability of candidate engines, based upon the applicable emission standards or emission test data.
The engine should be well maintained and not consume lubricating oil at a rate greater than that specified by the engine manufacturer;
Johnson Matthey must install a backpressure monitor and high pressure indicator light on all vehicles equipped with a CCRT.
The engine must be operated with a fuel that contains a sulfur content of no more than 30 ppm.
Johnson Matthey has indicated that there is a negligible (approximately 1%) fuel economy penalty with the use of this product.
** This product has been verified by CARB to give minimum 85% reductions in PM, CO and HC emissions. CARB also includes additional model years in its verification of Johnson Matthey's products.
The Environmental Protection Agency's (EPA's) Voluntary Diesel Retrofit Program signed a Memorandum of Agreement (MOA) with the State of California Air Resources Board (ARB) for the Coordination and Reciprocity in Diesel Retrofit Device Verification. The MOA establishes reciprocity in verifications of hardware or device-based retrofits.

	New	Regenerated
Removal from SCR System	Comparable	Comparable
Transport Out	Comparable	Comparable
Purchase Price	$758,000–$975,000	$455,000–$585,000
Shipping	Comparable	Comparable
Installation	Comparable	Comparable
Net Savings from Regeneration	$303,000–$390,000 Plus Disposal Costs	
Disposal Cost	$20,000–$500,000	0

Annualized Costs and Benefits of the 2007 Rule

- Compliance costs
  - Estimated at $1200-1900 per engine
  - 4-5 cents per gallon fuel, partially off-set by maintenance savings of ~ 1 cent per gallon
  - Total costs are $4.3 billion/year
- Health benefits
  - The program will prevent annually
    - Over 8,300 premature deaths
    - Over 750,000 respiratory illnesses, including asthma
    - 1.5 million lost work days
    - 2.6 million tons of NO_x, 110,000 tons of PM, and
    - 17,000 tons of toxic pollutants
- Monetized benefits: $70.3 billion/year
  - Upgrading refineries and pipeline distribution systems
  - Developing advanced emission control technologies

Manufacturers of Diesel Emission Controls