CLEAN AIR TASK FORCE

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Diesel Engines: Emissions Controls and Retrofits

Affordable Diesel Retrofit Technologies Significantly Cut Harmful Emissions

While new EPA rules will require that newly manufactured highway and non-road vehicles meet tough new emission standards beginning in 2007 and 2008 respectively, there have been no major federal regulatory actions to similarly clean up diesels that are in use today. EPA is currently promoting a voluntary diesel retrofit program (http://www.epa.gov/otaq/retrofit/overview.htm). Because of the long working lives of heavy-duty diesels, action is needed now to clean up today's 13 million working diesels in addition to the assurance of cleaner engines in the future. Indeed, new emissions control technologies and fuels now hold the promise that cleaner diesel engines may soon rival the emissions profiles for gasoline and natural gas engines while emitting about one quarter less carbon dioxide and providing better fuel economy. In fact, many of these technologies are currently available, cost-effective, and affordable. The combination of retrofit controls, new engine designs, and low-sulfur fuels will minimize the impacts of diesel exhaust and make our cities, schools, and workplaces healthier places to breathe while providing the durability and efficiency that heavy duty equipment operators demand. EPA has verified certain technologies for retrofitting existing diesel engines. See EPA's retrofit technology verification web site at: http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

This summary describes emissions control options currently available or presently under testing. The summary is informed by EPA regulatory and research documents[1], the Houston Diesel Fuel Demonstration project[2], DOE/NREL[3], 2002 Manufacturers of Emissions Controls Association (MECA)[4], the Boston MTA study[5], a 1998 SAE study[6], California Air Resources Board (CARB)[7], and the Washington Metropolitan Area Transit Authority/University of West Virginia study.[8] Companion Clean Air Task Force diesel fact sheets are: 1) Health and Environmental Impacts, 2) Emissions and Exposure, and 3) Sources and Regulations. Also see Clean Air Task Force's report Diesel and Health in America and interactive companion web at http://www.catf.us/dieselhealth/ .

Particulate Matter Retrofits Achieve 90+ Percent Reductions.

Diesel Particulate Filters (DPFs). Diesel particulate matter (DPM) is largely comprised of elemental carbon particles, organic particles (unburned hydrocarbons), and sulfates. DPM filters, also known as "traps", remove particulate matter from the diesel exhaust through physical filtration. Diesel particulate filters are durable but must be supplemented by some means of self cleaning (regeneration) to remove the collected carbon and organic particles. This can be done by adding heat to the exhaust, raising the temperature high enough to oxidize the carbon to gaseous CO_2, or it can be done by adding a catalyst to the filter which will promote oxidation of the collected carbon at typical exhaust temperatures without adding additional heat. The first approach is called active regeneration, the second passive regeneration. Passive regeneration requires a minimum exhaust temperature to work properly, and is not applicable to all engines and all duty cycles. Nonetheless, many fleets, including school buses and transit buses, have successfully introduced passively regenerated catalyzed filters to their vehicles over the last few years. In order to maximize the reliability of filter systems that will be required to meet the EPA's on-road (highway) and non-road standards and for PM in 2007 and beyond, most engine manufacturers are working to develop systems that use both approaches – they include a catalyst to promote continuous passive regeneration but also have supplemental active regeneration systems that inject diesel fuel into the exhaust to help regenerate the filter when required. All DPFs, whether actively or passively regenerated, require periodic maintenance to clean out ash that accumulates from the non-organic components of engine oil

Installation of a DPF requires replacement of the muffler and tailpipe.

- **Catalyst–Based DPFs:** DPFs that regenerate using catalysts were demonstrated many years ago, but were unnecessary from a regulatory perspective because of the leniency of the particulate matter PM emissions standards. The added catalyst effectively reduces the temperature necessary for regeneration of the filter in most applications. Since the catalyst is poisoned by sulfur, this type of DPF can only be used with ultra low sulfur diesel fuel (ULSD) that has a sulfur content of less than 50 parts per million.[9] Current on-road diesel fuel typically has 350 ppm sulfur, but will drop to 15 ppm beginning in mid-2006. The average cost of a catalyzed DPF for a truck or bus is approximately $7,500 depending on size of retrofit.[10]

- **Catalyzed DPFs Achieve 90 Percent PM Reductions**: Catalyzed PM traps or DPFs can provide in excess of 90 percent reductions in emissions of PM when combined with ULSD in both new and retrofit applications.[11] Indeed, results of the 2002 Washington D.C. Metro bus study showed that retrofit DPFs reduced PM by over 90 percent, along with a carbon monoxide reduction of 95 percent and *complete elimination of hydrocarbon emissions*. Some European DPFs have demonstrated removal efficiencies of over 99 percent. EPA, as well as an independent review subcommittee of the Clean Air Act Advisory Committee, believes that catalyzed DPFs are available and necessary to meet or exceed EPA's 2007 requirements.[12,13]

- **Catalyzed DPFs Reduce Ultrafine PM and Toxics**: Catalyzed DPFs are effective in reducing the smallest measurable ultrafine particles and thus also the "particle count" or number of particles in addition to total particulate mass. Catalyzed DPFs also provide the advantage of oxidizing and removing much of the toxic organics in DPM. Testing on New York City Transit buses equipped with DPFs has shown >99% reductions in toxic carbonyl compounds and PM-bound PAH compounds compared to buses equipped with standard oxidation catalyst mufflers. The same test program showed 90-99% reductions in particle counts in all size ranges, including the smallest nano-particles, when DPFs were used. These reductions were shown to be stable, even after the DPFs had been in service for 9-12 months .[14] Reducing the *numbers* of particles is important because health research suggests that ultrafine DPM could be even more harmful than fine PM.[15]

- **On-Road Applications of Catalyzed DPFs Are Utilized Worldwide:** DPFs have been used in over 50,000 retrofit applications worldwide.[16] EPA reports some units in field trials accumulated over 360,000 miles of use.[17] Catalyzed DPFs have been utilized in 3,000 retrofit applications with low sulfur fuel (10 ppm) in Sweden (including buses, mail trucks, garbage trucks, and trains) without a single failure. MTA New York City Transit has already retrofit over 2,500 transit buses in New York City with DPF, some of which have been in service since 2001. Clean Air Task Force recently completed a 3-city study of the benefits of DPFs on school buses. A DPF, ULSD and a closed crankcase filtration device effectively eliminated particulate matter self pollution.

CATF STUDY SHOWS THAT SCHOOL BUS CABIN PM CAN BE ELIMINATED WITH DPF AND A CLOSED-CRANKCASE FILTRATION DEVICE.

Twenty four million students ride to school every day on yellow school buses that travel 4 billion miles a year. Students spend and average of an hour an a half a day on the bus.[18] School buses are, by far, the safest way to get to school.[19]A recent study undertaken by Clean Air Task Force in cooperation with Purdue University researchers investigated cabin air quality on yellow buses in three cities (Chicago, IL, Atlanta, GA, and Ann Arbor MI). [20] In all three U.S. cities researchers found that diesel exhaust routinely entered into the bus cabin during typical school bus routes from the tailpipe and the engine compartment through the front door. At many stops, levels entering the bus exceeded multiple times the level of the daily fine particle (PM2.5) standard. During idling and queuing—where buses are parked closely end-to-end-- rapid build up of fine particles (PM2.5), ultrafine particles and black carbon occurred. Most importantly, installation of a diesel particulate filter and ultralow sulfur diesel fuel (ULSD) along with a closed crankcase filtration device eliminated all in-cabin particulate matter self-pollution including PM2.5, ultrafine particles, black carbon and particle bound PAH. The study showed that the closed crankcase filtration system by itself has significant benefits. The Spiracle provided immediate and low cost reductions in particulate matter levels on school buses that have crankcase vents by rerouting the crankcase emissions back into the engine instead of into the engine compartment where it can blow into the front door of the bus. For a comprehensive report on the study go to: http://www.catf.us/goto/schoolbusreport/.

- **Department of Energy (DOE)-National Renewable Energy Laboratory (NREL) Study Demonstrates Major Emissions Reductions from Catalyzed DPFs Retrofitted onto HD Trucks:** In a 2001 DOE-NREL study[21], catalyzed DPFs were applied to twenty 1999 tractor-trailer trucks using Englehard and Johnson Matthey passive regenerative catalyzed DPFs. The DPFs performed reliably for over 100,000 miles despite the fact they were not serviced for ash removal in that interval. PM emissions were 98 percent lower than trucks not similarly retrofitted. Performance did not deteriorate after one year of use. Furthermore, carbon monoxide (CO) emissions were 62-95 percent lower and hydrocarbon (HC) emissions were reduced by 98-99 percent—below limits of detection.

Diesel Oxidation Catalysts: Less Costly But Less Effective than Diesel Particulate Filters: Diesel oxidation catalysts (DOCs) use the same type of catalyst material used in passively regenerated DPFs, but applied to a flow-through monolith, without the physical filter. DOCs promote the oxidation of carbon and hydrocarbon in diesel exhaust, reducing the amount of primarily organic carbon based PM that exits the tailpipe. DOCs have been one of the most popular control options for both on-road and non-road applications to date because of their low cost and ease of installation. 1.5 million DOCs have been installed on new heavy-duty highway trucks since 1994[22] and have been installed on all new transit buses since 1996. EPA verification shows DOCs can reduce PM by approximately 20-30 percent.[23] DOCs also are reported to reduce CO by up to 90 percent and to significantly reduce hydrocarbons (including up to 70 percent of hydrocarbons such as formaldehyde).

Construction Equipment Retrofit with Diesel Oxidation Catalyst in Boston (DOC attached to tailpipe in photo)[24]

- **DOCs Successful on Non-Road Construction Equipment in Boston's Big Dig:** DOCs have been installed on over one quarter million non-road vehicles around the world.[25] In Boston's Central Artery/Tunnel Project, construction equipment including bulldozers, excavators, and cranes is being retrofitted with DOCs in a voluntary program established by the Massachusetts Turnpike Authority (MTA). The program, which began in 1998 and is scheduled to be completed in 2004, uses on-road ULSD fuel.[26,27] A total of nearly 100 pieces of equipment have been retrofit with nearly 200 retrofits planned in the future. This effort will achieve reductions equivalent to removing 1,300 diesel buses off of Boston's streets for a year.[28]
- **DOCs are Inexpensive and Require Minimal Installation Effort.** Costs for DOCs are estimated at $425 -$2,500 depending on engine size and sales volume.[29] Installation of DOC retrofits for the Big Dig was easy, took approximately two hours per engine, and was done by the construction equipment contractors themselves. The average cost of the Engelhard DOC was $2,500 --about one percent of the cited average $250,000 cost for a piece of off-road construction machinery in the study. DOCs were chosen by MTA due to lower cost, better reliability and the ability to spread the technology over more equipment.

Closed Crankcase Emissions Filtration Device

In many diesel engines, crankcase emissions—or "blow-by"-- are released directly from the engine through the "road draft tube," and do not pass through the exhaust system. Crankcase emissions are composed of particulate matter, nitrogen oxides, hydrocarbons and toxics. Clean Air Task Force research has documented that crankcase emissions can lead to high levels of particulate matter inside school buses. EPA recognized the importance of crankcase emissions in its 2007 highway diesel rule. While falling short of requiring closing off crankcase emissions, EPA's 2007 rule requires that engine manufacturers consider crankcase emissions as a part of overall emissions that must be reduced. To reduce these emissions, crankcase ventilation must be rerouted back into the engine where it can be control in the post-combustion emissions controls devices. A closed crankcase emissions filtration device, such as the Donaldson Spiracle, can be fitted to school buses, effectively eliminating these emissions in the bus cabin, as shown by Clean Air Task Force research. (See http://www.catf.us/goto/schoolbusreport/.)

The Donaldson Spiracle closed crankcase filtration device redirects crankcase blow-by emissions back into the engine and out through the tailpipe. EPA has verified the Spiracle in combination with a DOC.

Retrofit Controls Remove Nitrogen Oxides (NO_X)

Lean NO_X catalysts: Lean NO_X catalysts use diesel fuel injected into the exhaust and a special catalyst to reduce NOx to elemental nitrogen. They offer NO_X reductions of 20-40 percent, but incur a fuel penalty of 5-10%. Typically they are deployed in conjunction with a DOC or DPF to give hydrocarbon and PM reductions as well.

NO_X Adsorber Catalyst[30]: The materials in a NOx adsorber chemically combine with NOx during normal diesel engine operation, effectively removing it from the exhaust. Periodically, this NOx is released from the catalyst as elemental nitrogen, by injecting diesel fuel into the exhaust, similar to the way a lean NOx catalyst works. Like lean NOx catalysts, NOx adsorbers also incur a fuel penalty of 4-6% because of this need to periodically regenerate the catalyst. This is a more promising technology, however, because it has been shown to be able to reduce NOx by 90% or more. EPA believes that it will be the primary technology used to meet the NOx requirements of the 2007 on-road diesel rule. The adsorber is easily poisoned by even small quantities of fuel sulfur and must be periodically cleaned by exposure to high temperatures that can affect its durability. The applications described below were tested on *new* vehicles.

- **Application of NO_X Adsorber Catalysts in Trucks**: in one test, EPA tested four versions of the NOX adsorber on new vehicles and all reduced NO_X by 90 percent—including a highway truck demonstrating a removal efficiency of 99 percent.[31] All of these results are for nearly new adsorbers. Laboratory results have indicated losses in removal efficiency with time. EPA's independent panel on diesel technology report that NO_X adsorbers have proven efficiencies of 70 percent or greater on bench and dynamometer tests.[32]
- **Application of NO_X Adsorbers in Cars:** Volkswagen has reported NO_X reductions of 71 percent on its diesel Passat car with the NO_X adsorber catalyst. DOE reports that NO_X adsorber combined with a regeneration system reduced NOx by 90 percent on a Mercedes A-class car with 150 ppm sulfur content fuel (performance was degraded by the high-sulfur fuel; production challenges remained in 2000 when this was reported). Toyota will introduce a "Diesel Particulate-NO_X Reduction (DPNR)"

system in 2003 light duty vehicles; in this application the NO_X adsorber catalyst is applied on the surface of the DPF.

Diesel-Water Emulsion: In a diesel-water emulsion, up to 20% water is blended with diesel fuel and a special additive manufactured by Citgo and Lubrizol. The additive creates a stable emulsion that will not separate, with each water molecule completely enclosed by fuel molecules. During combustion in the engine cylinder, the water lowers the combustion temperature, which reduces the amount of NO_X produced. During engine testing under the EPA retrofit technology verification program, water diesel emulsions were shown to reduce NOx by 9-20% and to reduce PM by 17-23%. Depending on whether Citgo or Lubrizol fuel was used, NO_X was reduced by 16-41 percent in the Houston Diesel Fuel Demonstration project; PM was reduced 24-69 percent; increases in carbon dioxide (CO_2) emissions were seen; hydrocarbon emissions were mixed: some increased some decreased. Because the water does not contribute energy during combustion, all engines using a water-diesel emulsion will experience reductions in fuel economy (miles per gallon of fuel emulsion), as well as a modest reduction in power output at the same throttle setting. This may or may not be significant depending on the application.

Selective Catalytic Reduction (SCR): SCR operates similarly to a Lean NOx catalyst, but uses a more effective ammonia bearing "reductant" in conjunction with a catalyst to get much higher NOx reductions. Rather than using diesel fuel as a reductant, SCR systems inject ammonia or urea from an onboard tank into the exhaust, which can result in NOx reductions of 75-90 percent. This technology can also reduce hydrocarbon emissions by 80 percent and PM emissions 20 percent. SCR systems have been used to reduce NOx emissions from electric generating plants for many years, and the technology is well-developed for these large stationary plants. Adaptation to vehicles is more difficult due to constraints on size, as well as the need for much more complicated control systems to account for the variability of engine operation seen in vehicles (power plants operate in more of a steady-state, with few transients).

Diesel SCR unit (MECA)

- **Applications of SCR:** There have been only about 50 installations of SCR since 1995 in the U.S. and several hundred have been installed in Europe.[33] The city of Houston evaluated the potential use of diesel NO_X reduction catalysts and concluded that the technical objective of a 50-75 percent reduction of NO_X was shown to be achievable with retrofit technologies for in-use diesel powered vehicles. Widespread use of SCR has been limited due to engineering issues and the need for refilling with urea or ammonia.

Exhaust Gas Recirculation (EGR): Exhaust gas recirculation returns a portion of the exhaust gas to the engine, which lowers the peak combustion temperature and reduces the amount of NOx produced. EGR is the primary technology used by most engine manufacturers to comply with the 2004 EPA on-road NOx regulations, when the allowable standard fell from 4 g/bhp-hr to 2.5 g/bhp-hr (a 38% reduction). EGR can also reduce NO_X by 40 percent or more in retrofit applications.[34] However, SAE concludes that EGR can *increase* total PM emissions and the potential cancer potency of the hydrocarbons such as PAHs if not combined with a DOC or DPF. The only commercially available retrofit EGR system must be combined with a DPF. Such systems were successfully demonstrated in the Houston study. The cost to retrofit a bus or truck engine with EGR is about $13,000-$15,000, including the required DPF.[35]

Retrofit Control Combinations Most Effectively Reduce NO_X, PM and Hydrocarbon Emissions.

Although the stand-alone technologies do not deliver high emissions reductions for all pollutants, combinations of these technologies have proven effective.

- **Exhaust Gas Recirculation System/Catalyzed Diesel Particulate Filter:** In one study, EGR was combined with an Englehard DPF and ultra-low sulfur diesel fuel resulting in PM reductions of up to 83 percent and NO_X reductions of up to 81 percent.[36] Hydrocarbons were reduced by 80-86 percent. In a different trial, a combined EGR and filter system reduced NO_X by over 40 percent and PM by over 90 percent.[37]
- **Selective Catalytic Reduction and Particulate Trap:** In the same study, the SCR/DPF combination reduced particulate matter by up to 92 percent and NO_X by 78-82 percent using baseline diesel fuel (300-500 ppm sulfur). Similarly, MECA reports that engines equipped with SCR and a filter can achieve NO_X reductions of 75-90 percent and PM reductions of greater than 90 percent.[38]
- **Diesel Oxidation Catalyst / Diesel Emulsion Fuel:** Testing in the Houston study that combined DOCs with diesel emulsion fuel resulted in NO_X reductions of 18-48 percent, particulate matter emissions reductions of 58-76 percent and a 67 percent reduction in carbon monoxide.

Table of Particulate Matter Retrofit Technologies. (M.J. Bradley & Associates)

Primary PM Reduction Technologies					
Technology	Effectiveness (% reduction)	Engine Technology Level	Fuel Penalty	Maximum Sulfur Level	Cost (250 HP engine)
Diesel Oxidation Catalyst (DOC)	PM: 20 – 40%[1] PM_{EC}: 0-5%[1] NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	\$1000 to \$1500
High Efficiency DOC (HE DOC)	PM: 40 – 60%[1] PM_{EC}: 5-10% NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	\$2000 to \$3000
Partial Flow Filter (PFF)	PM: 40 – 70%[1] PM_{EC}: 10-20%[2] NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	\$3000 to \$4500
Catalyzed Diesel Particulate Filter (C DPF)	PM: >95% PM_{EC}: >95% NOx: 0-5%[3]	Euro 1 + Mechanical or electronic control	Marginal	50 PPM	\$4000 to \$7000
Active Diesel Particulate Filter (A DPF)	PM: >95% PM_{EC}: >95% NOx: 0%	Euro 1 + Mechanical or electronic control	3 – 6%	500 PPM[4]	\$12000 to \$15000

NOTES:

1 DOCs primarily reduce the "wet" organic portion of PM, while removing only modest amounts of the smallest carbon particles. Older technology engines tend to have much more wet PM, so the % reduction of PM mass will be highest on these engines. Very high sulfur levels (above 50-ppm) will tend to deactivate the catalyst, and will also produce significant sulfate PM across the catalyst at high exhaust temperatures.

2 A partial flow filter directs a portion of PM through a physical filter where even the smallest carbon particles are captured and oxidized. This results in greater reductions of fine PM than a DOC or high efficiency DOC

3 Catalyzed DPFs result in modest reductions in total NOx as NO_2 is reduced during oxidation of carbon. These devices also increase the percentage of NOx emitted as NO_2 by 20-30%.

4 All of the active DPF systems being developed for on-highway vehicles in the US include a catalyzed filter and require fuel with maximum 50-ppm sulfur. Theoretically, active systems could be developed to work with up to 500-ppm fuel, but these systems would incur greater fuel penalty and would require additional annual maintenance.

EC – Elemental Carbon

Table of Nitrogen Oxides Retrofit Technologies. (M.J. Bradley & Associates)

Primary PM Reduction Technologies					
Technology	Effectiveness (% reduction)	Engine Technology Level	Fuel Penalty	Maximum Sulfur Level	Cost (250 HP engine)
Diesel Oxidation Catalyst (DOC)	PM: 20 – 40%[1] PM_{EC}: 0-5%[1] NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	$1000 to $1500
High Efficiency DOC (HE DOC)	PM: 40 – 60%[1] PM_{EC}: 5-10% NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	$2000 to $3000
Partial Flow Filter (PFF)	PM: 40 – 70%[1] PM_{EC}: 10-20%[2] NOx: 0%	Euro 0 + Mechanical or electronic control	Marginal	500 PPM[1]	$3000 to $4500
Catalyzed Diesel Particulate Filter (C DPF)	PM: >95% PM_{EC}: >95% NOx: 0-5%[3]	Euro 1 + Mechanical or electronic control	Marginal	50 PPM	$4000 to $7000
Active Diesel Particulate Filter (A DPF)	PM: >95% PM_{EC}: >95% NOx: 0%	Euro 1 + Mechanical or electronic control	3 – 6%	500 PPM[4]	$12000 to $15000

NOTES:

1 DOCs primarily reduce the “wet” organic portion of PM, while removing only modest amounts of the smallest carbon particles. Older technology engines tend to have much more wet PM, so the % reduction of PM mass will be highest on these engines. Very high sulfur levels (above 50-ppm) will tend to deactivate the catalyst, and will also produce significant sulfate PM across the catalyst at high exhaust temperatures.

2 A partial flow filter directs a portion of PM through a physical filter where even the smallest carbon particles are captured and oxidized. This results in greater reductions of fine PM than a DOC or high efficiency DOC

3 Catalyzed DPFs result in modest reductions in total NOx as NO_2 is reduced during oxidation of carbon. These devices also increase the percentage of NOx emitted as NO_2 by 20-30%.

4 All of the active DPF systems being developed for on-highway vehicles in the US include a catalyzed filter and require fuel with maximum 50-ppm sulfur. Theoretically, active systems could be developed to work with up to 500-ppm fuel, but these systems would incur greater fuel penalty and would require additional annual maintenance.

EC – Elemental Carbon

Low Sulfur Diesel Fuels Are Requisite for Retrofit Controls.

Some of the most effective retrofit devices discussed above require ultra low sulfur fuels. Unfortunately, low sulfur fuels are not available everywhere in the U.S. (see http://www.epa.gov/otaq/retrofit/fuelsmap.htm for current fuel availability map). The primary challenge to technological application of these devices is making the fuel widely available throughout the U.S. as soon as possible.

- Current on-road diesel fuels are limited to 500 parts per million (ppm) sulfur or less.
- Non-road diesel fuel used in 49 states is commonly 10 times higher in sulfur than on-road vehicle diesel fuel.
- Diesel particulate filters cannot be utilized using high sulfur fuels. In Denmark, testing on nine vehicles utilizing 150 ppm sulfur diesel fuels caused clogging of the filters in less than six months.[39] The generally accepted limit for maximum sulfur level to be used with a DPF is 50 ppm.
- NOx Adsorber technology is even more sensitive to fuel sulfur level. The generally accepted limit for maximum sulfur level to be used with a NOx Adsorber is 15 ppm

Ultra-low sulfur diesel (ULSD): Federal regulations have established diesel fuel and additive formulation requirements for *on-road* vehicles, limiting fuel sulfur content to 15 ppm beginning in mid-2006 nationwide. In July 2002, some California bus fleets were required to use fuels with less than 15 ppm sulfur.

Biodiesel: EPA testing suggests that biodiesel fuels made from soybean oils, which have inherently low fuel sulfur concentrations, may be effective in lowering PM, carbon monoxide, and hydrocarbon emissions. [40] However, pure biodiesel can also increase NOx emissions. For that reason, biodiesel is typically blended with other diesel fuels, including ULSD. The most common formulation is a blend of 20% biodiesel and 80% standard diesel or ULSD, which is typically referred to as "B20". More than 200 fleets use biodiesel as a fuel or fuel additive. A B20 biodiesel blend reduces PM by 10 percent, hydrocarbons by 21 percent and carbon monoxide by 11 percent, while NO_X increases by 2 percent. Biodiesel may also reduce cancer-causing polycyclic aromatic hydrocarbons (PAH) by 80-90 percent. Because biodiesel is a renewable fuel produced from plant materials, it can also reduce net life-cycle carbon dioxide emissions by 78 percent [41] compared to the use of non-renewable petroleum diesel. According to NJDEP, the incremental cost of 20 percent biodiesel fuel (a common blend) is about $0.10/gal.[42]

Other Emissions Reductions Strategies Help Reduce Exposure to Diesel Exhaust

The following represent other options for reducing diesel emissions:

- Anti-idling ordinances and enforcement
- Driver education
- Truck stop electrification and climate control (heating/air conditioning)
- Relocation of school bus loading areas away from building entrances and air intakes
- Emissions /smoke testing

Truckstop Electrification and Anti-Idling Ordinances Are an Effective Ways to Reduce Unnecessary Diesel Exhaust Emissions.[43]

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[9] Ultra low sulfur diesel is limited to 15 ppm sulfur.

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[18] http://www.epa.gov/cleanschoolbus/
[19] Latest statistics from the U.S. Department of Transportation tell the story: school buses have the best safety record of any form of transportation. Last year, just six youngsters were killed as school bus occupants. Yet, 800 youngsters are killed every year getting to and from school by some other means than a school bus.Source: Bus Information Council: http://www.schoolbusinfo.org/report.htm
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